HANDBOOK OF FISHERIES AND AQUACULTURE

भाकृअनुप
ICAR

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Handbook of Fisheries and Aquaculture

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Publisher's Note

This is the revised second edition of *Handbook of Fisheries and Aquaculture*. In appendices, recent information on Indian fisheries sector has been included (*Source: Handbook of Fisheries Statistics*, 2008, Ministry of Agriculture). For latest statistics, visit site www.iasri.res.in/agridata. Readers are advised to consult the latest recommendations for chemicals/antibiotics before their use, and for latest scientific names, website www.fishbase.org may be consulted.

Preface

Indian fisheries occupy the second position in global fish production with an annual growth rate of 4.7%, recording 3.2% growth in marine sector and 6.2% growth in inland sector, thereby contributing 1.10% to the total GDP and 5. 3% to the agricultural GDP of the nation. The sector engages 14 million people at the primary level, and is earning over ₹ 10,000 crore annually through exports. Fish consumption has shown a continuous increasing trend assuming greater importance in the context of 'Health Foods'.

The focus in the coming years would be to achieve resilience in fisheries and sustainability in aquaculture. These also bring in the dimensions of biodiversity and ecosystem management, productivity enhancement and regulatory measures. The issues that need to be addressed are impact of changing climate, water management, natural fish stock management, diversification of fish and shellfish species, breeding and seed production, fish feeds, fish health management including diagnostics and vaccines, post-harvest management, quality assurance and food safety. Indian fisheries sector is to be viewed in the global context for both marine fisheries that is contiguous with several neighbouring countries and aquaculture that has to be managed in tandem with trends across the world.

In 2006, the Indian Council of Agricultural Research (ICAR) brought out the First Edition of '*Handbook of Fisheries and Aquaculture*' which documented various segments (marine, island, coastal, inland and highland) of fisheries; different aspects of aquaculture (freshwater, coastal, mariculture and ornamental); fish harvest, post-harvest and processing technologies; fishery legislation, fishery extension, biotechnological and fish genetic aspects, and fish trade under one cover. The effort was well received by students, teachers and extension workers alike and there has been a demand for a revised version.

The present revised edition comprises 42 updated and six new chapters, viz. Fish physiology; Aquaculture engineering; Fisheries development in India; Fisheries cooperatives; Demand and supply of fish; and Climate change—Impact and mitigation.

I am sure the Handbook would be of great value to students, researchers, planners, farmers, young entrepreneurs and all stakeholders in fisheries and aquaculture. I would like to thank the Directorate of Knowledge Management in Agriculture, ICAR, for bringing out this publication in an elegant manner.

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Preface to first edition

India is a major maritime state and an important aquaculture country in the world. Being home for more than 10% of global fish biodiversity, the country ranks third in the world in total fish production with an annual fish production of about 6.4 million metric tonnes. Constituting over 1% of the GDP, fisheries contribute to 5.3% of the agricultural GDP. There has been a paradigm shift in the production scenario from that of marine to inland fisheries, and further to aquaculture that is increasingly becoming important, with an annual growth rate of over 6%. Producing about 4.4% of world's fish, India trades to the extent of 2.4% in the global fish market, with the annual export earnings from fish and shellfish being over Rs 6,000 crore. Fisheries, apart from contributing to nutritional security component of the food basket of the country, is recognized for providing livelihood and employment to millions of people.

The different segments of fisheries—marine capture fisheries, mariculture, coastal aquaculture, inland capture fisheries, freshwater aquaculture, coldwater fisheries and aquaculture, fish processing and post-harvest technology and trade—have evolved over the years, assimilating traditional know-how and practices along with scientific innovations and technologies during the past five decades. The rich aquatic biodiversity that a few countries have, and the range of ecosystems from the coastal and island systems to mountainous lakes and cold streams, present both challenges and opportunities. The partnership of fishers, farmers and researchers, have enabled a steady progress in fish production trends. Along with basic disciplines of fisheries, the efforts are on increasingly incorporating new branches of sciences like biotechnology, information and communication technology, to address the emerging issues in production as well as international trade. The fast developments in integration with other farming systems as well as diversification in terms of ornamental fish culture, sports fisheries, aqua-tourism, etc., are spectacular. Fish as a health food is also gaining importance in the recent years.

The first edition of the *Handbook of Fisheries and Aquaculture* is an effort to document present status, developments and future possibilities in different areas. While major fisheries in terms of resources including island fisheries have been presented, emphasis has also been laid on different culture systems in marine, brackish and freshwater environments. Chapters on Fish in Human Nutrition, Disaster Management and Information Communication Technology in Fisheries, bring out the new approaches in the field. We hope the book would be useful to students, researchers, planners, farmers and all stakeholders in fisheries and aquaculture. This is the first attempt in our endeavour to provide comprehensive information in all areas of fisheries and aquaculture.

I would like to express my gratitude to Dr Mangala Rai, Secretary, DARE and Director General, ICAR, who initiated the process of the first edition of the *Handbook* *of Fisheries and Aquaculture*, for his guidance, support and encouragement. I wish to thank all the contributors for their enthusiastic response to our request, in providing valuable, information in a reader-friendly language through 44 chapters in this Handbook. I would like to thank the Directorate of Information and Publications of Agriculture, ICAR, in bringing out the publication timely.

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1. Indian Fisheries

Indian fisheries is increasingly contributing to the nutritional security of the country, with the present production of fish and shellfish from capture fisheries and aquaculture being around 8.0 million tonnes. The country also has an important role in global fisheries as the second largest producer of fish in the world and higher enhancement levels as compared to world fish production levels (Table 1.1).

Table 1.1. Fish production in the world and India

(million tonnes)

Year	World	% change	India	% change	India's share (%)
1950-51	23.50	-	0.75	-	3.19
1960-61	43.60	85.53	1.16	54.67	2.66
1970-71	66.20	51.83	1.76	51.72	2.66
1980-81	72.30	9.21	2.44	38.64	3.37
1990-91	98.26	35.91	3.84	57.38	3.91
2000-01	129.00	32.35	5.66	47.40	4.39
2005-06	136.09	5.73	6.57	16.08	4.82
2006-07	140.48	3.00	6.87	4.57	4.89
2007-08	142.30	1.30	7.13	3.78	5.01
2008-09	145.10	1.97	7.63	7.01	5.25
2009-10	147.45	1.62	8.00	4.85	5.42

Further, with an annual yield of over 4.93 million tonnes from the inland fisheries sector, India is next only to China in the area. Increase in production of finfish and shellfish from 0.75 million tonnes in 1950-51 to 8.0 million tonnes during 2009-10, over 11 times growth in the last six decades, is a testimony to the contributions of the sector. The share of inland fisheries sector, which was 29% in 1950-51, has gone up to over 61% at present (Table 1.2).

While the marine sector is almost constituted by capture fisheries, aquaculture has been the principal contributor in inland fisheries sector, with a share of 78%. Besides providing livelihood security to more than 14 million people, the sector has been one of the major foreign exchange earners, with revenue reaching ₹10,048 crore in 2010-11

Table 1.2. Fish production in India

Year	Fish production (million tonnes)		
	Marine	Inland	Total
1950-51	0.534	0.218	0.752
1960-61	0.880	0.280	1.160
1970-71	1.086	0.670	1.756
1980-81	1.555	0.887	2.442
1990-91	2.300	1.536	3.836
2000-01	2.811	2.845	5.656
2001-02	2.83	3.126	5.956
2002-03	2.99	3.210	6.200
2003-04	2.941	3.458	6.399
2004-05	2.779	3.526	6.305
2005-06	2.816	3.756	6.572
2006-07	3.024	3.845	6.869
2007-08	2.920	4.207	7.127
2008-09	2.978	4.659	7.637
2009-10	3.070	4.930	8.00

Source: Handbook on Fisheries Statistics. Government of India.

accounting for about 18% of the agricultural export. Producing 5.42% of the world's fish, India trades to the extent of 2.5% in the global fish market. The contribution of fisheries sector, at an overall annual growth rate of 4.5% during the previous five year plans is estimated around 1.10% to the GDP and 5.3% to the agricultural GDP.

Marine fisheries

With vast resources in terms of 8,118 km long coast line, 0.53 million km^2 of continental shelf and 2.02 million km^2 of exclusive economic zone, the marine fisheries in India has been playing a pivotal role in meeting the demands of fish over the years (Fig.1.1).

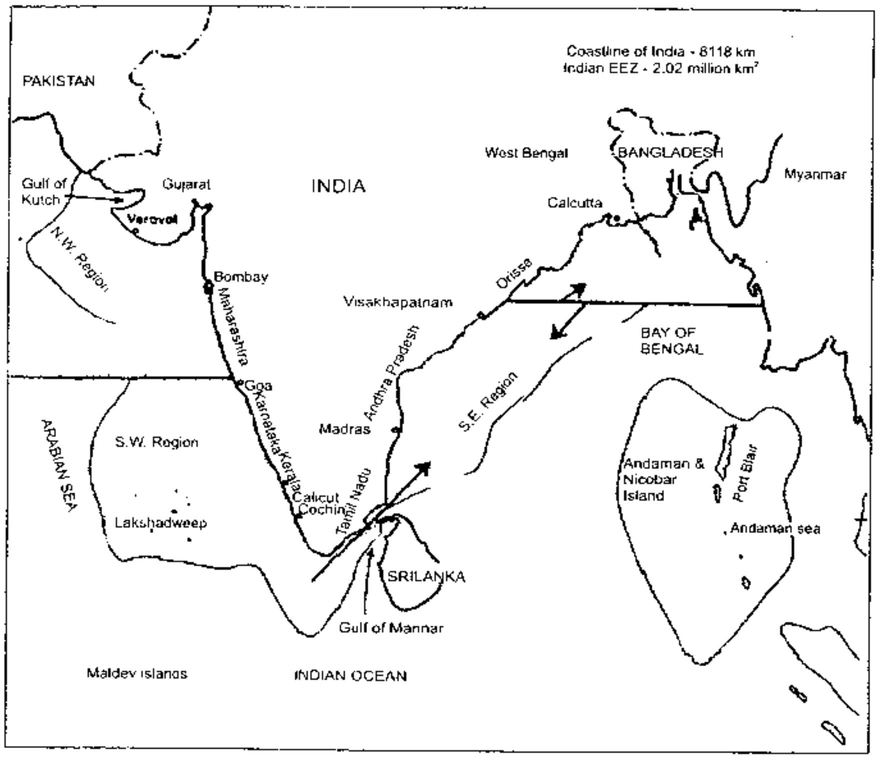

Fig.1.1. Indian coastline along with exclusive economic zone (EEZ).

The marine fisheries sector in India has registered a phenomenal growth during the last five decades both quantitatively and qualitatively (Fig.1.2). While the subsistence fisheries during the early 1950's produced about 0.5 million tonnes annually, the current annual production is about 3.0 million tonnes, forming 76.3% of the revalidated fishery potential of 3.93 million tonnes, comprising 1.67 million tonnes of pelagic, 2.02 million tonnes of demersal and 0.24 million tonnes of oceanic resources.

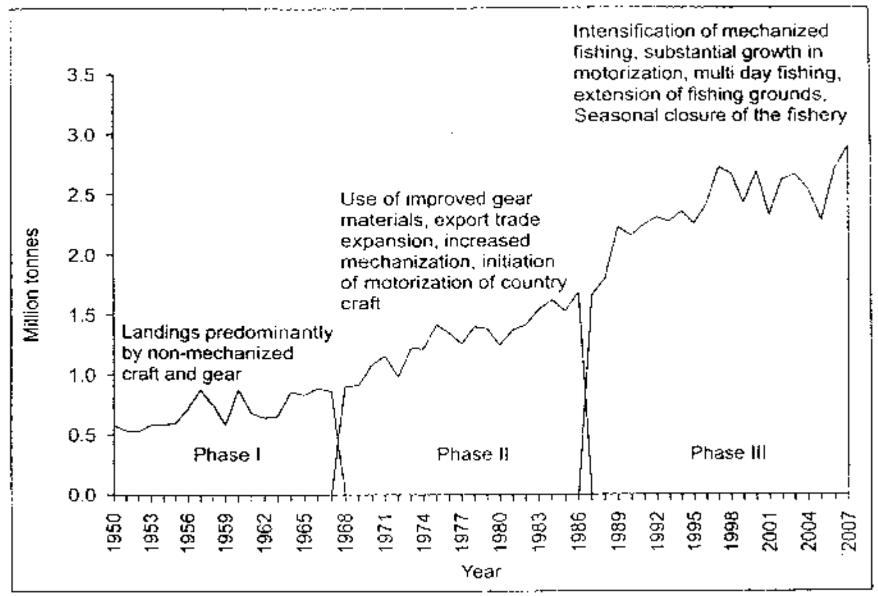

Fig. 2. Marine fisheries during different phases of growth

Research efforts in the areas of biology of commercially important species and monitoring their stocks for proper management; judicious exploitation and conservation; exploratory surveys, mapping of productive fishing grounds and location of new areas and resources; and environmental studies relating to fisheries, along with emphasis on mechanization of indigenous crafts, introduction of mechanized fishing boats, improvement of fishing gears and upgradation of infrastructure facilities over the years have contributed to the observed growth in the sector. Important marine fisheries resources of the country are: (*i*) Pelagic resources (oil sardine, mackerel, seer fish, tuna, lesser sardine, anchovies and ribbonfishes); (*ii*) demersal resources (perches, sciaenids, catfishes, polynemids, flat fishes, pomfrets, eels, sharks, skates, rays and fishes which are mainly caught by trawls); (*iii*) mid-water resources (Bombay duck, silver-bellies and horse mackerel); (*iv*) crustacean resources (prawns, shrimps, lobsters and crabs); (*v*) molluscan resources (oysters, mussels, clams, chank, squids and cuttlefishes); and (*vi*) seaweed resources.

Among the coastal states, Gujarat followed by Tamil Nadu, Kerala, West Bengal and Maharashtra contribute a major share (59.2%) to the marine fish production of the country. However, considering the production per unit length of coast line, West Bengal has the maximum production of 2,259 tonnes/km followed by Karnataka (953 tonnes/km), Kerala (878 tonnes/km), Goa (682 tonnes/km), Tamil Nadu (496 tonnes/km) and Maharashtra (439 tonnes/km). While the east coast has 57.2% of the total coastline (4,645 km including 1,912 km in Andaman and Nicobar Islands), it contributes 28.8% of the total fish production, with rest 70.2% contributed by west coast.

Diversification of fishing practices

The annual potential yield from the Exclusive Economic Zone (EEZ) of India has been estimated as 3.93 million tonnes, of which 2.24 million tonnes is from the zone up to 50 m depth and 1.69 million tonnes in deeper waters. Considering the current yield from 0-50 m depth zone reaching almost the potential level, refraining from further increase in yield from this zone, focus therefore, needs to be given on the region beyond 50 m depth for enhancing production in the years to come. Though several modern gears, namley trawling, purse seining, gill nets, mechanized hooks and line, jigging, trolling lines, etc., are under operation at present, traditional gears such as ring seine, stake net, shore seine, trammel net, mini trawls, gill nets and hook and line are also bringing bulk of the catches.

At present, about 279,546 fishing crafts comprising 53,684 mechanized boats, 44,578 motorized crafts and 181,284 non-mechanized crafts are in operation. While mechanized fishing sector of the country produces 64% of the marine landings, motorized and artisanal sectors contribute 26 and 9% respectively. There are about 170 deep-sea fishing vessels of >20 m overall length (OAL) operating along the east coast.

The present fish production in the marine sector has been largely due to: (*i*) introduction of mechanized fishing vessels and synthetic gear materials, and the development of infrastructure for preservation, processing and storage in the 1950s; (*ii*) expansion of trawl fleet and indigenous boat construction in the 1960s; (*iii*) introduction of purse-seining, diversification of fishing, development of fishing harbours and expansion of export trade in the 1970s; (*iv*) motorization of traditional fishing craft, introduction of ring seines and increase in the number and efficiency of craft and gear in the 1980s; (*v*) substantial growth in the number and efficiency of trawlers and motorized craft, and acoustic fish detection and satellite-based remote sensing techniques; advances in electronic navigation; (*vi*) change in the export trade from resource-based to food-engineering based industry in the 1990s. The pattern of marine fish landings in India during the past fifty years clearly reveals that the contribution by the artisanal sector to the total production was significant up to the sixties. As a result of the popularization and consequent expansion of mechanized fishing during the subsequent periods along with the motorization of artisanal crafts, the contribution by the artisanal sector declined considerably. The contribution by the mechanized and motorized sectors accounts for 87% of the total catch while the artisanal sectors accounts for only 13%. The growth in marine fisheries certainly has led to significant increases in the production, employment generation, domestic and export earnings.

Trawling has been the most common commercial demersal fishing method and the deleterious effects of this non-selective fishing method on the associated biodiversity are well documented—a bottom trawl capturing 40-50 species of target as well and non-target fish and shellfish species of different stages. In this regard, necessary modifications such as incorporation of juvenile escapement device and by-catch reduction device have been made. Design of multi-gear fishing vessels and conversion of trawlers to long liners are some of the other important interventions. This also requires assessment of stocks of different fish species on a continuous basis for setting up maximum sustainable yields and maximum economic yields. Further, closure of trawling by mechanized vessels for 45-60 days during southwest monsoon along the west coast and 45 days during April-May along the east coast is one of the restrictions being followed under the Marine Fishing Regulation Act, 2004. To a great extent, this has helped recruitment of several species and showed signs of recovery of a few stocks.

Sustainability of marine fisheries

An analysis of the impact of biodiversity loss on ocean ecosystem services, projected a global collapse of all currently fished taxa by the mid-21st century. This was based on controlled experiments on effects of variations of marine diversity on primary and secondary productivity, resource use, nutrient cycling and ecosystem stability as also long-term trends in 12 coastal and estuarine ecosystems. The risks include beach closures, harmful algal blooms, oxygen depletion and species invasion, among others. However, the analysis also indicated the positive effect of the marine protected areas (MPAs) on biodiversity restoration across different marine ecosystems and productivity enhancement. As regards the possible impact of climate change, has been predicted fluctuations in major fisheries due to frequency and intensity of extreme events. In the Indian context, small increment in sea surface temperature has been observed to be influencing pelagic fish species like sardine and mackerel to be moving northwards and higher incidence of the species on the east coast. It is predicted that further rise in temperature might lead to bleaching of corals, affecting the coral-associated fish communities.

Marine fisheries, largely practised as coastal fisheries, is an open access, multi-species, multi-gear regime. Unrestrained expansion of fishing efforts and extensive use of non-selective fishing gears have led to increasing pressure on several groups of fishes. Over-exploitation of the coastal resources by artisanal and small mechanized fishing sector over the years, especially up to 50 m has been leading to reduction of catch per unit effort, with annual production levels showing a plateau.

The major issues in the sector are–excess coastal fishing capacity and over-exploitation, unregulated open access fisheries, discards at capture/indiscriminate capture of juveniles and sub adults, coastal pollution and environmental degradation, biodiversity loss due to both natural processes of climate change and anthropogenic pressures, increasing fishing costs and reduced profitability, poor infrastructure at fishing harbours and landing centres and linkages for domestic marketing, underutilization of oceanic and deep-sea resources, emerging inter- and intra-sectoral conflicts, and sea safety.

A paradigm shift would be necessary from increasing marine fish production to increasing profitability and sustaining the marine fishery resources through management interventions. In this context, reducing overcapacity in the mechanized sector and diversification of fishing for capture of underutilized deep sea and oceanic resources assume high significance. For tackling the issues responsible for depletion of fisheries in coastal waters as discussed above and for sustaining the growth of the sector, need-based management measures must be formulated either as input controls (restriction of fleet size, mesh size, closed season) or output controls (restriction on fishery for certain species, size of fish caught, etc.). Other regulatory measures such as ban on the destructive gears, promotion of marine sanctuaries, installation of artificial reefs and sea ranching, effective code of conduct for responsible fishing, etc. would aid in sustaining the coastal fisheries. Awareness creation among all stakeholders against non-sustainable fishing practices with a participatory approach has become inevitable in fisheries management.

The approach to ecosystem-based management would need to consider the complexities in the multi-species, multi-gear fishery, which is provided in the Code of Conduct for Responsible Fisheries. The efforts at assessing the sustainable fishing stock sizes for different species, as also being done by the Marine Stewardship Council (MSC), takes into account aspects of carrying capacity, biomass at each trophic level and the optimal number of craft and gear required for sustainable harvest of pelagic, mid-water and demersal species. The MSC standard is consistent with the 'Guidelines for ecolabeling of fish and fishery products from marine wild capture fisheries' adopted by the FAO in 2005. Efforts at certification of some of the important fisheries in the country are underway.

Establishment of Marine Protected Areas (MPAs), restoration of critical habitats and stock enhancement through provision of fish aggregation devices (FADs) and sea ranching are some of the recent interventions. As regards sea safety, while communication facilities such as radiotelephone and Global Positioning System (GPS) are being included in the fishing vessels, satellite-based Vessel Monitoring System (VMS) is still to become operational. Facilities at the fishing harbours and landing centres need to be upgraded, along with product diversification, value-addition and domestic marketing, to realize the value of marine fish landings. These can be achieved in a time frame of 5-10 years by agencies, namely ICAR, Department of Animal Husbandry, Dairying and Fisheries (DADF), Marine Products Export Development Authority (MPEDA) and Ministry of Environment and Forests.

Deep-sea fishing

In view of the concerns regarding the stagnating catches from inshore waters, it is relevant to consider the potential of the offshore waters (Table 1.3).

Deep-sea fishing is a potential commercial activity, wherein issues of both investments and policy are being examined. They include the aspects of mid-sea transfer of fish and onshore landing, ensuring a minimum component of Indian crew on the vessels and related capacity building, deferred payment for vessels, complying with the regulations of the Indian Ocean Tuna Commission (IOTC), provision of necessary infrastructure for landing and processing deep-sea fishes especially tuna for overseas markets, single window facility for clearances for different agencies such as the Ministry of Agriculture, Reserve Bank of India, Director General (Shipping) and Coast Guards and other related issues. In order to exploit this component, the steps suggested are —

introduction of vessels comprising 500 tuna long liners/drift gill netters, 18 purse-seiners and 15 squid jiggers–as well as developing storage and harbour facilities incorporating total quality management (TQM) and hazard analysis and critical control points (HACCP) concepts. To realise the full potential and ensure that the country benefits from deep-sea fishing, it is necessary that the authorities undertake measures such as deployment of IOTC-recognized observers on fishing vessels; monitoring, control and surveillance (MCS) of vessels; and provision for certified graders at the landing sites. Several developing countries with tuna resources not exploited up to the allowable catch levels have entered into fisheries access agreements with developed nations, providing access to the formers' fishing grounds with suitable compensations. This concept is yet to be adopted in India.

Table 1.3. State of exploitable fisheries resources in EEZ

(in '000 tonnes)

Resource	Potential yield	Harvestable stock
Yellow fin tuna	115.0	57.50
Big eye tuna	12.5	6.25
Skipjack tuna	85.2	42.60
Billfishes	5.1	2.55
Sharks	26.2	13.10
Coastal pelagic	6.8	3.40
Oceanic squids	19.9	9.90
Deep sea lobsters	2.3	1.10
Total	273.0	136.40

Island fisheries

The waters of Andamans have some of the world's richest tuna stocks, as per the Government of India's Revalidation Committee Report, 100,000 tonnes of coastal tuna and 82,000 tonnes of oceanic tunas are available for exploitation and export around the Island. Potential tuna resources in the seas around Lakshadweep have been estimated to be between 50,000 to 90,000 tonnes, while only about 10,000 tonnes are caught mostly by pole and line and troll. At Lakshadweep, over 85% of the total landings constitute tunas of which about 50% is used for *'masmin'* production and the remaining is consumed fresh. Exporting chilled tuna to Japanese markets, where *sashimi* grade tuna would fetch up to US $ 15/kg, would be the most profitable proposition, that requires facilities of on-board chilling and cold chain to the mainland and further, the overseas destinations. The main constraints in marketing tuna are: lack of proper fish marketing chain, fishers not getting adequate value for their diversified catch (yellow-fin and non-tuna species), high cost of tuna cans, poor connectivity with the mainland, lack of public awareness on environment-friendly and responsible ways for fishing practices.

In order to establish a standard module of fishing, processing and export of tuna, it is necessary that modern new vessels including mother/collector vessels are introduced and the existing boats are upgraded by fibre-reinforced plastic (FRP) lamination of underwater hull, provide live bait tanks, insulated fish box and solar panels in the boats. Acquisition of special vessels, both in the range of 15-30 m and over 30 m would be required, for fishing *sashimi* grade tuna. 'Pay and Fish' concept is being practised in some countries that would be practical with VMS in place. Apart from fishing, handling practices are important for tuna exports because retaining the texture is required for exports in order to command the price. Important requirements for post-harvest handling of tuna are in terms of ice plants, chilled storage, freezing facilities, cold storage, canning plants, insulated vehicles, curing and waste-disposal facilities. In view of the island fisheries resources and the markets almost only overseas, it is necessary that the two island systems are equipped with processing facilities and exports made directly without bringing the produce to the mainland.

Mariculture as a new dimension

Mariculture, with technologies developed in the recent years, is an option for supplementing the marine capture fisheries and also for gainful employment for the fisherfolk in the coastal areas. Mussels, oysters and seaweeds have been the main component of mariculture, with some possibilities of crab and lobster fattening.

Green mussel, *Perna viridis* and brown mussel, *P. indica* are the two important mussel species available in the country, the culture technologies of which have already been standardized. Rack method, long line and raft culture methods are used for mussel farming depending on the water depth and nature of the site. Commercial mussel farming has started in the south-west coast during the last 15 years and from a meagre production of about 20 tonnes in 1996, the cultured mussel production of the country has increased to around 18,432 tonnes in 2010.

Edible oyster farming had been in different forms at a low level, but got an impetus in the 1970s with the technology of collection of spat and growing the spat to adult stage. Indian backwater oyster, *Crassostrea madrasensis* is the most important candidate species for farming and also having a wide distribution. Two types of farming methods are followed, viz. the rack and ren, and the rack and tray method. Production levels of 120 tonnes /ha/year are achieved by the tray method. At present, Kerala has well-established commercial farms and more than 2,000 villagers directly involved in oyster farming. The production has increased from 5 tonnes in 1996 to 2,450 tonnes in 2010, mainly from three main estuaries, Ashtamudi, Kayamkulam and Vembanad lakes in Kerala.

The pearl oyster resources include the golden pearl oyster, *Pinctada fucata* in Gulf of Mannar, Palk Bay and Gulf of Kachchh producing golden pearls, and the black lip pearl oyster, *P. margaritifera* in Andaman and Nicobar Islands producing black pearls. The pearl culture programme was initiated in the country in 1972 and there have been some commercial ventures, that however need to be enhanced to be competitive at the global level.

Of the 60 commercial species of seaweeds available in the country, only a few of them, viz. *Gracilaria, Gelidiella, Sargassum* and *Turbinaria*, are commercially important. The seaweed resources of the country are mainly confined to the coasts of Tamil Nadu and Gujarat. Culture of seaweeds in the country mostly deals with cultivation of *Gracilaria edulis* due to its high regenerative capacity. During the last decade, cultivation of *Kappaphycus*, a carragenophyte, has attracted the attention of entrepreneurs along the south-east coast and is spreading to other areas. Without proper

post-harvest processing facilities, seaweed cultivation has yet not been a commercial activity in the country.

In countries like China and Vietnam, sea cage farming is a common practice whose potentials have just been demonstrated in the country with culture of seabass (*Lates calcarifer*). This could provide supplementary income for fishers as also livelihoods during the closed seasons for capture fisheries. In order to take mariculture forward, it is necessary that potential mariculture sites along the Indian coast are mapped with due reference to prevalent tidal and wave conditions, water quality and aquatic pollution, availability of seed and feed, infrastructure and access to markets. The potential fishes for cage culture include groupers, snappers, seabass, rabbitfish and cobia. Success has been achieved in open sea cage culture of seabass, cobia and other marine fish species. Selective intensification and scaling up of these culture systems and developing a package of practices can lead to substantial increase in the production of marine fish. The traditional practice of artisanal cage farming can also be improved and expanded by extension and training programmes to the fishermen by central/state government developmental agencies. Breeding and seed production of marine finfishes such as groupers (*Epinephelus* spp.) and cobia (*Rachycentron canadum*) is of utmost importance to provide for systematic cage farming in the country. Possibilities of cultivation of sea cucumber (*Holothuria scabra*)–a major and preferred export item from India–must be explored, with its achieved success in breeding. The growth of *H. scabra* in the shrimp farms was three-times faster because of the rich organic matter present at the bottom of the farm. The prospect of developing commercial interest in lobster farming (*Panulirus* spp.) in India is bright mainly owing to the substantial increase in price consequent to the heavy demand from export market. Seabass (*Lates calcarifer*) and cobia have been successfully bred and their seed production technology standardized. These species will form viable choices for shrimp farmers as well as alternative crop for ecological balance of the coastal aquaculture systems. Entrepreneurship response would determine the commercial projects with assured necessary institutional finance.

Mariculture is expected to be a major activity in coastal areas in the years to come. Given the wide spectrum of cultivable species and technologies available, the long coastline and the favourable climate, mariculture is likely to generate considerable interest amongst the coastal population. However, development of mariculture needs to be done keeping in view the environmental and social issues, including management of inputs such as feeds, fertilizers and chemicals and the access of fishers to their conventional sites for capture fisheries. While the strategy will be to develop mariculture in selected areas by following norms of environmental sustainability and social equity, there is a need for relook at the permissible species of marine organisms that can be collected and used for cultivation. Several countries have now relaxed regulations for collection of sea cucumbers and sea-horses, in view of the technologies available for their breeding and further possibilities of ranching. This would facilitate not only new enterprises, but also add to conservation efforts through large-scale ranching that could be made mandatory for a culture unit. A scientific leasing policy for coastal waters and bringing the cultured commodities under value chain for export or upward domestic markets are essential, as at present, most of them are non-conventional produce without set processing or marketing models.

Coastal and brackishwater aquaculture

Brackishwater aquaculture in India, though a traditional practice in *bheries* of West Bengal and *pokkali* fields of Kerala, the scientific farming in the country has been initiated only in early 1990s. The commercial farming, however, is confined to a single commodity, i.e. shrimp, *Penaeus monodon,* owing to its high export potential. The total area under shrimp culture in the country at present is 12.88% (154,598 ha) of the potential water area of 1.2 million ha. The production of shrimp has recorded over five-fold increase from 28,000 tonnes in 1988-89 to 144,346 tonnes in 2006-07 and operating at around 100,000 tonnes over the years. Among the coastal states, Andhra Pradesh followed by West Bengal have been the largest producers of shrimp, together contributing 79% of the total aquaculture production of the country and also possessing 77% of the area under farming.

About 52% of the farms are less than 2 ha holdings and are operated by small cultivators. Farms over 5 ha size amount to only 19% of the total area under cultivation. The infrastructure facilities established over the years include hatchery chains both in private and public sectors, laboratories, and aerators besides buildings and communication networks. Since the development of this sector, about 3 lakh persons have gained direct employment in aqua-farming and about 6-7 lakh persons are employed in the ancillary units and activities. In brackishwater aquaculture main emphasis is on a single shrimp species, *Penaeus monodon* by virtue of its excellent export value. In addition, there are a number of shrimp species, viz. *Fenneropenaeus* (*Penaeus*) *indicus, P. merguiensis, P. penicillatus, P. japonicus, P. semisulcatus,* etc. and finfish species like seabass (*Lates calcarifer*), grouper (*Ephinephelus tankina),* grey mullet (*Mugil cephalus*), pearl-spot (*Etroplus suratensis*), milkfish (*Chanos chanos*) and mud crabs (*Scylla serrata* and *S. tranquebarica*), which are ideal for brackishwater aquaculture. In order to develop brackishwater aquaculture through the sponsored schemes, Department of Agriculture and Cooperation, Government of India established 39 Brackishwater Fish Farmers Development Agencies (BFDAs) in all the coastal states and the UT of Andaman and Nicobar Islands.

Brackishwater aquaculture is presently synonymous with coastal aquaculture, that too dependent on a single species, tiger prawn, *Penaeus monodon.* However, with increasing salinization of inland soils, spreading to over 8 million ha, inland saline aquaculture could become an important economic activity in the years to come. In the sector the major problems, viz. lack of disease-free shrimp seed, slumping prices of shrimp in overseas markets and lack of diversification, are impacting on the growth.

The semi-intensive culture practices mainly with black tiger prawn have been the core activity in shrimp farming. With the white spot syndrome virus affecting the seed, main concern over the last decade has been its control and management. Dependence of the culture practices on a single shrimp species and further dependence

on exclusive export have brought in uncertainties in the sector. Protocols for good management practices (GMPs) and diagnostic kits for viral diseases in shrimp have been developed for this purpose and efforts are on way to produce specific pathogen free (SPF) certified seed and distribute them to the farmers. Over the years, global price fluctuations, trade restrictions including anti-dumping duty and entry of other shrimp species such as *Litopenaeus vannamei* have affected farming. In this context, efforts are underway at promoting domestic market models.

Shrimp seed production is based on the spawners collected from wild. There are over 300 hatcheries in the coastal states with a production capacity of 14 billion PL-20/year. The global slump in shrimp prices has impacted their operation. Establishment of commercial hatcheries not only resulted in meeting the seed requirement of the sector, but also in minimizing the natural collection of seed from the estuarine areas, which was a threat to the fisheries and biodiversity earlier. However, there is presently overcapacity in the hatcheries as the area under farming is not increasing significantly.

Commercial shrimp farming in India largely involves use of formulated pellet feed, constituting a significant share of the input expenditure. There are 28 feed plants in India with a total production capacity of about 0.18 million tonnes/year. Most of the commercial feed production has been by multinational companies and only now indigenous feed manufacturers with local feed formulations are entering the market. Farm-made feed is an alternative for small farmers and availability of feed ingredients, namely quality fish meal, squid meal, shrimp meal, fish oil, lecithin, feed binders, etc. is to be facilitated.

With most hatcheries using wild spawners for seed production, contamination of wild populations of shrimps with white spot virus has been a major problem. With the diagnostic kits developed for detecting the white spot virus, PCR-tested seed is available all over the country. Low-density farming and use of probiotics are the other measures being resorted to by the farmers. Non-specific immunostimulants are also being incorporated in the feed for enhancing the immune response of the shrimps. Effluent treatment management in larger farms of more than 5 ha has been made mandatory to achieve optimum environmental parameters, thereby preventing from disease threats. The Coastal Aquaculture Authority has introduced regulatory measures with regard to use of drugs and chemicals in shrimp farming, ensuring good management practices. As stated earlier, brackishwater aquaculture sector of the country is largely based on farming of *Penaeus monodon*. Other shrimp species, viz. *Fenneropenaeus indicus, P. merguiensis* and *P. semisulcatus*, are considered as potential ones and cultivation of *Litopenaeus vannamei* has been gaining momentum in the recent years.

Among the finfishes, technology for the breeding and seed production has been developed for seabass, *Lates calcarifer*, along with farming demonstrations. Some enterprising farmers in Tamil Nadu have taken up seabass culture. High export prices of crabs have made fattening of species like *Scylla serrata* and *S. tranquebarica* a remunerative farming practice.

About 9 million ha of salt-affected land has been estimated in the hot semi-arid and arid eco-region of northern plains and central high lands in the states of Haryana, Rajasthan, Uttar Pradesh and Gujarat with surface and sub-soil saline water. Pond-based fish farming opens up avenues for restoring these degraded resources. Apart from the tiger shrimp (*Penaeus monodon*), certain marine/brackishwater fish/shrimp species such as milkfish (*Chanos chanos*), pearl-spot (*Etroplus suratensis*) and mullets (*Mugil* spp.) have shown promises for commercial aquaculture in such inland saline soil/water areas. Production potential ranging from 500 kg to 3 tonnes/ha/year has been demonstrated from such waters.

Inland capture fisheries

The inland water resources of the country are in terms of 29,000 km of rivers, 0.3 million ha of estuaries, 0.19 million ha of backwaters and lagoons, 3.15 million ha of reservoirs, 0.2 million ha of floodplain wetlands and 0.72 million ha of upland lakes, which contribute about 1.05 million tonnes of fish annually.

Riverine fisheries: The 14 major, 44 medium and innumerable small rivers of the country provide for one of the richest fish faunal resources of the world. Estimates from major rivers have shown yields varying from 0.64 to 1.64 tonnes/km with average of 1 tonne/km, but this is constantly declining due to increasing pollution, sedimentation and water abstraction in the river systems. The riverine systems, through the years of anthropogenic stresses of water abstraction and construction of dams, sedimentation, pollution, have come under serious threat of loss in ecosystem properties and fish stocks, causing considerable economic loss to the country. Initial studies on impact of climate change with small increments in water temperature have indicated a shift in the breeding grounds of some of the fish species.

This open water resource is also an open access resource. While several management measures have been taken to overcome these problems and conservation of the open water resources, viz. declaration of 'protected waters' or sanctuaries, mesh size regulations, restrictions on use of non-selective gears and destructive fishing such as dynamiting, restrictions on discharge of untreated effluents, restricted access with issuing of licenses, etc., open water fisheries management has remained a difficult proposition. Provision of fish passes or fish ladders constructed in the dam to allow the migratory species to move freely for breeding has not become effective. The concept of provision of environmental flows in rivers is still to be incorporated. As the inland fisheries activities are largely governed by the Indian Fisheries Act, 1897, a Model inland fisheries and aquaculture bill has been prepared for comprehensive management, both regulatory and promotional. A major initiative is needed to restore riverine ecology and fisheries, with programmes of generation of database on resources, yields and production estimates on GIS format, habitat restoration and pollution abatement for protection of breeding grounds, river ranching, fish passes for migratory fish species and regulated fishing practices with closed seasons and mesh regulations in accordance with the Code of Conduct for Responsible Fisheries.

With increasing emphasis on irrigation, canal network is becoming a resource for fish cultivation, to serve as a supplementary resource to riverine fisheries. Fish culture in enclosures within the canals as also in the submerged areas along the canals is a

possibility that deserves attention and investments. Issues to be addressed in this context are ownership and harvesting rights, leasing, duration of water retention and suitable practices.

Estuaries being important breeding grounds for a variety of commercially important fish and shellfishes require special attention in terms of regulated discharge of freshwater, reduced fishing efforts particularly with regard to mechanized fishing, controlled collection of natural fish/shellfish seed and mangrove conservation.

Reservoir fisheries: Open waters that contribute to the bulk of inland fisheries production even at their minimum level of exploitation and also hold the key for increased fish production in coming years, are the reservoirs and floodplain wetlands. Indian reservoirs are diversified and located under different geo-climatic situations, classified as large (>5,000 ha), medium (1,000-5,000 ha) and small (<1,000 ha). With 56 large reservoirs, 180 medium reservoirs and 19,134 small reservoirs covering water area of 1.14 million ha, 0.527 million ha and 1.485 million ha, respectively, substantial area is also added year after year, due to construction of new impoundments created through erection of dams over rivers, streams and other water courses.

The fish yields from the reservoirs have remained in the range of 11-15 kg/ha in case of large and medium ones, while it is about 50 kg/ha in small reservoirs. Efforts on scientific management of small reservoirs have shown improved yields, viz. 102–316 kg/ha, in different reservoirs across the country. This production potential can be harnessed by providing policy and technology support to improve the overall productivity of reservoirs in the country and enhance the production by more than 160% (Table 1.4). It has been estimated that the 1.5 million ha of small reservoirs can produce at least 0.15 million tonnes against the present levels of less than 0.07 million tonnes. Further, the medium and large reservoirs can yield another 0.08 million tonnes through proper species and stock enhancement. Greater thrust therefore is necessary to exploit the fisheries potential of these water-bodies through culture-based fisheries.

Table 1.4. Potential for fish production enhancement in reservoirs

Category	Production (in '000 tonnes)			% increase
	Existing	Potential	Gap	
Small	74.2	148.6	74.4	100.4
Medium	6.5	39.6	33.1	510.0
Large	13.0	57.0	44.0	337.4
Total	93.7	245.2	151.5	161.8

The programmes to be pursued are: stocking with fingerlings of carps and other relevant species, provision of adequate rearing space for fingerling production, cage and pen culture, appropriate/improved fish-harvesting gear and crafts, post-harvest management (storage, transportation and marketing) and manpower development for reservoir fisheries managers and skill development among fishers. Ownership and leasing of reservoirs on long-term basis are issues to be dealt with, for providing complete fishery rights and desired interventions for achieving higher productivity.

Fisheries of floodplain wetlands and lakes: Floodplain wetlands or *beels* are another potential fisheries resource in the states of Asom, West Bengal and Bihar, which offer scope for both culture and capture fisheries. These water-bodies play a vital role for recruitment of fish stocks of the riverine system and provide nursery grounds for commercially important finfishes and shellfishes. The *beels* are estimated to possess potential production levels of 1,000-1,500 kg/ha/year, while the present levels remain at only 100-150 kg/ha. Rich nutrient load and availability of fish food organisms make these water-bodies ideal for culture-based fisheries leading to higher growth of stocked fish species than those of reservoirs (Table 1.5). Further, the marginal areas of the *beels* can be utilized for construction of ponds or pens of suitable sizes for raising the required fingerlings.

Apart from food fish, these ecosystems have large varieties of potential ornamental fish species. They need specific approaches for integrated fishery development, conservation, sport fishing and eco-tourism promotion. The other indirect benefits to the community are water recharging of aquifers, ensuring water for crops and other uses, etc. The new database of water-bodies over 0.5 ha mapped in the eastern states through remote sensing provides a tool for planned development of the resource.

Table 1.5. Potential for fish-production enhancement in floodplain wetlands

State	Area ('000 ha)	Production ('000 tonnes)			% increase
		Existing	Potential	Gap	
West Bengal	42.5	9.56	53.15	43.59	455.96
Bihar	40.0	4.80	30.00	25.20	525.00
Asom	100.0	12.00	95.00	83.00	691.67
Uttar Pradesh	152.0	22.80	114.00	91.20	400.00
Other NE states	192.0	1.49	15.78	14.29	959.06
Total	526.5	50.65	307.93	257.28	507.96

Coldwater fisheries: The aquatic resources in terms of upland rivers/streams, high and low altitude natural lakes, man-made reservoirs, both in Himalayan region and the Western Ghats hold large populations of both indigenous and exotic fish species. Important food fishes of these waters are mahseers and schizothoracids among the indigenous species and trouts among the exotic varieties. Research efforts over the years have led to the development of technology of seed production of important cultivable species such as trout, mahseers and snow trout.

The contribution of coldwater fish to the national fish basket is meagre, which however is of high-value and low-volume category and the projected volume is of the order of 1%. Immediate programmes would need to be put in place with regard to establishment of small hatchery units for seed production of mahseers and snow-trouts; mid-altitude exotic carp farming; integrated fish farming with agriculture, horticulture and livestock; and development of sport fishery in streams and high altitude lake.

Freshwater aquaculture: India, as the second largest aquaculture producer in the world, has the major contribution from freshwater aquaculture, whose share in inland fisheries has gone up from 46% in the 1980s to over 85% in the recent years (Fig. 1.3).

Freshwater aquaculture, showed an overwhelming ten-fold growth from 0.37 million tonnes in 1980 to 4.03 million tonnes in 2010; with mean annual growth rates of over 6%, freshwater aquaculture has been able to meet the increasing fish requirement of the country when the production from marine capture and other open waters has remained almost stagnant. It is estimated that only about 40% of the available area of 2.36 million ha of ponds and tanks has been put to use and there exists scope for expansion of area under freshwater aquaculture.

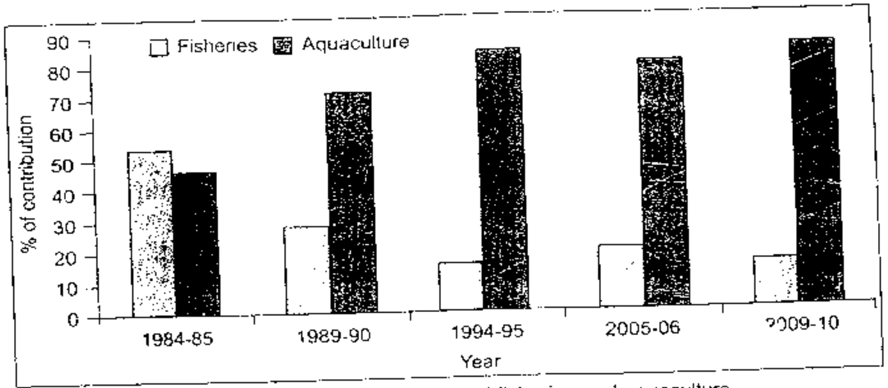

Fig.1.3. Percentage share of inland fisheries and aquaculture

Culture of carps: Carp culture in India, during the last five decades, has grown in geographical coverage with diverse systems, besides intensification of farming practices. The researches over the years have led to the development, refinement and standardization of a host of technologies with varied production levels depending on the input use, incorporating the Indian and Chinese carps. Technologies for semi-intensive and intensive culture in different forms of pond culture, raceway farming, integrated farming, etc., have led to practices with production levels ranging from 8 to 10 tonnes/ha/year, in Punjab and Andhra Pradesh. A concern however is with regard to species diversification, in spite of the fact that the country possesses several other potential and cultivable medium and minor carp species having a high regional demand, viz. *Labeo calbasu*, *L. fimbriatus*, *L. gonius*, *L. dussumieri*, *L. bata*, *Cirrhinus cirrhosa*, *C. reba*, *Puntius sarana*, *P. jerdoni*. Presently, efforts are being made for mass-scale seed production of these species and their inclusion as a component of conventional carp polyculture, based on their regional importance.

Culture of catfishes: Catfishes, *Clarias batrachus* (*magur*) and *Heteropneustes fossilis* (*singhi*), both air breathing, could be grown in swamps and have a high consumer preference. However, in spite of availability of resources in the form of swamps and derelict waters that could be effectively used for commercial farming, their large-scale seed production and culture is yet to be given due importance. Technologies have been developed for seed production and grow-out of these fishes with relevant feed formulations.

Non-air breathing catfishes such as *Pangasius pangasius*, *Sperata seenghala* and *Ompok pabda* are potential species for diversification in the coming years. Further, climbing perch (*Anabas testudineus*) and murrels (*Channa striatus* and *C. marulius*) are also being considered for culture. The constraints in propagating these fishes are with regard to availability of seed in adequate quantities and special feed formulations to suit the diet of carnivorous fishes needing incorporation of fishmeal.

Culture of freshwater prawn: Freshwater prawn farming has received increased attention only in the last two decades owing to its demand. The giant freshwater prawn, *Macrobrachium rosenbergii*, the largest and fastest growing prawn species, is cultured either under monoculture or polyculture with major carps. The country produces over 30,000 tonnes of freshwater prawn annually from a cultivated area of 43,433 ha with a mean productivity of 990 kg/ha/year. Andhra Pradesh has been the lead producer with 87% of the total production. Seed production has been adequately addressed through hatcheries not only in the coastal states, as larval rearing requires an amount of salinity, but also demonstrated in inland states using artificial sea water or ground saline water. As in case of shrimp, *Penaeus monodon*, much of the market for *scampi* was overseas and there has been a slump in the last two years. Hence, there has been no significant addition to culture areas but there have been attempts to grow tiger shrimp in freshwaters. White tail disease has been another problem in its cultivation. However, polyculture with carps has become remunerative but requires establishing domestic market models.

Non-conventional culture practices: Sewage-fed fish culture in *bheries* of West Bengal is a traditional farming system. Though the area of coverage is gradually reducing, over 4,000 ha are still utilized for growing fish by intake of raw sewage into the system and as much as 7,000 tonnes of fish, mainly contributed by carps, are produced annually. While catla, rohu, mrigal, kalbasu (*Labeo calbasu*) and silver carp are important candidate species being cultured in sewage fed system, other minor carp species, viz. bata (*Labeo bata*), reba (*Cirrhinus reba*) and mola (*Amblypharyngodon mola*), are also grown along with major carps. There have been public health concerns with regard to the farmers working in these waters as also the consumption of fish cultured in sewage. Precautionary measures for handling sewage and depuration of fish using freshwater are being incorporated to culture practices. In an attempt at bioremediation and modification of this practice, an aquaculture model comprising duckweed and fish culture for treatment of domestic sewage has been standardized and demonstrated.

Commercial culture of fish in cages is almost non-existent in the country, though certain experimental results, especially with carps and pearl spot have shown encouraging results. It is necessary to develop robust designs of cages, feeders and formulate pelletized, floating feeds for achieving good results in cage farming. Experimental small-volume, high-density farming of pearl spot (*Etroplus suratensis*) in floating net cages (1.0–2.0 m^3) in Kerala was highly rewarding; seeds of *E. suratensis* (30 g size) with a stocking density of 200 nos/cage reached the marketable size of 300 g in 6 months with locally blended compounded feed. The average cost of production was ₹ 62/kg against the market value of ₹ 300/kg. Being a scraping species, *E. suratensis* was found to be the most ideal candidate species for cage farming as the net cages stocked with pearl spot were almost devoid of fouling and mesh clogging algae. Being a brand cuisine of the backwater tourism and with high market demand, cage culture of pearl spot offers great promise in Kerala. Pens have been used to a large extent for raising fingerlings and juveniles for stocking the reservoirs and *beels*.

Region-specific aquaculture models

Though the country is rich in aquatic resources, the index of biodiversity utilized for aquaculture is of the order of 0.13 (~85% from Indian major carps; ~ 5% air-breathing fishes; ~10% rest all species together). Hence, for furthering freshwater aquaculture, it is necessary to adopt region-specific models in view of the available aquatic biodiversity as well as the consumer preferences and economics of operations in different parts of the country. Of over 640 species of freshwater fishes of India, several species are confined to south Indian (peninsular) waters and North-eastern India. These include: (*i*) some of the endemic food/sport fishes, viz. *Labeo dussumieri, L. ariza, L. kontius, L. dero, L. dyochilus, Tor khudree, T. mussullah, Neolissochilus hexagonolepis, N. wynaadensis, Semiplotus semiplotus, Osteobrama belangeri, Clarias dussumieri, Gonoproktopterus (Hypselobarbus) curmuca, Cirrhinus cirrhosa, Puntius pulchellus* and *P. carnaticus, Channa diplogramme, Etroplus suratensis*; and (*ii*) several brightly coloured attractive ornamental fishes such as loaches, *Nemacheilus* and *Travancoria*, channids and species of very elegant barbs such as *Puntius arulius, P. denisonii, P. narayani, P. filamentosus, Danio malabaricus*, etc. Despite its vast water resources and a rich faunal biodiversity, the contribution of these regions with local species to total inland fish production in the country is negligible. It is desirable to conserve and propagate some of them, especially those which are in high demand in the peninsular region and North-eastern India. Efforts have been initiated to incorporate some of these local potential cultivable species in culture systems for diversification of aquaculture in peninsular states and simultaneously to generate more information on their biology, breeding pattern, recruitment and stock identification. Captive breeding and larval rearing techniques have been developed for *Labeo dussumieri, Gonoproktopterus (Hypselobarbus) curmuca, Etroplus suratensis, Osteobrama belangeri, Clarias dussumieri, Puntius pulchellus* and *P. carnaticus* and native ornamental species having export potential such as *Pristolepis marginata, Puntius denisonii, Horabagrus brachysoma, Danio malabaricus, Puntius filamentosus* and *P. fasciatus*. Research and development efforts are also evolved along north-east uplands to include indigenous medium carp having high regional preferences like pengba (*Osteobrama belangeri*) in polyculture system.

Integrated farming practices

Cattle-based fish farming is most common, where the dung and urine from 3 to 4 cattle is used to fertilize a pond of 1 ha, with production levels of 2-4 tonnes/ha/year, without any supplementary feed. Pig is perhaps the most efficient feed-converting animal sustaining itself by scavenging on farm wastes and kitchen refuse. The excreta from 30 to 40 pigs has been found adequate to fertilize 1 ha pond, for production levels of 2-3 tonnes/ha/year of fish. Duck-cum-fish farming is one of the most viable and economically sound integrated farming systems of the country. About 200-300 ducks are adequate to fertilize 1 ha pond and fish yields from duck-cum-fish farming system range from 3 to 4 tonnes/ha/year, in addition to 4,000-6,000 duck-eggs and 500-750 kg duck meat from the unit. In integration with poultry, 500 country-birds are adequate to fertilize 1 ha pond, for yielding 4-5 tonnes fish/ha and more than 7,000 eggs and 1,250 kg meat (live weight) in a year. It is however necessary that customized models for different regions and components of integrated farming are employed and the farmers adequately trained to work with the different aspects.

Rice-cum-fish culture is undertaken in medium to deep water-bodies with strong dykes. Fish species like catla, rohu, mrigal and common carp are stocked at a density of 5,000-10,000/ha along with freshwater prawn and other minor carps. Production levels of 3.5 tonnes of paddy and 0.5-1 tonne of fish/ha are achieved in well-managed paddy-cum-fish culture plots. The traditional rice-fish farming systems practised in the North-Eastern hill region such as the mountain valley system in Apatani plateau of Arunachal Pradesh and running water terrace system in the hilly terrain of Meghalaya, Sikkim and in certain parts of Arunachal Pradesh are unique and yield about 200 kg fish/ha/season with the traditional rice crop. These systems need to be improved with better water and other inputs management and integration of other suitable crop and animal-based components for high water productivity.

The net water productivity in the irrigated rice is around ₹ 1.5/m^3 that can be enhanced by 80% (₹ 2.7/m^3) with the integration of fish. Incorporation of horticultural crops on dykes and a dry season crop in the field further increases the net water productivity to ₹ 3.8/m^3. Adoption of rice-fish-prawn-field and horticulture crops-agro-forestry-livestock based diversified farming systems can greatly enhance the net water productivity to a level of ₹ 13.8/m^3. However, rice-fish farming requires 26% more water compared to the sole rice crop. This excess water use is recompensed well with the realization of higher water productivity in addition to other benefits in rice-fish farming such as control of weeds under continuous flooding besides and other advantages realized by both the rice and fish crop due to synergism.

Ornamental fish farming

With a rich diversity of ornamental fishes with over 100 varieties of indigenous species, in addition to similar number of exotic species that are bred in captivity, the export potential of ornamental fishes from India is of the order of US $ 30 million. However, the export of the country at present is mainly confined to some indigenous species from north-eastern states and a few exotics, with the share in Asia's exports being only about 2%. Gold fish is the most common and preferred fish because of its varied colouration and morphological characteristics, the common varieties being comet, lion head, oranda, fringe tail, veil tail, fan tail, *shubunkin* and telescopic eye.

Marine aquarium fish trade is gaining increasing popularity the world over with an estimated value of US $ 4.5 billion. The Gulf of Mannar, Palk Bay, Gulf of Kachchh, south west coast and the Lakshadweep and Andaman Group of Islands are known to

be rich in ornamental fishes. The wrasses, damsel fish, sturgeons, butterfly fish, moorish idol, squirrel fish, trigger fish, rabbit fish, parrot fish, angels, goat fish and puffer fish are the major aquarium fishes represented by nearly 180 species. The survey and assessment of marine ornamental fishes of Lakshadweep (nine islands) indicate an annual potential yield (rough estimate) of 25 lakh of fish, consisting of 38.0% wrasses, 32.7% damsel fishes, 8.4% goat fish, 7.4% parrot fish, 4.9% squirrel fish, 4.8% surgeon fish, 2.1% butterfly fish, 0.8% trigger fish and others. As majority of these fishes are associated with coral reefs and those in great demand are not very abundant, their exploitation may disturb the habitats and result in depletion of stocks. The sea-horses or pipe fishes (Syngnathidae) have ornamental value and live in sea grass beds, mangroves and reefs in most shallow coastal waters of the temperate and tropical regions, but their exploitation is banned as they are enlisted in schedule I of the Indian Wildlife Protection Act. The exploitation and export of ornamental fish resources from the Palk Bay have been assessed. Four species of clown fish (*Amphiprion percula, A. ocellaris, A. sebae, Premnas biaculeatus*), eight species of damselfishes (*Dascyllus trimaculatus, D. aruanus, Pomacentrus caeruleus, P. pavo, Chromis viridis, Neopomacentrus cyanomos, N. nemurus, Chrysiptera cyanea*) and dottyback (*Pseudochromis dilectus*) have been successfully bred and their seed production technology standardized.

Development of culture technologies is the answer to a long-term sustainable trade of marine ornamentals, that reduces the pressure on wild population, for production of uniform-sized juvenile and market sized fish round the year. In addition, hatchery produced fish are hardier and fair better in captivity and survive longer. Attempts for spawning and rearing in closed systems have proved technically challenging for many of the species except few Pomacentrids, and the greatest obstacle to successful breeding of most of the ornamental reef fish is larval rearing beyond sixth to eighth day of development, due to problems associated with larval feeding. Intense efforts are needed to commercialize seed-production techniques and developing standardized packages and practices for a dozen of species which are in high demand in the marine ornamental fish trade.

The areas adjacent to the metros, Kolkata, Chennai and Mumbai have become major breeding centres for freshwater ornamental fishes due to ready urban market and access to export business. In recent years, breeding units have been established in states like Kerala, Andhra Pradesh, Odisha and Bihar. Researches on domestication and improvement need to be stepped up, including production of transgenics for enhancement of colouration, fin features and so on. A hub and spoke model is suggested for seed production and grow-out of the ornamental fishes, with the central breeding unit providing seed material for satellite units and collection at one point for ensuring the bulk quantities required for both domestic trade and exports. Importing seed of preferred species and re-export after a period of growth and value-addition is another possibility to be considered, with due quarantine measures. In this direction, a list of non-invasive species that could be imported has been prepared to facilitate trade of ornamental fishes.

quaculture inputs

Seed is the basic input into culture systems, hence its production has been accorded gh priority in terms of broodstock management, establishment of hatcheries, finement of induced breeding techniques, rearing and production of quality seed und the year across the country. Carp hatcheries in both public and private sectors ve contributed for the increase in seed production from 6,321 million fry in 1985- to over 37,000 million fry presently. The states of West Bengal and Asom are ghest producers of seed, exporting to other parts of the country. However, availability fingerlings of recommended size as ideal stocking material for grow-out culture in servoirs has been a constraint all over the country.

Problem of inbreeding depression has also been reported from several places. egular replenishment of broodstock in the hatcheries has been prescribed but in the sence of any regulatory measures, is not practised. Steps at hatchery accreditation d fish seed certification have been initiated, that are expected to enable quality surance in the area. In this context, the categories of carp seed such as spawn, fry, ngerlings have been redefined. While ploidy manipulations in carps was conducted the earlier years, emphasis presently is on functional genomics. Development of nproved rohu, CIFA IR 1 (*Jayanti*) by the Central Institute of Freshwater Aquaculture, hubaneshwar, through selective breeding, demonstrating more than 17% higher rowth per generation after seven generations, is a landmark in the area of quality fish eed. The ICAR Mega Seed project is one of the recent initiatives at producing quality nfish and shellfish seed in different ecosystems and parts of the country, with due eference to the regional preferences and requirements.

Supplementary feeding in freshwater aquaculture has been largely in the form of rovision of mixture of rice bran and groundnut/mustard oilcake. With gradual tensification of practices, several balanced feed formulations have been developed nd the commercial production of supplementary feed is usually in the form of pellets, provide higher water stability, ensure better consumption and utilization by the sh. Provision of commercial floating feed is also gaining increased importance owing its minimum wastage and better acceptability, besides its advantage of total nonitoring during consumption by the fish. Establishment of state-of-art extrusion eed plants in Andhra Pradesh and Chhattisgarh in last one year envisages the possibility f transformation of carp farming from traditional bran-oil cake mixture practice to loating feed application in the coming years.

With intensification of practices, health management has become an essential omponent of aquaculture. Epizootic ulcerative syndrome that has caused severe threat freshwater aquaculture since late 1980s has been tackled by application of a chemical ormulation, CIFAX. Diagnostic kits for bacterial pathogens such as *Aeromonas ydrophila* and *Edwardsiella tarda* as also for white tail disease of freshwater prawn nd therapeutics including herbal formulations have enabled control of some of the acterial diseases. However, in spite of efforts at control of the exo-parasite, *Argulus*, as remained a problem in carp culture ponds for want of suitable eco-friendly ormulations.

With the available resources in terms of ponds and tanks and the fish species, doubling of fish production through freshwater aquaculture is being seen as a clear possibility. However, with water availability going to be restricted in the coming years, strategies of multiple use, reuse and integration of aquaculture with other farming systems need to be developed. At the same time, resources of wastewater and degraded waters such as ground saline water provide new opportunities for aquaculture practices. Water productivity would be the key issue in farming practices, and water budgeting for different stages of broodstock management, breeding and seed production and grow-out under different systems has to be worked out. The developmental strategies proposed are: extending the coverage of freshwater aquaculture area; optimizing productivity of existing waters; diversification of species and intensification of culture practices and fish health management and disease diagnostics.

Fish processing and marketing

Over 0.6 million tonnes of fish produce exported from the country is subjected to some form of processing, but bulk of the produce for domestic market is consumed fresh. Traditional methods of fish preservation like drying, salting and smoking are in vogue in coastal areas, while freezing, canning and production of *surimi* have been employed for exports. With increasing inter-state movement of fresh fish, chilling and icing have become important preservation methods for domestic marketing of fish produce. Along with battered and breaded products, ready-to-cook, ready-to-eat fish in modified atmosphere packages and fish-incorporated products like condiments and maricream form the range of value-added products. The low-valued fishes or byproducts are also subjected to processing for several industrial products, viz. fishmeal and oil; chitin and chitosan from the exoskeleton of shrimp, lobster, crab or squilla; fish maws from fish bladder; shark fin rays, etc.

Marketing of fish and fishery products in the country is still unorganized, except in a few towns and cities, with municipalities and other local bodies looking into the marketing aspects. About 75% of fish produced in the country is marketed domestically through wholesale, major and minor retail (including roadside) markets. Majority of domestic markets lack proper fish storing and hanunic sfacilities. Other concerns are with regard to transportation system including roaand inlancated vehicles, availability of potable water, good-quality ice, electricity ze sections of thsal system. There is considerable time lag during the transportation similar stuch the landing centre to the interior markets, which results in poor quality of the assterial leading to high nutritional and post-harvest losses. A study in the Ernakulam district of Kerala and West Godavari district of Andhra Pradesh showed the post-harvest losses in fish to the extent of 15%, amounting to over ₹ 2,700 crore annually on a national basis. There exists a cold chain in case of fish production from Kolleru Lake region of Andhra Pradesh (East Godavari and Krishna districts), where fishes are transported in insulated trucks with ice to distances of more than 2,000 km, with Kolkata being the major market. Hence, public investments to expand access to rural infrastructure and services such as rural roads and transport services, primary and secondary fish markets, telecommunications, and electricity, will be critical to reducing transaction costs and physical losses and to enhance transparency and competitiveness in traditional fish markets.

The export of marine products in India both in terms of quantity and value has been more or less increasing at a steady pace during last five decades. The export in terms of value has increased from a meagre ₹ 3.9 crore in 1961-62 to ₹ 10,048 crore in 2010. Frozen shrimp was the prime export commodity earlier, but now there has been considerable diversification in terms of both products and markets in the recent past. The shares of frozen shrimp and fresh/frozen fish to the total export are presently 21 and 40% in terms of quantity and 43 and 19% in terms of value respectively.

As regards overseas destinations, the European Union, Japan and USA have become important markets for fishery products. The USA has been the top importer of shrimps from India, and squid and cuttlefish are two important commodities exported mainly to the EU and south-east Asian countries. Considering better market potentials, the country has to develop appropriate strategies for marketing of ornamental/live fishes and value-added fishery products to realize better export earnings in the coming years.

The National Committee on implementation of Code of Conduct for Responsible Fisheries has suggested the following measures to promote and monitor exports and domestic marketing: Improving fish handling and preservation facilities on board the fishing vessels; encouraging fishing boats to have insulated and refrigerated fish holds; adequate facility for catch handling at fisheries harbours and landing jetties and facility for catch preservation such as chilled/cold storage; hygienic handling of raw material, ensuring quality of the ice and production of value-added products; setting up small-scale projects for production of semi-processed ready-to-cook fish products from low-valued fishes, fish pickles, quality dried products, fish curry, etc. by coastal population; imparting training to workers of pre-processing and processing plants on various aspects connected with hygiene and sanitary drills; setting up a network of cold storages, refrigerated outlets and small-scale training units; exploring domestic market for a variety of value-added products and related aspects; collection of complete details of cases coming before the Appellate panel of World Trade Organization (WTO); setting up of a National data centre and necessary support to trade to fight antidumping; changes in the Export Import by thM) Policy so as to grant preference to value-added products over commqesh and Chhattmarket promotion steps through benefits under schemes like Brand Ee, farming from Market Access Initiative and Joint ventures for production and marketing o. coming yded products.

International agreements

India is a signatory to important international treaties such as the United Nations Convention on the Laws of the Seas (UNCLOS), Convention on International Trade in Endangered Species in Wild Fauna and Flora (CITES), Convention of Biodiversity (CBD) and Indian Ocean Tuna Commission (IOTC), among others. As regards the WTO and fisheries, Doha round in 2001 was important because the fisheries subsidies were on the agenda of negotiations for the first time, and reduction or elimination of tariffs on products of export from developing countries was considered. The Code of

Conduct for Responsible Fisheries (CCRF) evolved by the FAO has been endorsed by India, which aims at long-term sustainable measures for optimal exploitation of fishery resources. The Code serves as an instrument of preference to establish or improve the legal and institutional framework for exercising responsible fisheries. The general principle of the code is 'the right to fish carries with it the obligation to do so in a responsible manner'. It calls for effective legal and administrative framework for the refusal, withdrawal or suspension of authorization to fish in the event of non-compliance with conservation and management measures. The member countries have further been given responsibility to implement effective fisheries monitoring, control and surveillance, and law enforcement measures wherever necessary.

Centre-State programmes

During the last two decades, several regulations and notifications have been promulgated by the central and state governments for protection of coastal ecosystems, including Environment (Protection) Act (1986); General standards for discharge of waste -waters in marine coastal areas (1993); Notifications declaring certain coastal areas as a marine sanctuary or marine national park; Notifications declaring coastal stretches as Coastal Regulatory Zone (CRZ) and regulating the activities in the CRZ (1991, 1994, 1996); and Environmental impact assessment notification (1994). The Coastal Zone Regulation (CRZ) notification in February, 1991 under the Environment (Protection) Act, 1986 issued by the Ministry of Environment and Forests, Government of India specified that the coastal zone influenced by tidal action up to 500 m from the high tide line shall be treated as Coastal Regulation Zone and setting up of new industries in this zone are prohibited. As regards marine fisheries, Indian Fisheries Act, 1897; Charter Policy, 1981, revised in 1986 and 1991 for deep-sea fishing; Comprehensive Marine Fisheries Act, 2004 are in vogue.

Several central sector schemes and centrally sponsored schemes in marine as well as inland fisheries are in operation. An important mechanism in the sector is the Fish Farmers' Development Agencies and the Brackishwater Farmers' Development Agencies at the district level, facilitating freshwater and brackishwater aquaculture. There have been concerns regarding the socio-economic status of the fishermen. While those engaged in fishing activities, both marine and inland, are largely traditional fishers, aquaculture has been taken up by diverse sections of the society. There has been a decennial census of marine fisheries, but similar studies in the inland fisheries are lacking, and presently, efforts are being made to assess the status of literacy, health and income, the last one differentiating the sources, among the fishers and farmers in the country.

The Government of India established the National Fisheries Development Board in 2006, to address the immediate needs of reservoirs fisheries development and organized domestic marketing in fisheries.

Policy and planning

Policy issues in areas of deep-sea fishing-uniform closed seasons and mesh regulations in states along east and west coasts, alternative livelihoods for fishers during closed seasons, provisions for culture of certain marine invertebrates like sea cucumbers, regulations on wild seed collections and destructive fishing, leasing of waters (both inland and marine), quarantine and regulated introduction of exotics, fish/shellfish seed certification, ranching of water-bodies and domestic markets with customized cold chains–are continuously addressed. The policy measures suggested for harvesting sector include: protection and consideration of subsistence-level fisherman; area demarcation for traditional, motorized and mechanized sectors; motorization of traditional crafts and provision of infrastructure support in terms of landing and berthing facilities for deep-sea vessels; introduction of more resource-specific vessels of above 20 m length; special incentives for wholly Indian-owned vessels for venturing into international waters and engaging in fishing in the EEZ of other nations under license; regulation of fishing capacity and incorporation of code of conduct for responsible fishing operations in the different components.

The management measures for resource conservation include implementation of closed season, ban on destructive methods of fishing and mesh size regulations. The policy also envisages through legislation that there should be prohibition of catching of juveniles and non-targeted species and discarding less-preferred species once they are caught. Seed production for sea ranching, designation of certain areas as marine sanctuaries, and regulating capture of broodstock from these locations would form important components of resource-enhancement programmes.

Coastal aquaculture is covered by the provisions of the Coastal Aquaculture Authority Act, 2005, that relate to preventing construction of shrimp farms in mangrove areas, other sensitive areas and in agricultural land; compulsory EIA for larger farms; wastewater quality standards and effluent treatment plants; use of chemicals and drugs; licensing and mandatory application of code of conduct; provision for registration of shrimp farms valid for a period of five years which may be renewed from time to time for a like period.

The policies and regulations with regard to freshwater aquaculture in the country are being discussed in the wake of the sector's unprecedented growth in the recent years, with reference to land use, conversion of agricultural land, use of surface and groundwaters, provision of power and taxing practices. Unregulated introduction of exotic fish species such as tilapia (*Oreochromis* spp.), African catfish or Thai *magur* (*Clarias gariepinus*), bighead (*Aristichthys nobilis*), *Pangasius sutchi* and a number of ornamental fishes has been a matter of concern. While presently, a National Committee on Introduction of Exotic species at the Centre monitors the movement of live aquatic animals, it is necessary to provide the relevant quarantine and biosecurity mechanisms.

Considering the potential of inland fishery resources and the development of fisheries sector, a Model Inland Fisheries and Aquaculture Bill has been formulated. The main objective of the Model Bill is better management of the inland fishery resources so as to ensure sustainability and increased productivity. The aspects of the Bill pertain to control, regulation and ban on destructive fishing, craft and gear, untenable fishing practices in inland waters, conservation of fish stocks and resources, encroachment/reclamation of inland waters, leasing/licensing of open waters, fish seed certification and inter-State movement, feed quality and certification, use of chemicals, antibiotics, etc., health monitoring and disease reporting/control, coldwater fisheries, integration of aquaculture with other farming systems.

Aquarian reforms in inland and coastal waters are essential for their sustainable and equitable use. The proposed reforms include leasing policy for major inland waters and coastal waters for aquaculture, treating aquaculture at par with agriculture for water and power tariffs, as has already been done in some of the states, enforcement of closed season in large waters and easy credit support for production of feed for aquaculture species. These also involve inter-ministerial discussions as the issues are often in different domains of operation.

Apart from the traditional fishers in both marine and inland fisheries, entrepreneurs in different aspects of deep-sea fishing, mariculture, coastal and freshwater aquaculture, fish processing and export have become important stakeholders in the sector. In order to deliver the necessary technical know-how as well as provide the required policy and finance support, capacity building in Fisheries Departments of the State Governments in areas of extension and technology transfer, project formulation and public-private partnerships, business models and marketing has become crucial. The resources available at the research institutions, fisheries colleges, agencies of Ministries of Agriculture, Commerce, Food Processing and Industries, Environment and Forests, Science and Technology; international organizations such as the FAO, IOTC, BOBP (Bay of Bengal Programme) as well as the Associations of fishers and farmers would need to be effectively utilized for achieving greater efficiency in the sector.

Perspective

The issues in fisheries and aquaculture that need to be addressed to realize the full potentials of the sector pertain to biodiversity loss and depletion of fish stocks; excess coastal fishing, oceanic and deep-sea fisheries; impact of climate change on fisheries; transboundary fisheries aspects including movement of fish species and incidence of diseases; inland and coastal pollution; large-scale sedimentation of rivers, estuaries and lakes/wetlands; effective compliance of code of conduct of responsible fisheries; lack of diversification in aquaculture practices; water management in aquaculture; quality seed and relevant certification measures; planning for feed provision in farming; introduction of exotics with due quarantine procedures; emergence of new diseases; mechanization in fisheries and aquaculture; cold chain and hygienic fish handling; quality assurance in value-addition and exports; overseas market fluctuations and suitable models of domestic marketing; disaster management; credit and insurance; and database management. Suitable programmes must hence be formulated to build in resilience in fisheries and sustainability in aquaculture.

Demand projections for fish by 2012 is 9.99 million tonnes at an estimated annual consumption growth rate of 3.5% and that by 2020 is 12.70 million tonnes. The required annual growth rate for meeting the demand would be of the order of 5.4% and the supply projections are given in Table 1.6.

Table 1.6. Present and projected fish production scenario from different segments

(million tonnes)

Area	Production 2009-10	Projected production 2012	Projected production 2020	Approach
Marine capture fisheries	3.05	3.20	3.50	Regulated fishing and capacity reduction in mechanized sector; conservation efforts; sea ranching; FADs; diversified fishing in deep sea and oceanic resources; CCRF; VMS and sea safety measures; infrastructure for fish landing and marketing
Mariculture	0.02	0.04	0.20	Identification of suitable sites along the coastline; suitable leasing policy; hatcheries and grow-out systems for high-value fish, crustaceans, molluscs, sea cucumber, ornamental fishes, seaweeds; cage culture in open seas and island ecosystems; market linkages
Coastal aquaculture	0.10	0.12	0.30	Increasing water area under aquaculture; diversification of species, both in shrimp and finfishes; quality seed and feed; inland saline aquaculture as an added component; domestic marketing
Inland capture fisheries	0.8	0.9	1.20	Culture-based fisheries in reservoirs with stocking of advanced fish fingerlings; pen and cage culture in large water-bodies; canal fishery development; resource-specific harvesting techniques; CCRF
Coldwater fisheries	0.0003	0.0005	0.01	Seed production of trout and mahseer; hill aquaculture; ranching of streams; sport fisheries
Freshwater aquaculture	4.03	5.73	7.50	Increase in the coverage of areas of ponds and tanks for fish culture; reclamation of weed choked waters; diversification of species; intensification of culture practices; integrated fish farming and wastewater aquaculture; aqua-shops; customized cold chains
Total	8.00	9.99	12.71	
Export quantity (million tonnes)	0.68	0.70	0.82	Diversification of products and markets, upgradation of infrastructure; hygienic handling of fish; quality assurance
Value (₹ crore)	10,048	12,000	15,400	

FADs, Fish aggregating devices; CCRF, code of conduct for responsible fisheries; VMS, vessel monitoring system.

The strategy for realizing the potentials of the sector are: ensuring adoption of responsible and sustainable fishery practices; enhancing fish productivity in all cultivable waters; establishing agro-aqua farms; aqua-shops and fishery estates from production to consumption; spreading fish-quality literacy among fishers and aqua-farmers; improving facilities for fish landing and handling at harvest and post-harvest stages; developing social marketing techniques; introducing aquarian reforms with regard to leasing, ownership and community management; and human resource development in different aspects of fisheries and aquaculture.

Marine fisheries: The strategy for sustaining and augmenting marine fish production (Fig.1.4) comprises changing over from an open access to a regulated regime, employing a fishery-management regime supported by a multi-dimensional information platform, upgrading technologies and capabilities in the artisanal and small mechanized sector for diversification, reducing the excess capacity of fishing fleet, freezing the entry of new coastal mechanized fishing crafts, establishing an

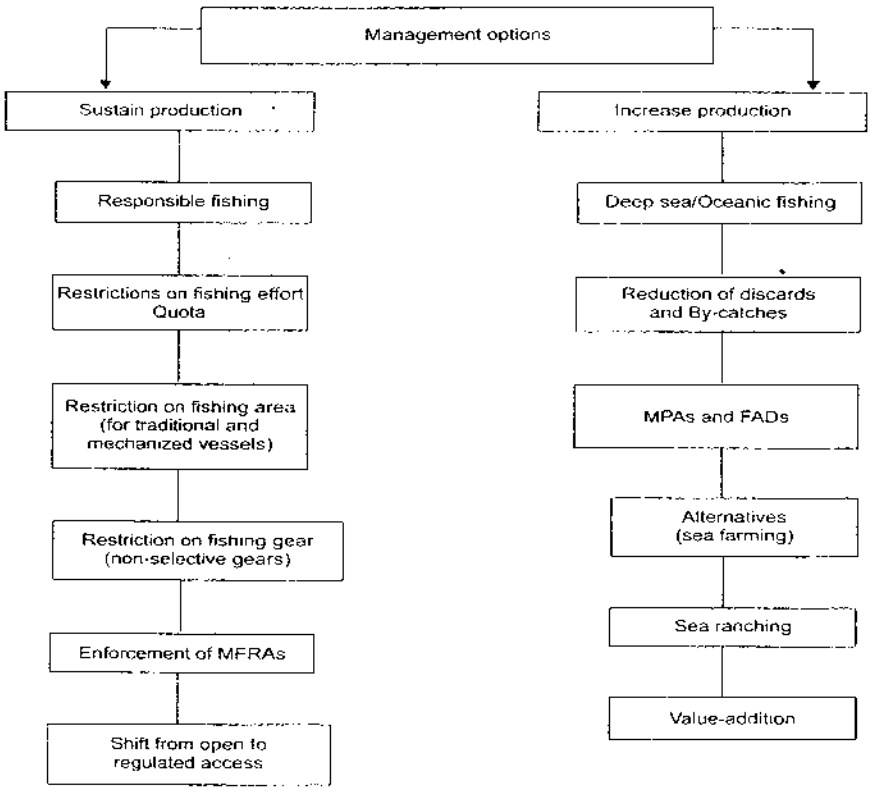

Fig.1.4. Options for sustaining and increasing marine fish production (MPAs, Marine Protected Areas; FADs, Fish Aggregating Devices).

oceanic tuna and squid fishery, promoting mariculture for finfishes, edible bivalves, sea plants, and other commercially important species and sustain fish production through the effective enforcement of marine fishing regulation acts (MFRAs).

The process of motorization initiated in the 1980s has largely been successful and the future course of action needs to be only on selective, need/area-based motorization of traditional crafts with engines of less than 10 HP capacity. The emphasis needs to be on fuel efficiency, including the use of LPG for the purpose. Diversification from shrimping is an immediate need and the trawling fleet needs to be reduced and resource-specific deep sea fish fleet introduced for offshore fishing. Combination gear vessels with gill nets, hooks, trawls, enhanced fish hold capacities and ice storage facilities to improve the quality of the catches and reduce discards are required. Co-management needs to be encouraged for empowering fishers and other stakeholders for the opportunities and an environment needs to be created for them to work with the Government hand-in-hand.

The present production from marine fisheries is mainly contributed by the coastal zone up to a depth of 50 m, but the harvestable potential of 1.69 million tonnes in deep sea and oceanic resources beyond 50 m depth are being exploited only at marginal levels. Being a major maritime State, India has tremendous scope to harvest the oceanic tuna and allied stocks from the national waters in the region. The available rich crustacean resources like deep sea shrimps and deep sea lobsters between 120 and 500 m depth zones along southwest coast can be exploited. Initiatives therefore, would be necessary by the government to encourage the entrepreneurs and fishers to undertake the operations in the deep sea and distant waters.

Stock assessment studies have shown that the present fishing effort in case of oil sardine, mackerel, Bombay duck, seer fishes, ribbon fishes and coastal tunas is close to or in some cases, even exceeded the levels of maximum sustainable yield and further increase in effort in the coastal sector would be detrimental for sustaining the yields. Reliable estimation of stock size is required to formulate any fisheries management policy. Predictions for oil sardine fishery along the Indian coast based on sun spot activity, rainfall intensity, sea level change and duration and upwelling indices have proved successful, which could be attempted for other pelagic species.

Considering the multispecies fisheries potential of the Indian waters, it is envisaged that the temporal ban and restrictions on craft and gear will be effective under a larger, holistic management regime which should include spatial ecosystem-based fishing restrictions, mesh size regulations, capping the capacity of fishing craft in major harbours, etc. However, the monsoon ban as it is known, is relevant to coastal fisheries and should not be applied to deep-sea fishing, ensuring that these vessels do not fish in coastal waters. Ecosystem-based management approach can be considered as an effective tool which is expected to provide a long-lasting solution to the problems of declining fish stocks.

Mariculture: Indian mariculture, although has shown considerable development during the last decade, has been confined to farming of mussels and edible oysters and to a limited extent, pearl oysters in the coastal areas of Kerala and Tamil Nadu only.

Considering the technological advances made in the aspects of seed production and farming of bivalves, seed production of sea cucumbers, sand lobsters, crabs, etc., mariculture in the country needs to diversify. The following aspects, therefore, are suggested for the development of the sector: Development of mariculture sites along the coasts, including island systems and enabling leasing policy; provision of inputs and facilities for collection of material for transport to markets; large-scale cage culture in open seas; development of different types of re-circulatory and raceway systems for land-based mariculture; development of entrepreneurship for large-scale production of high-valued marine ornamental species like clown fish for international market; emphasis on greater interactive mode of technology transfer for different commodities to have noticeable impact.

Coastal aquaculture: Taking into account the present growth trend as well as market fluctuations, the area under shrimp farming would need to be increased to 300,000 ha with an annual production of about 400,000 tonnes. In order to achieve this goal, the steps suggested are: Species diversification, i.e. from the present dependence on single shrimp species, *Penaeus monodon* to a wide spectrum of candidate species; at least three species of shrimp, six of finfish and two of crab have been identified as potential species; development of captive broodstock and domestication of identified species; ensuring adoption of appropriate biosecurity measures by the hatcheries for supply of pathogen-free seed; suitable national aquatic biosecurity measures; development of environment-friendly and cost-effective culture technologies of both shrimp and finfish focusing on small-scale farmers; protocols for water-quality management in ponds including effluent treatment plants; comprehensive health-management approach in shrimp hatcheries and farms, including development of diagnostics, therapeutants, probiotics and vaccines.

Since brackishwater aquaculture is presently mainly dependent on exports, issues such as traceability and anti-dumping are expected to have a significant influence on growth of the sector. Development of a strong domestic market for the produce, establishing a well-knit system for market information and intelligence for aquaculture produce are other aspects needing thrust. Implementation of aspects of HACCP, traceability, eco-labeling and quality assurance criteria for uniform and wider compliance is necessary for building the confidence of the importing nations and boosting the export of our produce. Further, promotion of institutional mechanisms and addressing the issues of aquaculture finance are other aspects which warrant attention for ensuring the small-scale farmer to be empowered for realizing the gains from technological interventions.

Inland capture fisheries: Substantial gaps between the potential and actual fish yields from culture-based fisheries resources such as reservoirs and wetlands provide ample opportunity for fisheries enhancement. The following steps are suggested for development: Fish yield enhancement initiatives in small and medium reservoirs and wetlands, preferably through co-management with the stakeholders; large-scale cage and pen culture in reservoirs for raising proper stocking material; wider coverage of reservoirs for stocking advanced fingerlings; employing Remote Sensing and GIS technologies for creation of appropriate databases required for formulation of appropriate management norms, lacking in open-water fisheries; ensuring environmental flows for the riverine systems for sustenance of fisheries and conservation of biodiversity; effective enforcement of regulations on fishing operations.

Coldwater fisheries: The perspectives for upland coldwater fisheries in the country are promotion of trout farming through scientific management for enhancing production for both domestic market and exports; fish stock enhancement in upland reservoirs; developing sport fishery based on trouts and indigenous mahseer in hill streams and lakes for fish-based eco-tourism; extension of the success of carp farming in mid-altitude waters to other hilly regions.

Freshwater aquaculture: On one hand, only about 40% of the available pond and tank resource of 2.36 million ha is under utilization, on the other hand, the mean national pond productivity has remained at about 2.4 tonnes/ha/year, despite production levels of 6-8 tonnes/ha/year being realized by farmers in several parts of the country. This indicates the enormous scope for both horizontal and vertical expansion of freshwater farming. In this regard, it is necessary that district-wise developmental plans are made based on the soil fertility, water retentivity and nutrient status, climatic conditions, available water resource structure, market structure of the area, investment capacity of farmers, etc. Considering the availability of technologies and resource potentiality of the Indian farmers, it is feasible to enhance the mean pond productivity to 4 tonnes/ha/year in the next ten years.

The strategy for enhanced freshwater aquaculture production is: Mapping of aquaculture resources of the country through remote sensing and potential aquaculture zones on GIS platform; diversification of practices with 15-20 species across the country; check on unauthorized introduction of exotic species, ensuring a suitable biosecurity system and quarantine mechanism; selective breeding in important fish/shellfish species for traits such as growth and disease resistance on the lines of improve rohu; programmes on transgenics in ornamental fishes as a novel approach for enhancing marketability; promotion of ornamental fish farming both as cottage industry and large-scale enterprize; quality seed supply of carps as well as other species of catfishes, prawn and ornamental fishes with adequate rearing space in different regions; establishment of certified brood banks and seed villages for commercially important fish/shellfish species; promotion of both farm-made feeds and commercial feeds to suit different levels of farming, along with feed dispensers; ensuring the availability of required diagnostics, vaccines and other therapeutics; water management and mechanization; aqua-shops as one-window facility for all inputs; and customized cold chains with cooling chambers in villages and mobile vans, along with hygienic outlets.

Post-harvest management

In order to ensure effective utilization of the produce and better economic realization, following post-harvest efforts are suggested, where there are high possibilities of public-private partnerships: Bringing out better designs of new-generation, fuel-efficient and multi-purpose fishing vessels and gears; thrust on deep sea and distant water fishing

with facilities of on-board handling, preservation, packaging, quality control and connectivity to markets; greater focus on domestic marketing with both customized products for different regions as well as delivery systems in terms of cold chains and outlets; quality assurance in products for both domestic markets and exports, with suitable analytical laboratories and implementation of HACCP and TQM concepts.

Fisheries is a sunrise sector, with varied resources and potentials. With increasing awareness about wholesome diets, fish consumption in the country is steadily going up, in view of its high quality protein, omega-3 fatty acid and mineral contents. Coupled with rising income levels, domestic market for fish is assuming importance and necessary models and quality control protocols in this regard need to be developed. With the projections made in Table 1. 6 till 2020, it is expected that the fish requirement by 2025 would be of the order of 16 million tonnes, of which at least 12 million tonnes would need to come from the inland sector and aquaculture is expected to provide over 10 million tonnes.

With an action plan indicated as above and road maps being brought out for enhancing productivity and production in different segments, it is expected that the sector would increasingly contribute to the nutritional security. It is necessary that capacity building at different levels is duly addressed and extension mechanism strengthened. As capture fisheries is still an important component of Indian fisheries, due importance needs to be given to habitat restoration and fish conservation in different ecosystems. It is important to recognize that aquatic food could form an important part of the Indian diet, critical in view of increasing pressure on land. Fish further becomes important in the context of health food and in order to enhance access to fish and fishery products in the domestic market, ensuring quality and effective distribution would need to receive greater attention.

2. Fish Genetic Resources and their Conservation

Conservation and sustainable utilization of natural resources are issues receiving global attention after signing the Convention on Biodiversity. Fish as a group, apart from its economic value from a biodiversity viewpoint, has the highest species diversity among all vertebrate taxa. Fishes exhibit enormous diversity in size, shape, biology and in the habitats they occupy. In terms of habitat diversity, fishes live in almost all conceivable aquatic habitats, ranging from Antarctic icecap to hot springs as well as fresh to saline waters. The great majority comprises bony fishes, mainly teleosts. Besides, there are around 800 species of cartilaginous fishes and 70 of jawless fishes (lampreys and hagfishes). It is believed that out of 61,259 species of vertebrates recognized world over, 30,700 are fish species; of which 8,411 are freshwater and another 160 species require freshwater at one stage or other to complete their life cycle; while 11,650 are marine. Global surveys emphasized that there could well be at least 5,000 species more to be discovered. Almost 25% of global vertebrate diversity is accounted for by fish and is concentrated in this meagre 0.01% of the earth's water. India with its four of the 34 global biodiversity hotspots (the Western Ghats, North-East Region, the Himalayas and Nicobar Islands) contributes a major share to the world's biological resources. Being home for about 11.72 % of global fish biodiversity, the country ranks third in the world in total fish production. While marine sector is almost constituted by capture fisheries, aquaculture has been the principal contributor in inland fisheries sector, with a share of 77%. The fisheries sector provides employment to 14 million people and its share in GDP is around 1%. Besides a source of food and nutrition, germplasm resources are also important source of various products of pharmaceutical and other commercial value and sustain other related trades like ornamental fishes. The fishery sector also contributes significantly to the foreign exchange earnings of India to the tune of over ₹ 10, 000 crore (US$ 2.5 billion). A study by the Food and Agriculture Organization projects a global average per caput demand for all seafood is about 19.1 kg in 2015. The study also highlighted that developing countries already produce and consume more fish than developed countries and it predicts that the dominance of developing countries will grow further by 2020. To meet these challenges, appropriate planning for conservation of fish diversity and its sustainable utilization is of utmost importance.

It is a known fact that aquatic environments are experiencing serious threats to both biodiversity and ecosystem stability and many strategies and priorities have been proposed to solve this crisis. It has been recorded that the biological changes that environmental degradation bring about, due to enumerated pollution, increased sedimentation, flow alteration and water diversion, and introduced species are the main causes for decreased ichthyofaunal diversity in Asian countries. The international community has also become sensitive to conservation of natural resources, rights of

native inhabitants etc., as is evident from the Convention on Biodiversity. Government of India has legislated the Biological Diversity Act, 2002 and Biological Diversity Rules, 2004; which aim at conservation of our natural heritage and ensures the sharing of benefits of the utilization of biological resources in an equitable manner. There is also growing awareness of how biodiversity supports livelihood and sustainable development. Research and policy requirements for aquatic biodiversity conservation are basically based on other resources; however, conservation of fish resources must also take into consideration the distinct and diverse nature of water resources.

Fish diversity in Asia

The number of recognized finfish species in the world is estimated to be around 28,400 (updated to 30,700; http:// www.iucnredlist.org/doc/2008).

It is reported that aspects of biodiversity and conservation of the ichthyofauna in the Asian region have been relatively less documented. The freshwater fish fauna in the nations of the regions, South and South-East Asia is reputed to consist of 6,707 native and widely distributed fish species. Nation-wise, the maximum number of endemic freshwater finfish species occur in India contributing 27.8% of the native fish fauna followed by China, Indonesia and Myanmar. The number of widely distributed and endemic freshwater finfish species recorded from the two biodiversity hotspots of India and major rivers like Ganges and Brahmaputra are given in Fig 2.1. The number of endemic fish species is high (69%) in the Western Ghats as compared to the North-East Region.

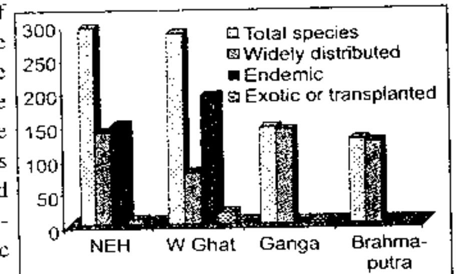

Fig. 2.1. The number of widely distributed, endemic and exotic finfish species reported from two biodiversity hotspot areas (North-Eastern Hills, Western Ghats) and two river basins of India.

Fishery resources of India

India is blessed with huge aquatic resources with 29,000 km of rivers, 0.3 million ha of estuaries, 0.9 million ha of backwaters and lagoons, 3.15 million ha of reservoirs, 0.2 million ha of floodplain wetlands, 0.72 million ha of upland lakes and 2.02 million km^2 area of Exclusive Economic Zone (EEZ) surrounding the seas (8, 129 km of coast line, which includes those of Andaman and Nicobar and Lakshadweep Islands). The seas surrounding the country, 14 major rivers, 44 medium rivers and innumerable small rivers and other inland water-bodies provide one of the richest fish faunistic resources (Table 2.1) of the world [*Source:* INDFISHDATABASE, 2011, National Bureau of Fish Genetic Resources (NBFGR), Lucknow].

Table 2.1. Fish germplasm resources of India

Ecosystem	Total species
Freshwater	877
Brackishwater	113
Marine	1,368
Total	2,358

New freshwater fish species: During the last decade many new fish species have emerged from the biodiversity hotspot areas like North-East and the Western Ghats region. Under a World bank funded National Agricultural Technology Project at the NBFGR, Lucknow, 32 new species were described from the above regions. Many other new species have also emerged in the recent years including *Betadevario ramachandrani, Puntius muvattupuzhaensis, P. pookkodensis, P. rohani, P. exclamatio, Pseudoconta madhusoodani. Gagata gasauyuh, Badis chittagongis, B. ferrarisi, B. kanabos, Mystus falcarius, Sisor chennuah, Pseudolaguvia austrina, P. ferula, P. inornata, P. muricata, Batasio spilurus, Gogangra laevis, Pseudecheneis crassicauda, P. serracula, Amblyceps arunachalensis, A. apangi, Psilorhynchoides arunachalensis, Pseudecheneis sirenica, P. ukhrulensis, Puntius ater, P. khugae* and *Danionella priapus*. Many more new species could be distributed in the drainages of the Western Ghats, North-East Region and other unexplored areas and therefore more biodiversity exploration is required.

Coldwater fish diversity: The aquatic resources above 914 m msl in the Himalayas, sub-Himalayan zone and mountains of the Deccan are known as coldwaters. The Himalayan chain of mountains have been divided into: (*i*) Greater Himalayas containing the 2 highest peaks in India, the Nanga Parbat (8,126 m above msl) and Nanda Devi (7,817 m above msl), (*ii*) Lesser Himalayas includes spurs and highly dissected uplands, and (*iii*) the Shivaliks constituting the southern section of rocks and broken chain mountains (less than 1,200 m msl). In the Deccan plateau, the Western Ghats including the Sahyadri, the Nilgiris, the Annamalai, and the Cardamom hills are important for coldwater fishery. The temperature of the upland coldwater ranges between 0° and 20°C with an optimal range between 10° and 12°C. The lakes and streams of high altitude are characterized by high transparency and dissolved oxygen (7.9 to 9.7 ppm) as well as sparse biota. Most of the fishes are of small size, exhibiting distribution pattern depending upon the rate of flow of water, nature of substrata and food availability. Some fishes living in turbulent steams have developed special organs for attachment. The major coldwater resources are upper stretches of Indus and Ganga and Brahmaputra rivers and their tributaries as well as several coldwater lakes and reservoirs, which harbour fishes belonging to more than 6 different families such as Cyprinidae, Balitoridae, Cobitiidae, Sisoridae, Psilorhynchidae and Homalopteridae. Some of the commercially important Indian coldwater species are *Tor tor, T. putitora, T. mosal, T. progeneius, T. khudree, T. mussullah, T. malabaricus, Naziritor chelynoides, Neolissochielus wynaadensis, N. hexagonolepis, Schizothoraichthys progastus, S. esocinus, S. curvifrons, S. micropogon, Schizothorax richardsonii, S. plagiostomus, S. kumaonensis, Barilius bendelisis, B. vagra, B. shacra, B. (Raiamas) bola, Bangana dero, Labeo dyocheilus, Crossocheilus periyarensis, Garra lamta, Garra gotyla gotyla, Glyptothorax pectinopterus, G. brevipinnis, G. stoliczkae* and *Lepidopygopsis typus*. The Trans-Himalayas is a fragile biome, characterized by extremes of both climatic and biotic factors. Very low productivity and a high degree of resource seasonality and unpredictability give rise to a unique diversity of life that is persistently prone to any kind of disturbance. Flora and fauna of this cold desert are adapted themselves to

extreme conditions and have low population abundance. The fish diversity of Laddakh have been very inadequately explored and according to a study as many as 32 fish species have been documented from Indus, Shyok and Zanskar catchment. Some of the common species are *Diptychus maculatus, Schizothoraichthys stoliczkae, Triplophysa microps; T. tenuicauda, Nemacheilus stoliczkae* etc.

Warmwater fish diversity: In India, 14 major river systems share about 83% of the drainage. The important rivers are Ganga river system with a combined length of about 8, 047 km (the largest river system in India), Brahmaputra system (combined length 4,023 km), Indus river system consisting of Jhelum, Chenab, Ravi, Beas and Sutlej (total combined length of 5,600 km). East Coast river system consisting of Mahanadi, Godavari, Krishna, Cauvery (combined length 6,437 km) and West Coast river system including Narmada and Tapti (combined length 3,380 km). River Ganga harbours 250 fish species (marine, brackish and freshwater) of which about 150 are basically freshwater species. The fish diversity of other rivers is: Brahmaputra 167, Mahanadi 99, Cauvery 90, Narmada 95, Tapti 57 and Sutlej 55 and several species are common to different river systems. There are many small west-flowing rivers originating from the Western Ghats such as Chalakkudy, Chaliyar, Periyar, Sharavathi, Nethravathi that are rich in fish diversity and harbour several endemic genera such as *Gonoproktopterus, Homaloptera, Bhavania, Lepidopygopsis, Horabagrus, Oreonectes, Schistura, Horaglanis*. Some commercially important carps of India are *Catla catla, Labeo rohita, Cirrhinus mrigala, L. calbasu, L. dussumieri, L. bata, L. fimbriatus, Cirrhinus cirrhosa, C. reba, Puntius dubius* and *Barbodes carnaticus*. Catfishes are important groups contributing significantly (9.23 to 28.12%) to the riverine and reservoir catches. These are *Sperata aor, S. seenghala, Wallago attu, Pangasius pangasius, Silonia silondia, Bagarius bagarius, Rita rita* and *Eutropiichthys vacha*. Swamps represent the last stage in the evolution of land from lakes. Finfishes adapted to swampy areas owing to their accessory respiratory organs are known as air-breathing fishes and featherbacks. Murrels and other important species of the group are *Channa striatus, C. marulius, C. punctatus, C. diplogramme, Clarias batrachus, Clarias dussumieri, Heteropneustes fossils, Anabas testudineus, Chitala chitala* and *Notopterus notopterus*.

Rivers of the east coast harbour very rich fish fauna. Fish fauna of river Mahanadi support a diversity of Ganga drainage in addition to peninsular *Labeo fimbriatus*. The *Hilsa* occurs in lower reaches and makes a significant fishery. The principle fish fauna of Godavari are *Labeo fimbriatus*, transplanted Gangetic carps, catfishes like *Sperata* spp., *Wallago attu, Silonia childreni, Bagarius bagarius*, etc. The freshwater prawn *Macrobranchium malcolmsonii* also occurs in east coast rivers system. River Cauvery exhibits substantial variations in fish fauna/the game fishes: *Tor khudree* and *T. mussullah* occur all along the length. The *Hilsa* occurs in the lower reaches and total 50 species of fishes were reported. The commercial fishery is made up of cyprinids like *Neolissocheilus wynaadensis, Tor khudree, Puntius carnaticus, P. dubius, Labeo kontius*, silurids, *Glyptothorax madraspatnum, Sperata aor, S. seenghala, Wallago attu, Silonia silondia*, murrels and featherback, *Channa marulius* and *Notopterus*

notopterus, all transplanted Gangetic carps and exotic *Cyprinus carpio* as well as *Osphronemus gorami*. Along the west coast, in river Narmada, commercial catches are supported by 23 species of carps, important of which are *Labeo fimbriatus, L. calbasu, Cirrhinus mrigala*, catfishes *Rita pavimentata, Mystus* spp., *Wallago attu*, murrel, *Channa* spp. and featherback *Notopterus notopterus*. The important piscine fauna of river Tapti include *Tor tor, Labeo fimbriatus, L. boggut, L. calbasu, Mystus* spp. and *Wallago attu*.

Brackishwater fish diversity: The brackishwater habitats are considered as the transition zone between freshwater of the rivers and the saline water of seas. The salinity of brackishwater ranges from 0.5 to 30 ppt. The major estuarine systems are Hooghly-Matlah, Mahanadi, Godavari, Krishna, Cauvery, Narmada, Tapti and other estuaries of east and west coasts including large brackishwater lakes such as Chilka, Pulicat and Vembanad. The long coastline of 8,129 km, large lakes and estuaries offer immense scope for expanding the coastal aquaculture. The brackishwater harbours 113 taxa including commercially important species like *Elops saurus, E. machnata, Mystus gulio, Nematolosa nasus, Pseudosciaena coibor, Gerres setifer, G. oyena, Sillago sihama, Megalops cyprinoides, Polynemus tetradactylus, P. paradiseus, Eleutheronema tetradactylum, Mugil cephalus, Valamugil seheli, V. cunnesius, Liza macrolepis, L. tade, L. parsia, L. waigiensis, Ephinephelus tauvina, Rhinomugil corsula, Tenualosa ilisha, Chanos chanos, Etroplus suratensis, E. maculatus, Lutjanus argentimaculatus, Lates calcarifer* and *Tachysurus* spp. The brackishwaters also harbour lucrative shellfish species like *Penaeus monodon, Fenneropenaeus (Penaeus) indicus, P. semisulcatus, Metapenaeus monoceros, M. dobsoni, M. affinis, M. brevicornis, Macrobrachium rosenbergii, M. malcolmsonii, M. idella, M. rude, M. mirabilis, M. lamarrei, M. scarbiculum* and *Acetes indicus*. Sundarbans is the largest inter-tidal delta and covers two countries, i.e. India and Bangladesh, covering about one million ha in the delta of the rivers Ganga, Brahmaputra and Meghna is shared between Bangladesh (~60%) and India (~40%), and is the world's largest coastal wetland. This region is criss-crossed with many rivers, rivulets, creeks and canals with an agro-climate typical of a coastal region. The fish diversity includes about 250 species of freshwater and brackishwater sector.

Marine fish diversity: The seawater surrounding east and west coasts of the country with salinity more than 30 ppt is designated as marine water. Marine fisheries resources of the Bay of Bengal, Arabian Sea and Indian Ocean include coastal, offshore and deep sea as well as islands, comprising 1,368 taxa including the commercially important species like sharks (*Carcarhinus bleekeri, C. dussumieri, C. gangeticus, C. limbatus, Scoliodon palasorrah* and *S. sorrakowah*), rays (*Narcine brunnea, Pristis cuspidatus* and *P. microdon*), Bombay duck (*Harpadon nehereus*), oil-sardine (*Sardinella longiceps, S. fimbriatus, S. gibbosa* and *S. albella*), Malabar sole (*Cynoglossus semifasciatus*), parrot fish (*Pseudocarus* spp.), perches (*Lethrinus* spp. and *Epinephelus* spp.), white fish (*Lactarius lactarius*), Silver bellies (*Secutor muconius, S. insidiator, Leiognathus dussumieri, L. bindus* and *L. lineolatus*), seer fish (*Scomberomorus commersoni, S. guttatus, S. lineolattus* and *Acanthocybium solandri*), mackerel (*Rastrelliger kanagurta*), tuna (*Auxis thazard, A. rochei, Sarda orientalis, Euthynnus affinis* and *Thynnus tonggol*), carangids (*Caranx caranax, Megalaspis cordyla, Decapteus russelii* and *D. tabl*), polynemids (*Eleutheronema tetradactylum, Polynemus indicus* and *P. heptadactylus*), pomfrets (*Pampus argentius, P. chinensis* and *Parastromateus niger*), barracudas (*Sphyraena commersoni, S. obtusata, S. acutipinnis* and *S. jello*), red mullets (*Upeneus sulphurus, U. vittatus* and *Parupeneus indicus*), ribbon fishes (*Trichurus lepturus, T. gangeticus, T. pantulli, Eupleurogrammus intermedius* and *E. muticus*), anchovies (*Coilia dussumieri, Anchoviella commersoni, A. indica, A. heterolobus* and *A. bengalensis*) and catfishes (*Tachysurus thalassinus, T. tenuispinis, T. dussumieri, T. sona, T. serratus, T. jella, Plotossus canius* and *P. angullaris*) and shellfishes, *Parapenaeopsis stylifera, P. hardwickii, P. sculptilis, Penaeus merguiensis, P. indicus P. semisulcatusi, Metapenaeus monoceros, M. dobsoni, M. affinis, M. brevicornis* and *Solanocera crassicornis*). The Andaman and Nicobar Islands and the coral islands of Lakshadweep represent one of the richest repositories of biodiversity in the whole of south Asia. These islands are a virtual bio-reserve, which is unique both in terms of biodiversity and abundance. The fish fauna consists of more than 1,200 species of which over 250 are food fishes while another 250 are of ornamental nature.

Threats to fish diversity

All aquatic environments are experiencing serious threats to both biodiversity and ecosystem stability and several strategies and priorities have been proposed to solve this crisis. The environmental threats could be man-made and natural or in combination with cascading and interlinked impacts. Such threats are wide ranging including, habitat alterations, over-exploitation of resource, reduction of natural habitat area, construction of dams, diversion or reclamation of river beds for urbanization, that reduce water discharge in rivers, unsustainable fishing, introduction of non-native species and global climatic variations etc. Following destructive natural events such as floods, cyclones or disease outbreaks, aquatic ecosystems can be damaged or weakened. Earthquakes and tsunamis are infrequent but extremely dangerous natural hazards that threaten the coasts and inland waters such as the one that impacted on both southern India and the Andaman Nicobar Islands on 26 December 2004. Pollution, increased sedimentation, flow alteration, and introduced species are identified as the main causes for decreased ichthyo-faunal diversity in Asian countries. Coastal zone development coupled with population increase, has stressed the coastal marine environment. Some of the marine finfishes threatened by indiscriminate fishing are the whale sharks (*Rhincodon typus*), marine catfishes of the genera *Tachysurus* and *Osteogeneosus*, the white fish *Lactarius lactarius*, the flat head *Platycephalus maculipinna*, the threadfins *Polynemus indicus* and *P. hepatadactylus*, and Sciaenids *Pseudosciaena diacanthus* and *Otolithoides brunneus*. In hillstreams, the present trend of decline of fish is primarily due to interference of several factors. Several threats have adversely been affecting sustainability of fisheries resources since their gene pools and genetic diversity is being eroded.

Habitat alteration: Human beings became successful competitors for water with fish and other organisms when they started withdrawing water from rivers, lakes, springs or underground aquifers. The damming, deforestation, diversion and withdrawal of water for irrigation, urban and industrial consumption have caused large-scale changes in the channel bed and hydrology of the river in terms of flow, flow-rate, flood-rhythm and regime. The annual runoff in the Ganga basin is about 469 billion m^3 and of this 85 billion m^3 of water is diverted by canal projects and by hydroelectric and storage reservoirs for irrigation, power and flood control. Hydraulic structures have changed river morphometry, flow, increased bank erosion and created barriers for migratory fishes. Five critical components of the flow regime regulate ecological process in river ecosystems, the magnitude, frequency, duration, timing and rate of change of hydrology conditions. Dams impede upstream spawning migration of fishes and displace populations from their normal spawning grounds. In India, the construction of Farrakka barrage on River Ganga, has grossly affected abundance and migration of hilsa (*Tenualosa ilisha*). Inbreeding and genetic drift are the common problems in a small population that reduce genetic variability. Habitat modifications may lead to decline of endemic species and even species extinction. Siltation from the catchments, besides changing the ecology due to construction of dams, has obstructed the feeding and breeding grounds of many fishes. The Himalayan rivers carry nearly 2,050 million tonnes of silt, depositing approximately 480 million tonnes to the reservoirs causing eutrophication and reduction in the productivity of the water-bodies. Habitat alterations in the Himalayan waters have affected distribution and abundance of native fishes in mountain streams. A series of barrages and dams have been commissioned in the upper segment of River Ganga and these have reduced the water flow leading to the obstruction of feeding, spawning, and migration routes of mahseer (*Tor putitora* and *T. tor*) and snow trouts (*Schizothorax richardsonii* and *S. plagiostomus*) have been blocked.

Over-exploitation: The population size gets reduced because of disturbances in age structure and sex composition as a result of over-exploitation affecting demography of fish population. Over-fishing affects heritable life-history parameters like growth and age of sexual maturity. Efficient gears remove large individuals, which mostly happen in the quick growing ones in the population, resulting in reduced heterozygosity since there is a positive correlation between heterozygosity with growth rate. The analysis using molecular markers in many fishes showed that heterozygosity and overall genetic diversity get reduced in a population, if quick growing lager individuals are removed by fishing. Over-exploitation of fishery resources due to its higher economic value has exacerbated the vulnerability of the population in different ecosystems, viz. *Tor* spp. and *Schizothorax* spp. in upland waters, *Chitala chitala, Ompok pabda, Pangasius pangasius, Eutropiichthys vacha, Clarias dussumieri* in warmwaters, *Puntius denisonii* in rivers originating from the Western Ghats, and *Polynumus indicus, P. heptadactylus, Pomadasys hassta, Lactarius lactarius,* marine catfishes (*Arius* = *Tachysurus* spp.), whale shark *Rhincodon typus* and pomfrets in marine waters.

Aquatic pollution: Pollution is one of the most significant factors causing major decline in the population of many fish species. Industrial, sewage (municipal) and pesticides pollution have been causing detrimental environment to fish life in many

water-bodies. Poisonous pollutants like agro-chemicals, metals, acids and phenols affect reproductive functions and even cause fish mortality in high concentration. Besides Hot-water discharges from water treatment plants and large power plants can significantly alter the water chemistry in coastal areas. When pollutants are discharged, nutrient levels (nitrates and phosphates) in the water can increase. This can lead to an excessively nutrient rich environment (eutrophic), which encourages algae blooms and the growth of other organisms. Such a situation in coral reef areas can stifle corals or outcompete them for space. In addition, direct sedimentation can suffocate a shoreline reef, or it may increase the water's turbidity, which, in turn, obscures the light on which corals thrive. Light deprivation ultimately will starve a coral, which is dependent on its symbiotic algae (zooxanthellae) to generate food photosynthetically. Finally, coral reefs are directly impacted by marine-based pollution. Leaking fuels, petroleum spills, anti-fouling paints and other chemicals can leach into the water, adversely affecting corals and other species. Pesticides, industrial effluents and untreated or semi-digested sewage constitute a major anthropogenic addition to natural communities in rivers, lakes and estuaries in India leading to the increase in the BOD and depletion of dissolved oxygen levels.

Illegal fishing: Destructive fishing in the seas and estuaries without any consideration to conserve mother and juvenile fish stock have taken a heavy toll on natural recruitment of standing stock of many commercially important fish species of low fecund groups. Even spawning grounds were not left out. Fishing operations still depend on locating areas of concentrations and use of dynamite to catch more quantity from one place, bull trawling to sweep the entire fauna of the sea bottom, purse seining to catch fish shoals, and bag net fishing in estuaries to catch migrating stock of millions of juveniles daily during both high tide and low tide are going on all over the world for short-term economic gains. Coral reef habitats are over-fished or over-exploited for recreational and commercial purposes. Coral heads and brightly coloured reef fishes are collected for the growing aquarium and jewellry trade. Mass killing by the use of dynamites, electric shocks and poisoning of brood fishes in spawning season and juveniles during post-monsoon have affected a number of food, ornamental and game fishes of upland waters in the Himalayan and the Western Ghat regions. Mass scooping of shrimp and prawn seed in brackishwater areas, and hilsa juveniles just below the Farakka barrage are examples of threats to fish diversity.

Impact of exotic species: The use of exotic species for fisheries and aquaculture diversification has been practised since the middle of the 19^{th} century. Although many such introductions have been successful, others have resulted in highly publicized failure, generating controversy over protection of native biodiversity, spread of pathogens and disease. Several exotic species have been introduced in the Indian waters, and some are now well established too, with varying experiences. They include *Salmo gairdnerii, S. trutta fario, Pangassius sutchi, Oncorhynchus mykiss, O. nerka, Salveninus fontinalis, Cyprinus carpio, Carassius carassius, C. auratus, Oreochromis mossambicuss, O. niloticus, Aristichthys nobilis, Ctenopharyndon idella, Hypopthalmichthys molitrix, Tinca tinca, Osphronemus goramy, Gambusia affinis,* *Lebestes reticulatus*, *Clarias gariepinus*, etc. The recent illegal introduction is South American catfish *Pterygoplichthys anisitsi* belonging to family Loricariidae. The species was recorded by the NBFGR from River Ganga near Patna and Gomti (near Lucknow) in Uttar Pradesh and pacu *Piaractus brachypomus* from Periyar River, Kerala. The spread of pathogens with trans-boundary movements of live aquatic animals has been clearly associated with disease outbreaks and significant losses of aquaculture production and revenue. It was reported that introduced exotic species contributed to extinction of several North American fish taxa during the past century. Species introduction proved disastrous in many instances abroad such as Apache trout (*Oncorhynchus apache*) and Gila trout (*O. gilae*); the 2 native species of South-West USA faced extinction primarily due to hybridization with introduced cutthroat trout (*Oncorhynchus clarki* and *O. mykiss*). The exotic Nile perch (*Lates niloticus*), a predator and voracious feeder almost ousted native cichlids in lake Victoria which is economic as well as ecological tragedy. The *Clarias gariepinus* devastated some native species in eastern Cape in South Africa, sea lamprey (*Petromyzon marinus*), rainbow smelt (*Osmerus mordax*) and common carp (*Cyprinus carpio*) affected native fish communities of the basin of great lakes of North America. Non-native *Gambusia affinis* and *Fundulus heteroclitus* threatened cyprinodont stocks in the Europe and North America. The success of introduction should be measured by its benefits to the community and the fact that it should not unduly harm existing species. Introduction of exotic fast growing species is threatening the indigenous fish diversity. Common carp introduction has created decline of the indigenous schizothoracids in Kashmir Valley and the endemic fish *Osteobrama belangeri* in Loktak lake, Manipur. In Govindsagar Dam (Himachal Pradesh), the Indian major carp, especially *Catla catla*, has already been replaced by the silver carp. The tilapia, *Oreochromis mossambicus*, introduced accidentally into Amravathy and Vaigai reservoirs has established itself leading to the decline of endemic fauna. There are evidences to raise an alarm that *Clarias gariepinus*, *Cyprinus carpio* and *Pangassius sutchi* would adversely affect native fish fauna of the Indian rivers .The introduction of trouts in almost virgin niche at high altitude coldwater streams has, however, remained encouraging in India. Some exotic food fishes have also been performing by enhancing production in closed culture system. It was suggested that *Oreochromis niloticus* which grows to 250 g in 6 months and is prolific breeder may probably be more suitable for Indian reservoirs. However, the introduction and transfer of exotic species and breeds for aquaculture purposes may be done with extreme caution as it can change or impoverish the biodiversity and genetic resources through interbreeding, competition for food, habitat destruction and through transmission of diseases.

Disease: It is a major concern of aquatic species. Among the range of various diseases caused by bacteria, fungi, viruses etc., the most virulent and menacing one threatening many species is the epizootic ulcerative disease syndrome (EUS) and the white spot syndrome (WSS) that had wiped out large populations of several commercial and non-commercial species in major parts of the country. It was found that the species moved outside their range or reintroduced back into their range have caused unexpected

disease problems. European cupped oysters that were reintroduced to Europe from the pacific North-West of North America carried the pathogen bonamia with it that has caused collapse of European cupped oyster industry. Though the introduced species may have established well and disease resistance did come along with the domestication process, the genetically altered species may act as carriers for pathogens and could serve as mechanism to transmit disease to native species. The erosion of genetic variability and biodiversity is a serious threat from such diseases. At the international and national levels, quarantine and health certification programmes form an integral part of much broader strategies aimed to protect the natural environment and native faunas from the deleterious impacts of exotic species or pathogens. Currently, the only effective control measures for diseases in fish caused by exotic pathogens are prevention of exposure. Therefore, the foremost task is to have surveillance of native aquatic fauna for all OIE-listed pathogens. The NBFGR, Lucknow, has developed rapid diagnostic capability for detecting the eleven fish OIE listed pathogens using molecular and immunological tools and has achieved success in developing monoclonal antibodies against *Labeo rohita*.

Harmful algal blooms (HABs): The global spread of toxigenic and paralytic shellfish poisoning algal blooms is due to inadvertent trans-oceanic and inter-oceanic introductions of harmful algae through ballast water. On the west coast of India, blooms of *Alexandrium* species have been associated with the PSP. The mortality of a number of fish was associated with red water caused by *Gymnodinium nagasakiense* in 1989. Since these episodes were one-time events and unrelated to season, it is correlated to sudden introduction of the causative agent through ballast water or other shipping activities. Ignoring problems caused by ballast water introductions could pose a threat to the coastal bays, estuaries and mariculture sites that sustain renewable resources and impair understanding of the biodiversity and functioning of the ecosystem. Lack of strict regulations of ballast water discharges will exacerbate the establishment and impact of a potentially unending tide of invaders.

Global warming: It will result in increase in sea-surface temperature (SST) and sea level; decrease in sea-ice cover and changes in salinity, wave climate and ocean circulation. Changes in oceans are expected to have important feedback effects on global climate and on the climate of the immediate coastal area. They also would have profound impacts on the biological production of oceans, including fish production. For instance, changes in global water circulation and vertical mixing will affect the distribution of biogenic elements and the efficiency of CO_2 uptake by the ocean; changes in upwelling rates would have major impacts on coastal fish production and coastal climates. If warm events associated with *El Ninos* increase in frequency, plankton biomass and fish larvae abundance would decline and adversely impact fish, marine mammals, sea-birds and ocean biodiversity. Temperature plays a significant role in influencing biogeographic distributions and will affect cold-tolerant species move from equator ward edge of their ranges may retreat towards the pole. It is presumed that changing climate in Indian rivers will have implications for sustainable harvests, fishing practices and subsistence fisheries. In rivers and streams water flow can influence water chemistry, habitat, population dynamics and water temperature. The magnitude of potential temperature changes in freshwater sites will be significantly greater than that of marine environments. Rising in temperature in rivers, lakes and oceans means less food and less oxygen for fish populations. Climate change is likely to produce profound modifications to the structure and functioning of the aquatic ecosystem and has the potential to affect freshwater ecosystem use by fishes through habitat alteration and will result changes in the distribution and abundance of species. Change in monsoon rains, due to climate change, affects reproduction and recruitment of fish species and their fisheries might be put at risk by precipitation modifications. Changes in food availability, species-specific differences in thermal tolerance and disease susceptibility and shifts in the competitive advantage of species will alter species assemblages, distribution and migration. Studies of the NBFGR, Lucknow indicated biogeographical shifting of some warm water fish species (*Cirrhinus reba, Macrognathus aral*) in the upper Ganga river stretch up to Haridwar which might be caused due to effect of climatic and other environmental factors. Studies at CMFRI, Kochi indicated extension of distribution of Indian oil sardine (*Sardinella longiceps*) to Gujarat coast which might be due to the effect of climatic and other environmental factors. Coastal ecosystems such as coral reefs and atolls, salt marshes and mangrove forests and submerged aquatic vegetation will be impacted by sea-level rise, increasing sea-surface temperature and any changes in storm frequency and intensity. Impacts of sea-level rise on mangroves and salt marshes will depend on the rate of rise relative to vertical accretion and space for horizontal migration, which can be limited by human development in coastal areas. Healthy coral reefs are likely to be able to keep up with sea-level rise, but this is less certain for reefs degraded by coral bleaching, ultra-violet radiation-β, pollution and other stresses. Research is required to link available biological and ecological information on the impacts of climate change to water resource and the immediate priority should be to conduct studies of closely linked species, ecosystems and fisheries that have data and information on climate variation and changes response in coldwater ecosystem. The ICAR has already established a network project with the involvement of 15 institutions and SAU's for critical research on impact of climate change on crops, livestocks and fisheries. There is need to intensify efforts for increasing climate literacy among all stakeholders as well as farmers.

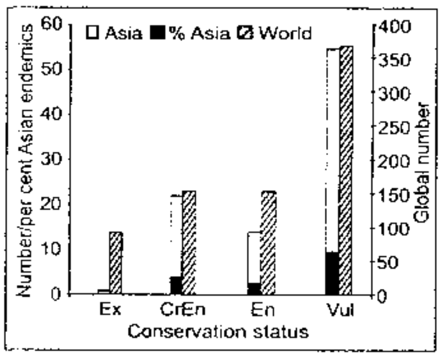

Fig. 2.2. The number of endemic finfish species in Asia that are in different states of vulnerability, and the number in each group expressed as a percentage of the total number of endemic species, together with the numbers of freshwater finfish species in the world in each category. (Ex, Extinct; CrEn, critically endangered; En, endangered; Vu, vulnerable).

Conservation status

Biodiversity loss is one of the world's most pressing crisis and there is global concern about the status of the biological resources on which almost human life depends. The estimated current species extinction rate is between 1,000 and 10,000 times higher than it would naturally be. According to the IUCN (International Union for Conservation of Nature and Natural Resources, 2008) Red List of all life forms, 16,928 species are threatened globally, and of these 1,275 species are fishes. In Asia as a whole 6,106 organisms are threatened of which 688 are finfishes. Overall, the conservation status of the endemic fish species in the Asia can be considered to be relatively satisfactory as shown in Fig. 2.2 in which only 16.3% of the endemics being in some status of vulnerability. To conserve the aquatic resources, the Ministry of Environment and Forests, Government of India included many marine finfish and shellfish species (Table 2.2) in schedule I and IV of the Wildlife (protection) Act, 1972 under Gazette notification no. 1-4 / 95 WL-I dated 5 December 2001.

Table 2.2. Aquatic species under Indian Wildlife (Protection) Act, 1972

Schedule - I. Part 1 Mammals

Sl. No.	Species	Notification No. and date
1	*Dugong dugon*	DL-33004/2003/17 dt. 20 January 2003
2	Cetacean spp. (all cetaceans - details not given)	DL-33004/2003/17 dt. 20 January 2003
3	Gangetic dolphin (*Platanista gangetica*)	DL-33004/2003/17 dt. 20 January 2003
4	Little Indian porpoise (*Neomeris phocaenoides*)	DL-33004/2003/17 dt. 20 January 2003
5	(Irrawaddy Dolphin) *Orcaella brevirostris*	DL-33004/2003/17 dt. 20 January 2003

Schedule - I. Part 2 Amphibians and Reptiles

Sl. No.	Species	Notification No. and date
1	Green sea turtle (*Chelonia mydas*)	DL-33004/2003/17 dt. 20 January 2003
2	Hawksbill turtle (*Eretmochelys imbricata inlskata*)	DL-33004/2003/17 dt. 20 January 2003
3	Leathery turtle (*Dermochelys coriacea*)	DL-33004/2003/17 dt. 20 January 2003
4	Loggerhead turtle (*Caretta caretta*)	DL-33004/2003/17 dt. 20 January 2003
5	Oliveback turtle (*Lepidochelys olivacea*)	DL-33004/2003/17 dt. 20 January 2003

Schedule - I. Part 2 (A) Fishes

Sl. No.	Species	Notification No. and date
1	*Anoxypristis cuspidata*	1-4/95 WL 1 dt. 05.12.2001
2	*Carcharhinus hemiodon*	1-4/95 WL 1 dt. 05.12.2001
3	*Glyphius gangeticus*	1-4/95 WL 1 dt. 05.12.2001
4	*Glyphius glyphius*	1-4/95 WL 1 dt. 05.12.2001
5	*Himantura fluviatilis*	1-4/95 WL 1 dt. 05.12.2001
6	*Pristis microdon*	1-4/95 WL 1 dt. 05.12.2001
7	*Pristis zijsron*	1-4/95 WL 1 dt. 05.12.2001
8	*Rhynchobatus djiddensis*	1-4/95 WL 1 dt. 05.12.2001
9	*Urogymnus asperrimus*	1-4/95 WL 1 dt. 05.12.2001
10	*Rhincodon typus* (Whale shark)	1-2/2001 WL 1 dt 28.05.2001
11	Sea horse - all species (all Syngnathidians)	1-4/95 WL 1 dt 11.07.2001
12	Giant grouper (*Epinephelus lanceolatus*)	1-4/95 WL 1 dt 11.07.2001

Schedule – I. Part 4 (A) Coelenterates

Sl. No.	Species	Notification No. and date
1	Reef building corals (all Scleractinians)	1-4/95 WL 1 dt 11.07.2001
2	Black coral (all Antipatharians)	1-4/95 WL 1 dt 11.07.2001
3	Organ pipe coral (*Tubipora musica*)	1-4/95 WL 1 dt 11.07.2001
4	Fire coral (all Millipora species)	1-4/95 WL 1 dt 11.07.2001
5	Sea fan (all Gorgonians)	1-4/95 WL 1 dt 11.07.2001

Schedule – I. Part 4 (B) Molluscs

Sl. No.	Species	Notification No. and date
1	*Cassis cornuta*	1-4/95 WL 1 dt. 05.12.2001
2	*Charonia tritonis*	1-4/95 WL 1 dt. 05.12.2001
3	*Conus malneedwardsi*	1-4/95 WL 1 dt. 05.12.2001
4	*Cypracasis rufa*	1-4/95 WL 1 dt. 05.12.2001
5	*Hippopus hippopus*	1-4/95 WL 1 dt. 05.12.2001
6	*Nautilus pompilus*	1-4/95 WL 1 dt. 05.12.2001
7	*Tridacna maxima*	1-4/95 WL 1 dt. 05.12.2001
8	*Tridacna squamosa*	1-4/95 WL 1 dt. 05.12.2001
9	*Tudicla spiralis*	1-4/95 WL 1 dt. 05.12.2001

Schedule - I. Part 4 (C) Echinodermata

Sl. No.	Species	Notification No. and date
1	Sea cucumber (all Holothurians)	1-4/95 WL 1 dt. 11.07.2001

Schedule - II. Parts 1 and 2 Mammals

Sl. No.	Species	Notification No. and date
1	Cetatcean spp. (Other than those listed in Sch. I and Part II)	DL-33004/2003/17 dt. 20 January 2003
2	Sperm whale (*Physter macrocephalus*)	I DL-33004/2003/17 dt. 20 January 2003

Schedule - III. No.20 Sponges

Sl. No.	Species	Notification No. and date
1	Sponges (all Calcareans)	1-4/95 WL 1 dt. 11.07.2001

Schedule - IV. No.19 Mollusca

Sl. No.	Species	Notification No. and date
1	*Cypraea lamacina*	1-4/95 WL 1 dt. 05.12.2001
2	*Cypraea mappa*	1-4/95 WL 1 dt. 05.12.2001
3	*Cypraea talpa*	1-4/95 WL 1 dt. 05.12.2001
4	*Fasciolaria trapezium*	1-4/95 WL 1 dt. 05.12.2001
5	*Harpulina arausica*	1-4/95 WL 1 dt. 05.12.2001
6	*Lambis chiragra*	1-4/95 WL 1 dt. 05.12.2001
7	*Lambis chiragraarthitica*	1-4/95 WL 1 dt. 05.12.2001
8	*Lambis crocea*	1-4/95 WL 1 dt. 05.12.2001
9	*Lambis millepeda*	1-4/95 WL 1 dt. 05.12.2001
10	*Lambis scorpius*	1-4/95 WL 1 dt. 05.12.2001
11	*Lambis truncate*	1-4/95 WL 1 dt. 05.12.2001
12	*Placenta placenta*	1-4/95 WL 1 dt. 05.12.2001
13	*Strombus plicatus sibbaldi*	1-4/95 WL 1 dt. 05.12.2001
14	*Trochus niloticus*	1-4/95 WL 1 dt. 05.12.2001
15	*Turbo marmopratus*	1-4/95 WL 1 dt. 05.12.2001

Schedule - IV. No.19 Snakes

Sl. No.	Species	Notification No. and date
1	Hydrophidae (freshwater and sea snakes) (all other snakes other than those species listed in Sch. I & II; Part 2)	DL-33004/2003/17 dt. 20 January 2003

IUCN categories of threatened species

Extinct (EX): A taxon is Extinct when there is no reasonable doubt that the last individual has died.

Extinct in the wild (EW): A taxon is Extinct in the Wild when it is known only to survive in cultivation, in captivity or as a naturalized population (or populations) well outside the past range. A taxon is presumed extinct in the wild when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life-cycle and life-form.

Critically endangered (CR): A taxon is Critically Endangered when it is facing an extremely high risk of extinction in the wild in the immediate future. The important criteria are: (*a*) an observed, estimated, inferred or suspected reduction of at least 80% over at least 10 years or 3 generations; or (*b*) population estimated to number less than 250 mature individuals.

Endangered (EN): A taxon is Endangered when it is not Critically Endangered but is facing a very high risk of extinction in the wild in the near future. The important criteria are: (*a*) an observed, estimated, inferred or suspected reduction of at least 50% over at least 10 years or 3 generations or (*b*) population estimated to number less than 2,500 mature individuals.

Vulnerable (VU): A taxon is Vulnerable when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term future. The important criteria are: (*a*) an observed, estimated, inferred or suspected reduction of at least 20% over at least 10 years or 3 generations; or (*b*) population estimated to number less than 10,000 mature individuals.

Rare (R): Taxa which are not presently Endangered or Vulnerable but can become vulnerable because of small populations usually located in restricted scattered over a more extensive range.

Lower risk (LR): A taxon is Lower Risk (LR) when it has been evaluated, does not satisfy the criteria for any of the categories: Critically Endangered, Endangered or Vulnerable. Taxa included in the Lower Risk category can be separated into three subcategories:

- **(i) Conservation dependent (LR-cd):** Taxa which are the focus of a continuing taxon-specific or habitat-specific conservation programme targeted towards the taxon in question, the cessation of which would result in the taxon qualifying for one of the threatened categories above within five years.
- **(ii) Near threatened (LR-nt):** Taxa which do not qualify for conservation dependent, but which are close to qualifying for Vulnerable.

(iii) Least concern (LR-lc): Taxa which do not qualify for conservation dependent or Near Threatened.

Data deficient (DD): A taxon is Data Deficient (DD) when there is inadequate information to make a direct or indirect assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution is lacking. Data Deficient is, therefore, not a category of threat or Lower Risk. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that threatened classification is appropriate. It is important to make positive use of whatever data are available. In many cases great care should be exercised in choosing between Data Deficient and threatened status. If the range of a taxon is suspected to be relatively circumscribed, if a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.

Not evaluated (NE): A taxon is not evaluated (NE), when it has not yet been assessed against the criteria.

Threatened (T): Taxa which are endangered, vulnerable or rare falls under this category.

List of Indian Fishes in threatened category: In 1989, late Dr A.G.K.Menon of Zoological Survey of India (ZSI) was the first who compiled a list of 21 Vulnerable fishes - 4 Endangered (*Barilius bola, Puntius chilinoides, Semoplotus semiplotus* and *Enobarbichthys maculatus*) and 17 Threatened species (*Notopterus chitala, Acrossocheilus hexagonolepis, Cirrhinus cirrhosa, Labeo fimbriatus, Labeo potail, Labeo kontius, Puntius carnaticus, P. curmuca, P. jerdoni, Tor khudree, T. putitora, T. tor, Schizothorax richardsonii, Schizothoraichthys progestus, Silonia childreni, Pangasius pangasius* and *Bagarius bagarius*) from the Indian subcontinent. In 1992-93, the National Bureau of Fish Genetic Resources tentatively identified 4 Endangered, 21 Vulnerable, 2 Rare, and 52 Indeterminate fishes from the different ecosystems of this subcontinent. Out of 329 warmwater taxa evaluated through Conservation Assessment and Management Plan by the NBFGR in 1997, one species was categorized as Extinct (EX), 1 Extinct in Wild (EW), 47 Critically Endangered (CR), 98 Endangered (EN), 82 Vulnerable (VU), 67 Lower Risk-near threatened (LR-nt), 13 Lower Risk-least concern (LR-lc) and 18 Data Deficient (DD). However, conservation status of these fishes required further verification through the actual field surveys. Based on further studies, the NBFGR in 2010 came out with a revised list of 120 threatened freshwater teleosts which included only two categories: 72 endangered and 48 vulnerable species.

Marine environment has traditionally been presumed to be resilient to human impact. However, the over-exploitation and subsequent collapse of marine fisheries has attracted wide attention. Sharks, rays and skates are most vulnerable to collapse or extirpation because of slow growth rate, late maturity (dusky shark is the slowest growing marine chordates, takes 20 years to mature) and poor fecundity (the sand tiger shark produces only two young ones every alternate year) when compared with bony fishes. The whale shark, *Rhiniodon typus*, occurring in the west coast of India is listed as critically endangered (CR) due to target fishing. Other species of the Indian marine waters which have become vulnerable due to over-fishing include *Tachysurus (=Arius) tenuispinis, T. dussumieri, T. sona, Batrachocephalus mino, Lactarius lactarius, Epinephelus lanceolatus*, sea-horse species, *Polynemus indicus, P. heptadactylus, Pseudosciana diacanthus* and *Platycephalus maculipinna*. Fishing of gestating males during breeding season appears to be responsible for endangerment of *Tachysurus* species in the Indian marine waters. It is pertinent to remark that several species of snappers as well as groupers (Lutjanidae, Serranidae), rockfishes (Sebastinae), some sharks (Selachii), rays (Rajidae) and sawfishes (Pristidae) seem to have become threatened due to excessive fishing, as these fishes have slow growth rate, late maturity and low fecundity. Great concern has been attributed on the by-catch (about 10% of the total landings) of the trash fishes including the juveniles/sub-adults in the mechanized nets resulting in the serious decline of the marine species such as bellies, sciaenids, catfishes, flatfishes, lizard fishes etc. Although the Marine Fisheries Regulation Act (MFRA) restricts the cod-end mesh size of trawlers to below 30 mm, the cod-end mesh of medium-size commercial shrimp trawlers generally range between 10 to 15 mm. Updated and precise information on threatened Indian brackishwater and marine fish fauna is yet to be prepared. It appears that endangerment of aquatic organisms is greater than that of terrestrial animals partly because of the social biases against small, cold-blooded and wet species and lack of information regarding the conservation status of these species.

Impact of anthropogenic factors

Habitat modifications, over-exploitation, pollution load and introduction of exotics etc., affect the fish genetic diversity directly or indirectly. Excessive mortality of fishes due to any of these factors leads to either of the two effects: (*i*) reduction of population size, and (*ii*) even extinction of the stock/population/species (Table 2.3).

Table 2.3. Impacts of anthropogenic factors on fish gene pools

Causes	Effects	Consequences
Over-exploitation	(i) Extinction of population (ii) Reduction in population size	(i) Loss of genetic diversity (ii) Inbreeding and genetic drift
Non-selective fishing pressure	Negative Selection	Adversely affects quantitative traits such as growth rate
Pollution load	(i) Population extinction (ii) Reduction in population size (iii) Genetic abnormalities	(i) Loss of genetic diversity (ii) Inbreeding and genetic drift
Habitat modifications	(i) Reduction in population size due to habitat fragmentation (ii) Genetic abnormalities	(i) Inbreeding and genetic drift (ii) Genotoxicity
Stock transfer	Cross-breeding	Genetic admixture of different stocks
Species introduction	Hybridization and back-crossing leading to introgression	Genetic pollution

Over-fishing, habitat modifications, exotic introduction and pollution, in addition o direct effects on natural fisheries may also influence natural fish populations enetically. Over-fishing drastically reduces population size and since the larger ndividuals are selectively removed, it is equivalent to selection for smaller-size fish. daptation of natural fish populations to their environment is reduced by rapid nvironmental changes resulting from pollution and infestation. Inbreeding, negative election and lack of adaptation are also considered as genetic causes for decline of atural fisheries. Due to various factors (Table 2.3), a number of fish are declining apidly in some conventional fishing grounds and some have even become endangered. ince genetic variations are the raw materials in species population enabling them to dapt to the changes in their environment, any loss of genetic variation results in rosion of evolutionary flexibility. This leads to a poorer match of organisms to adapt o the environment increasing the probability of their extinction. The associated severe enetic problems in the small genetically effective population take the form of genetic ottlenecks, genetic drift and accumulation of homozygosity (inbreeding depression) hich are discussed below.

Genetic variations: The genetic diversity in a species, with additive variance, rovides it an inherent ability to adapt and evolve in a changing environment. Genetic omozygosity due to loss of variance reduces fitness because of expression of recessive eleterious alleles while heterozygosity improves fitness like ability to resist diseases, aster growth and higher survival etc. Our major concern should be maintenance of xisting genetic variance since evolutionary flexibility is a function of genetic diversity. otal genetic variation within a species consists of two components: (*i*) variations ithin individual populations (demes) upon which natural selection acts, and (*ii*) ariations among different populations. Both types of variations thus need be aximized and maintained for perpetuity of fish genetic resources in general and reatened species in particular.

Within-population variance: Population size is a single most important factor in ustaining a high level of genetic variation within a deme. However, simple population ensus (N) alone is not indicative of the genetically effective population (Ne). Ne is erely always less than N because of the three following factors:

Sex ratio: If the sex ratio of breeding adults departs from 1:1, Ne and genetic ariation are reduced. The effective population size with respect to sex ratio is etermined as:

$$Ne = \frac{4Nm\ Nf}{Nm+Nf}$$

here Nm and Nf are the number of breeding males and breeding females respectively. or example, with a population census of 100 fish, we can compare Ne under the ondition of: (*a*) 50 males and 50 females versus, and (*b*) 10 males and 90 females. or (*a*) Ne = 4 (50) (50)/100 =100 fishes, and for (*b*) Ne = 4(10)(90)/100 = 36 fishes. ence, a population of 50 males and 50 females is nearly 2.8 times larger, in a genetic ense, than is one of 10 males and 90 females.

Progeny distribution: In an idealized population, the number of offspring per family

is distributed in a Poisson fashion. Deviation from this distribution with some matings producing disproportionately more offspring, will bias the representation of contributed gametes in the next generation and lower the Ne. A biased progeny distribution will effect Ne as = 4N/(2+ 2) where 2 is variation in progeny distribution.

For example, if 1,000 breeding females reproduced in a Poisson fashion with a mean of 2 offsprings and a variance of 2 in a Poisson distribution, variance = mean

$$Ne = \frac{4\ (2{,}000)}{2+2} = 2{,}000$$

However, if one female produced 1,001 offspring and the remaining 999 fishes produced one each, the mean remains at 2 but variance is now 31.6 and

$$Ne = \frac{4\ (2000)}{2+31.6} = 238$$

The effective population size of the next generation is thus drastically reduced by disproportionate offspring production.

Population fluctuation: Whenever a population declines, the genetic variance for all future generations is contained in the few survivors. Since those individuals represent only a sample of genetic variance contained in the original population, Ne is reduced by fluctuations to low levels. Ne is affected as the harmonic mean of population sizes in each generation or 1/Ne=1/t (1/N1+ 1/N2-----+ 1/Nt), where t = time of generation. Comparison of the following two populations illustrates the importance of fluctuations to Ne. In first case, there are 100 fishes for each of 5 consecutive generations for an arithmetical mean of 100; 1/Ne = 1/5 (1/100+1/100+1/ 100+1/100+1/100-0.01, and Ne =100. In second case, the arithmetic mean is also 100 but the population fluctuates at each generation as: 100, 10, 300, 10, 80: 1/ Ne = 1/5 (1/100+1/10+/1/300+1/10+1/ 80) = 0.045 and Ne = 22. In the second case, Ne for 5 generations is reduced by 78% through population crashes.

Importance of Ne: Importance of Ne to population genetic structure is immediately realized in consideration of three closely-related problems of small population, i.e. bottleneck, drift and inbreeding as below:

When the population size gets small, inbreeding may take place reducing the population viability, genetic bottleneck reducing genetic variance and genetic drift causing loss of important rare alleles. Cross-breeding and hybridization, on the other hand, combine and integrate two completely divergent gene pools (Table 2.3).

Genetic bottlenecks: This can be explained as a sudden and dramatic decline in number. The severe reduction in population size due to various factors like habitat modifications, pollution load, over-exploitation etc. precipitates genetic bottleneck. Since the effective population size or minimum viable population size is reduced, the genetic diversity gets affected. Bottlenecks result in a remnant population with less overall variations. Loss of variation during a bottleneck has two components: first is reduction in variance of quantitative traits. The proportion of quantitative variation remaining after a single bottleneck is approximately: 1- (1/2N), where N is number of individuals surviving. Small number of individuals contains most of the genetic variation of a source population. If the bottleneck is very severe or is prolonged over several generations, it will drastically reduce the amount of quantitative traits. Second, the more critical, is loss of specific and usually rare alleles in a bottleneck. Alleles at frequencies of say, 5% or less, contribute little to overall genetic variance but may periodically be important to the population as a whole. Assuming a locus with initially 6 alleles at frequencies of 0.90, 0.02, 0.02, 0.02, 0.02 and 0.02 with a bottleneck population size of 10, there would be an average loss of more than 3 alleles at this locus. Considering the repetition of this loss over hundreds or even thousands of similar variable loci, such losses can be considerable, causing severe damage to the threatened species.

Genetic drift: Reduction or change in the allelic frequency due to accidental loss is random genetic drift. It is, in fact, a prolonged bottleneck leading to repeated loss of variance until in its ultimate form, all loci are fixed, with complete absence of genetic variance. The depletion of genetic variance through drift is estimated by: 1-(1/2N) t where t is the number of generations at population size N. A rare allele (whose frequency is low) has greater probability of being lost than a common allele whose frequency is high. However, where a bottleneck may do little harm in one generation, a prolonged bottleneck can seriously reduce variance.

It is clear that longer the period of drift and smaller the population, the greater will be the loss of variance. Drift can be quite detrimental to long-term genetic health in small population of endangered fishes. For example 40% of variance would be lost in a population of 10 after 10 generations. A hatchery stock of Montana West-slope cutthroat trout (*Salmo clarkii lewisi*) derived 14 years earlier from approximately 60 wild individuals, exhibited reductions of 57% polymorphic loci, 29% average number of alleles per locus and 21% average heterozygosity per individual compared to the original stock. Genetic drift has led to the extinction of a strain of channel catfish (AU Rio Granade Strain) in Auburn University, USA

Inbreeding depression: Inbreeding is mating of individuals related by common ancestry, that is, those that share more genes in common due to descent than individuals randomly selected from population. Inbreeding leads to genetic homozygosity. The deleterious recessive alleles, which are generally masked by the dominant ones in a random mating population becomes homozygous due to inbreeding. Most useful measurement is the increase in inbreeding per generation, as expressed as F = 1/(2Ne). This formula illustrates that a smaller effective population size is more susceptible to inbreeding effects. A self fertilizing hermaphrodite would have 50% of its heterozygous loci become homozygous each generation as a result of inbreeding. A population of 10 would experience a 5% increase in homozygosity each generation. Contrary to random drift, bottleneck and inbreeding do not affect overall genetic variance in the population *per se*. Fitness characters (reproduction) are most affected by consanguineous mating. It has been observed that one generation full-sib (brother-sister) mating in rainbow trout resulted in increased fry deformity (37.6%), decreased food conversion efficiency (15.6%) and survival (19.0%). In common carp, one generation brother-sister mating reduced growth rate @ 10 to 20%. Inbreeding is a cumulative phenomenon as it accumulates, if mating of relatives is repeated for generations. Inbreeding depression reaches a plateau in a certain level of homozygosity after which further loss in viability does not occur. In India, 2 to 17% inbreeding depression in 1 year among Indian major carps (*Catla catla*, *Labeo rohita* and *Cirrhinus mrigala*) has been recorded when Ne ranged from 3 to 30 in a fish farm. Skeletal deformities and stunted body growth in the hatchery-bred mrigal (*C. mrigala*) and silver carp (*Hypophthalmichthys molitrix*) have been observed due to inbreeding. Similar observations have also been reported for mahseer (*Tor putitora*) in Dehra Dun. Species and populations differ markedly in their resistance to inbreeding depression and magnitude of inbreeding effects cannot be predicted before hand. The unavoidable conclusion is that relatively small amounts of inbreeding can do tremendous damage to the reproductive potential and productivity of the fish stock.

Genetic variance among populations: It is critical that variance among naturally isolated endangered/threatened populations, whatever subtle, be preserved and exploited. Another problem is mixing naturally isolated demes, is potential loss of co-adapted gene complexes. It appears that the potential exists for fitness reductions in fishes due to loss of co-adapted gene complexes. Besides, mixing of naturally isolated groups between populations, variation can be lost through "convergent selection" that is common artificial selective forces in modified natural habitats etc., as observed in *Atlantic salmon*. Formerly wide-spread contiguous populations that have been separated by man into isolated demes suddenly face the genetic problem of small population. In this case supplemental gene flow by man among these artificially isolated groups may be necessary to maintain a larger Ne in each deme and thus "genetically mimic" the natural situation.

Minimum size of Ne: The basic rule of conservation genetics for endangered/threatened fish species is that a genetically effective population size of 50 is the minimum requirement for short-term survival. The number of 50 will result in a 1% F per generation which is tolerable for several generations. For long-term genetic health, a Ne of at least 500 with an associated inbreeding co-efficient of 0.1% and a low rate of genetic drift. The FAO suggests, if possible, a Ne of 1,000 for practically no adverse effect. However, maintenance of as large fish populations as possible is desirable. Ne in any case may be maximized by maintaining equal sex ratio of breeding adults, ensuring even progeny distribution and avoiding population crashes, bottleneck and drift.

Genetic management of endangered populations: When population of a group of species decline and become severely threatened or endangered in particular, some appropriate corrective measures based on genetic principles need to be implemented. These should include: (*i*) maintenance of large effective population size (Ne), (*ii*) controlling the causative factors, and (*iii*) maintenance of continuity of gene flow by disrupting the barriers that create discontinuity in an interbreeding population. Captive breeding programme is a useful approach. Development of research programmes that minimize genetic damage and maximize chances of long-term genetic health of small populations is important and for this the action points recommended are: (*a*) monitoring genetics of field and captive populations, (*b*) maintaining largest

Government of Kerala has imposed ban on trawling in marine water during monsoon (June, July and August) since 1989. The committee set up to evaluate the effect of ban on marine fisheries has remarked that the ban has: (*i*) led to an increase in fish landings, (*ii*) revived the stock position leading to improvement in CPUE (catch per unit effort), and (*iii*) resulted in real improvement in the size groups of the exploited commercial fisheries.

Stock enhancement through ranching: One of the many ways in which to replenish declining natural stocks is through captive breeding or hatchery programmes. Often juvenile fishes are removed from their natural habitat and are then allowed to reach to sexual maturity and breed within the safe confines of an aquaculture or lab environment and the young ones reared in captivity are released back (ranching) to the natural environment. Captive breeding programmes have become the major tool used to compensate the declining fish populations and simultaneously to supplement as well as enhance yields of wild fisheries. Though culture, breeding and larval rearing technologies for the major carps have been developed for several decades, many non-conventional freshwater fish species having enormous commercial value are yet to achieve the demonstrated status. These include *Chitala chitala*, *Ompok pabo*, *O. pabda*, *O. malabaricus*, *Labeo dussumieri*, *Semiplotus semiplotus*, *Clarias dussumieri*, *Channa diplogramme*, *Anabas testudineus*, *Nandus nandus*, *Cirrhinus reba*, *Barbodes carnaticus* and *Puntius sarana*. These species are threatened in their natural habitat. The development of captive breeding technology will help in developing region-specific models for furthering freshwater aquaculture. At the NBFGR, efforts to develop protocols of captive breeding and larval rearing for these non-conventional species in collaboration with fish farmers, and the Regional Aquaculture Research Stations of State Agricultural Universities have shown remarkable success. The technique assumes significance, as these can be source of seed for ranching into natural waters as one of the major components of *in-situ* conservation programme. A holistic collaborative research effort involving scientists and farmers may solve the constraints related to induce breeding, raising seeds and production of table size fish.

The concept of stock improvement through sea ranching was first adopted by the United States of America and Norway during 1880s. The Anadromous species like shad (*Alosa* spp.), herring (Clupeidae), stripped bass (*Morone saxatilis*), sturgeon (Acipenseridae) and marine species cod (Gadidae), haddock (*Melonogrammus aegelfinus*) and mackerel (Scombridae), were ranched but its impact on stock enhancement and recovery was not thoroughly studied. Sea ranching of the Baramundi (*Lates calcarifer* in Australia), red drum (*Sciaenops ocellata* in Texas), Atlantic cod (*Gadus morhua* in Norway), numerous species in Japan, white seabass (*Atractoscion nobilis* in California), grey mullet (*Mugil cephalus*), Pacific threadfin (*Polydactylus sexatilis*) in Hawaii has been done successfully. For a successful stocking programme, the genetic structure of the original wild population should be determined before any new fish are released into the waters. With the help of appropriate molecular markers like micro-satellites, general information about the genetic diversity of fish populations can be established. This information can be used to develop hatchery guidelines for breeding fish for stocking purposes. By ensuring that the stocked population is having the same alleles as the wild population, reintegration of the stocked fish will likely be more successful and deviations from the original genetic structure will be minimal. The NBFGR in a joint programme with the Regional Aquaculture Research Stations, Kumarakom, Kerala successfully carried out stock-specific, breeding-assisted river ranching of two fishes (*Horabagrus brachysoma* and *Labeo dussumieri*) in Kerala; the landings of *H. brachysoma* after 2 years increased from 1.8% to 11 % and that of *L. dussumieri* showed an increase from 0.68% to 3.9% of the total-landings from the Vembanad lake and adjacent rivers in the state. Programme for ranching of artificially-bred golden mahseer fingerlings in Ladhiya and Sharda rivers and selected rivers of the North-Eastern Hills region by the NBFGR, Lucknow, and Directorate of Coldwater Fisheries, Bhimtal, has been initiated.

Around 350 species of brightly coloured attractive native freshwater ornamental fishes are available in India especially along the biodiversity rich Western Ghats and the North-Eastern Hills, such as loaches, *Nemacheilus* and *Travancoria* and species of very elegant barbs such as *Puntius arulius*, *P. denisonii*, *P. narayani*, *P. filamentosus*, *P. manipurensis*, *Danio malabaricus*. Considering the increased popularity of ornamental fish at household level and to curb indiscriminate exploitation from wild, captive seed production and rearing technology of 15 indigenous species having export potential such as *Pristolepis marginata*, *Horabagrus nigricollaris*, *Chela fasciata*, *Danio malabaricus*, *Puntius filamentosus*, *P. fasciatus* and *Mesonemachilus triangularis* have been standardized by the College of Fisheries, Kochi in a joint programme with the NBFGR. However, to avoid indiscriminate exploitation of the freshwater jewels from nature, captive breeding and domestication of more native species such as *Puntius denisonii*, *P. chalakkudiensis*, *Labeo nigriscens*, *Tetraodon travancoricus* and *Channa barca* need to be developed on a priority basis.

Concept of State fish: When an increasing number of species are being reported to be endangered and threatened, there needs to be concerted efforts towards management of the biodiversity. Hence, an innovative approach to fish conservation by declaring a State Fish was adopted for the first time in the country at the NBFGR in 2006. This involved integration of the key stakeholders in the conservation plan where 16 states of the country became partners with the NBFGR in developing strategies for conservation and enhancement of their selected State Fish to achieve the real time conservation success (Table 2.4). A dedicated approach is required to trash out the problems and issues relating to the management of the state fishes of India their and promotion.

Geographic information system: The geographic information system (GIS) and remote sensing tools have become very important for studying natural resources including aquatic habitats. In India, the application of this technique is limited to only marine and lake system. It is also very essential to develop methodology for applying these techniques to streams and rivers with reference to endangered fish habitats.

Life-history traits of prioritized fishes: Information on life-history traits of fish

Table 2.4. The fishes adopted by different states and declared as State Fish

S. No.	State	State Fish	
		Scientific name	Common name
1.	West Bengal	*Tenualosa ilisha*	Hilsa
2.	Bihar	*Clarias batrachus*	Magur
3.	Tripura	*Ompok bimaculatus*	Pabda
4.	Arunachal Pradesh	*Tor putitora*	Golden Mahseer
5.	Himachal Pradesh	*Tor putitora*	Golden Mahseer
6.	Haryana	*Labeo calbasu*	Kalbasu
7.	Kerala	*Etroplus suratensis*	Karimeen
8.	Manipur	*Osteobrama belangeri*	Pengba
9.	Karnataka	*Puntius carnaticus*	Carnatic carp
10.	Uttarakhand	*Tor putitora*	Golden Mahseer
11.	Uttar Pradesh	*Chitala chitala*	Chital
12.	Odisha	*Tor mahanadicus*	Mahanadi Mahseer
13.	Mizoram	*Semiplotus modestus*	Nghavang
14.	Nagaland	*Neolissocheilus hexagonolepis*	Chocolate Mahseer
15.	Jammu and Kashmir	*Tor putitora*	Golden Mahseer
16.	Andhra Pradesh	*Channa striatus*	Murrel

population is important and indispensable for understanding basic biology for planning, conservation and management of a species. There is increasing evidence that intra-species variation in life-history traits has a strong genetic basis. The parameters like fecundity, batch fecundity, annual fecundity, size at first maturity, gonado-somatic index, age and growth, length-weight relationship, oocyte size frequency profile, relative condition factor, food and feeding etc. are the crucial areas to be examined for any stock.

Live gene banks: A live gene bank contributes to delisting of threatened species by captive breeding and restocking in species-specific recovery programmes. Such gene banks can contribute to recovery and utilization of genetic diversity and can be use in conservation programmes and genetic enhancement. The NBFGR has established a live gene bank at Lucknow with 12 functional ponds holding species of high conservation significance and having the following main objectives: (*i*) collection of threatened, endangered, and rare fish species and management of their stocks under farm conditions, (*ii*) study of growth, maturity, survival, and adaptability of these species in controlled conditions, and (*iii*) study of the life-history traits of the threatened species as a tool for *in-situ* and *ex-situ* conservation. In all 12 ponds, different species are kept in captive conditions and these species are thriving and growing well. Biological observations of the species are monitored on a day-to-day basis. At regional level, the NBFGR has established live gene banks in collaboration with Gauhati University and Department of Fisheries, Asom to conserve northeastern fish germplasm resources. Success was obtained in the captive breeding of six species and more endemic species are being introduced in the system, so that suitable package of breeding and cultural practices can be developed. More regional live gene banks in different agro-climatic zones are proposed in collaborative mode to accommodate more species and developing some of these repositories into 'fish parks' or eco-tourism zones to create mass awareness.

***Ex-situ* conservation - cryopreservation of fish gametes and embryos:** Storage of fish spermatozoa, eggs and embryos without loss of viability is of considerable value in aquaculture and conservation. In India, the NBFGR is the primary organization carrying out fish sperm cryopreservation for long-term gene banking. The fish sperm cryopreservation needs development of species-specific protocols. Such protocols are developed through experimental standardization of various parameters, after the captive breeding protocol is developed. This becomes a bottleneck due to protracted breeding season and low domestication of most of the aquatic species, especially marine fishes. Nevertheless, in all such cases, time available in a year for conducting experiment is small and determined by breeding cycle of the species. In view of the constraint, it is essential that candidate species for sperm cryopreservation are prioritized. Species-specific sperm cryopreservation protocols have been developed for the following species, viz. *Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*, *Labeo dyocheilus*, *Oncorhynchus mykiss*, *Salmo trutta fario*, *Cyprinus carpio*, *Tenualosa ilisla*, *Tor khudree*, *Tor putitora*, *Labeo dussumieri*, *L. dero*, *Horabagrus brachysoma*, *H. nigricollaris*, *Barbodes carnaticus*, *Garra surendranathanii*, *Clarias batrachus*, *Heteropneustes fossilis*, *Ompok malabaricus*, *Gonoproktopterus curmuca*, *Labeo calbasu*, *Osteochilichthys longidorsalis*, *Pangasius pangasius*, *Puntius sarana subnasutus*, *Etroplus suratenesis*, *Puntius chalakkudiensis* and *Schizothorax richardsonii*. Out of these, the technique has been tested for twelve, through production of progeny using cryopreserved sperm. Continuous improvement in protocols has provided hatching success ranging from 65 to 100% of the control value for different species. The sperm cryopreservation protocol has also been tested for production of rohu seed in late season when natural milt is not available. Inadequate milt production or asynchronization in maturity of two sexes is generally reported in several cultivable species. In artificial propagation, sperm cryopreservation protocol can be an asset where such milt related problems exist.

Fish gamete cryopreservation research still faces an important challenge in the form of long-term storage of fish eggs and embryos except the minute fertilized abalone eggs. Due to large size, large amount of yolk and tough chorion or zona radiata with a low permeability coefficient, egg and embryo cryopreservation of teleosts and shellfishes have not met with success anywhere in the world so far. Development of fish cell lines, embryonic stem cells and germ cells from Indian fishes and cloning technology as an alternative to long-term storage of finfish eggs and embryos has been emphasized. Embryonic stem cells are pluripotent stem cell lines that are derived from early embryo and these cells can differentiate to become any tissue in the body. Successful protocols for grafting of embryonic cells to host embryos, for germline transmission of desired genome, can be instrumental in evolving effective programmes for production of transgenics and rehabilitation of endangered species. The NBFGR has initiated research programmes on cryopreservation of blastomeres of catfishes. The ultimate objective is to achieve germline chimeras, where the donor cell enters germline development and are able to give rise to fertilizable gametes.

Tissue banking: This is a fast mode of storing the biological material for longer durations and it can be used to retrieve genetic information and genetic manipulation studies in future. Tissue repository accessions unlike sperm banking protocol do not require species-specific protocol and at the NBFGR, emphasis is given to build up tissue accessions of endemic fish species of the biodiversity hot-spot regions. Nearly, 12,000 tissue accessions of freshwater and marine fish species collected from mainland and island ecosystems are maintained in the tissue bank. The NBFGR is also planning to establish a network of researchers across the country, so that tissue accessions of all fish from different ecosystems can be made.

Registration of germplasm: Securing the intellectual property rights related to fish genetic resources is an important aspect in the era of technological revolution, so that the country is able to maintain its stake on its natural wealth and their potential benefits. The germplasm registration process on fish genetic stocks and variability within species is yet to be studied for Indian species for which the NBFGR has initiated research programme. Based on the morphological descriptors, the NBFGR has documented a new red morphotype of *Labeo rohita* and *Macrobrachium lar*. There is urgent need to develop repositories of genetic resources including registered germplasm accessions, accessions of genetic stocks discovered/varieties discovered. The information with the registered accessions can serve as means to protect the traditional knowledge. The NBFGR in collaboration with other fisheries institutes has initiated a network project on fish genetic stock identification of 10 cultivable food fish based on morphological descriptors, reproduction and production traits and molecular markers.

DNA barcoding: The DNA-based approach to taxon identification which exploits diversity among DNA sequences and can be used to identify fishes and resolve taxonomic ambiguity including discovery of new species. "DNA Barcoding" - DNA sequence analysis of a uniform target gene (655 base pair of Cytochrome C Oxidase - I of mitochondrial genome) is the most recent and reliable approach to discriminate eukaryotic species including fish. Barcoding offers a simple, rapid and reliable means of identifying not only whole fish, but fish fragments, eggs and larvae. The NBFGR has initiated a mega programme on DNA Barcoding of all Indian marine finfishes in collaboration with the global Consortium for the Barcode of Life (CBOL) - Fish BOL. DNA barcodes of more than 450 finfish species reported from Indian seas have been prepared so far as a part of the international network. This could be of great utility in sustainable exploitation, management and conservation of Indian fish species.

Genetic characterization: The primary objective of the genetic characterization is to assess the distribution and pattern of genetic variability at intra-as well as inter-specific level populations, through the use of identified genetic markers. The first priority for such research is identification of appropriate genetic markers to assess the genetic diversity. The conclusions from genetic diversity data have varied application in research on management and conservation of fish species, to understand the pattern of migration of fish stocks, nature of breeding populations and also in taxonomy/ systematics. Several marker types are highly popular in aquaculture/fisheries genetics. In the past, soluble proteins, gene products (allozymes) and mtDNA markers have

been popular; more recent marker types that are finding service in this field include restriction fragment length polymorphism (RFLP), randomly amplified polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP), microsatellites, single nucleotide polymorphism (SNP) and expressed sequence tag (EST) markers. The choice of markers is crucial in achieving precise information that is useful for desired application. A concerted effort made at the NBFGR has provided description of genetic variation and population structure for prioritized fish species from their major range of natural distribution. These species include *Tor putitora*, *Catla catla*, *Cirrhinus mrigala*, *Labeo rohita*, *L. calbasu*, *L. dero*, *L. dyocheilus*, *L. dussumieri*, *Clarias batrachus*, *Chitala chitala*, *Tenualosa ilisha*, *Puntius denisonii*, *Horabagrus brachysoma*, *Tor malabaricus*, *Gonoproktopterus curmuca*, *Channa marulius* and *Etroplus suratenesis*. The study covered wide geographical area and used micro-satellites, allozyme and RAPD markers. Distinct population structure was observed in many of these species indicating that propagation assisted restoration programmes must be stock-specific to replenish declining populations. It is generally been assumed that marine species that has wide geographic distributions, and the apparent capacity for long-distance dispersal do effectively disperse over long distances in ecological time scales as observed in the studies of NBFGR on lobsters (*Panulirus homarus* and *Thenus orientalis*), and the deep-sea fish, *Priacanthus hamrur*. However, there has been growing evidence from genetic markers that even the widespread marine species are geographically structured, and that there can be sharp genetic disjunctions sometimes where there are no obvious barriers to dispersal. Such evidence has been observed in seahorses (*Hippocampus kuda* and *H. trimaculatus*) using cytochrome b gene sequences of mtDNA and micro-satellites, sampled from Arabian Sea and Bay of Bengal; the endangered marine white fish (*Lactarius lactarius*) and Bombay-duck (*Harpadon nehereus*) from east and west coasts of India.

Valuation and evaluation of biodiversity: Economic valuation provides a means for measuring and comparing the various benefits of fisheries and aquatic resources and their ecosystems and can be a powerful tool to aid and improve their wise use and management. It attains to assign quantitative values to the goods and services provided by environmental resources, whether or not market prices are available. However, the major difficulty for evaluating a complex environmental system is insufficient information about ecological processes underpinning the various values generated by the system. Therefore, there is need to develop methodology for the evaluation and valuation of the aquatic resources and fish biodiversity in India. Various components of aquatic eco-systems have three major category of attributes of valuation, i.e. existence, intrinsic and option values. Most of the goods and services provided by aquatic ecosystems are still available to consumers without price. Due to rising pressure of population, industrialization and other developments on this planet, now, environmental goods and services provided by aquatic ecosystems have private values. The collaborative efforts between biologists, economists and social scientists need to be initiated for developing model for economic valuations of biodiversity and their adoption at national, state and local levels. The model for economic valuation must consider all kinds of benefits ranging from socio-economic, nutritional security, the products to possible source of important genes.

Exotics and quarantine: Many introductions of exotic species for fisheries and aquaculture diversification have been successful, but others have resulted in highly publicized failure, generating controversy over protection of native biodiversity, spread of pathogens and diseases. To safeguard our indigenous fish genetic resources from infectious exotic diseases and to develop effective protocols for fish quarantine, the NBFGR is actively engaged in the upgradation of facilities and expertise. The NBFGR has already developed the rapid diagnostic capability for detecting the eleven fish OIE listed pathogens using molecular and immunological tools. The bureau has also succeeded in developing monoclonal antibodies against *Labeo rohita*, which will be extremely useful in serodiognostics for pathogen surveillance in aquaculture of Indian major carps. Steps have been initiated to establish a referral laboratory for all OIE (World Organization for Animal Health)-listed pathogens in India at the NBFGR. This needs development of fish cell lines and a major programme to develop cell lines from cyprinids, catfishes, native cichlids and marine species such as groupers has been undertaken at the NBFGR. Significant success has been achieved in developing cell cultures from *Cyprinus carpio*, *Chitala chitala*, *Labeo rohita*, *Puntius denisonii*, *Pristolepis fasciata*, *Etroplus suratensis* and *Epinephelus merra*.

Legislative framework for aquatic biodiversity: The Indian Government has various acts, rules and regulations for helping Indian society to conserve the fish and aquatic diversity and judiciously utilize it for the well being of the nation.

Biological Diversity Act, 2002: The United Nations Conventions on Biological Diversity (CBD) signed by the 188 countries took the landmark step by reaffirming the sovereign rights of states over their biological resources. The CBD is an international legal instrument for promoting conservation and sustainable use of biological diversity. The CBD links the diverse policy issues through its three objectives; the conservation of biological diversity; the sustainable use of its components; and the fair and equitable sharing of the benefits derived from the use of genetic resources. This is a fact that majority of resources are with developing countries in contrast to the developed countries who possess technological edge. This will enhance trans-boundry exchange of germplasm and information for use in product development. To respond to new challenges and developments, Government of India has enacted a legislation called Biological Diversity Act, 2002, and Biological Diversity Rules, 2004 and notification of main operational sections of Act. This encompasses guidelines to address wide range of issues related to utilization of bioresources and information within country and check bio-piracy. The objective is to put administrative procedures in place so that inherent biological resources are optimally utilized while maintaining its sovereignty over them.

The Indian Government has rules and regulations for various activities in the coastal zone, which covers the inter-tidal area and the land area of 500 m from the high tide line. The States have prepared a coastal-zone management plan, indicating various zones so that the rules and regulations can be applied appropriately at these zones.

The government proposes to extend these rules to the ocean part. Laws included the Fisheries Act of 1897, the Marine Products Export Development Authority of 1972, the Maritime Zones of India (Regulation of Fishing by Foreign Vessels) Act of 1980, and the Territorial Waters, Continental Shelf, Exclusive Economic Zones and Other Maritime Zones Act of 1976. Major central acts relevant to biodiversity are: Wildlife (Protection) Act, 1972; Forest (Conservation) Act, 1980; and the Environment (Protection) Act, 1986. The Parliament of India enacted the Coastal Aquaculture Authority Act, 2005 No. 24 of 2005 [23^{rd} June, 2005] for establishment of Coastal Aquaculture Authority to regulate the activities connected with coastal aquaculture and for matters connected therewith or incidental thereto. The Central Government of India established the Coastal Aquaculture Authority vide Notification dated 22^{nd} December, 2005.

State laws and statutes concerning forests and other natural resources support the central acts. Policies and strategies directly relevant to biodiversity include National Conservation Strategy and Policy Statement for Environment and Sustainable Development; Comprehensive Marine Fisheries Policy, 2004, Ministry of Agriculture, National Fisheries Policy (under preparation); National Biodiversity Policy; the Environmental Action Plan; National Lake Conservation Plan (NLCP) and National River Conservation Plan (NRCP). National Environment Policy, 2006 seeks to achieve balance and harmony between conservation of natural resources and development processes and also forms the basic framework for the National Biodiversity Action Plan. The Ministry of Environment and Forest, Government of India has set up the National Ganga River Basin Authority (NGRBA) in February 2009 to ensure effective abetment of pollution and conservation of river Ganga by adapting a river basin approach. One of the primary objectives of the NGRBA is to maintain minimum ecological flow in the river with the aim of ensuring water quality and sustainable development.

The India's National Water Policy was adopted in September 1987. The National Water Resources Council under the Chairmanship of the Prime Minister of India lays down the National Water Policy, reviews development plans and advises on implementation. The Policy aims at planning, developing and conserving water resources on an integrated and environmentally sound basis keeping in view the needs of the state governments. Envisaged strategies include groundwater development, water allocation priorities, drinking water, irrigation, water quality, water zoning, water conservation, flood control and management. The state governments make their water policies within the overall framework of the National Water Policy. In 2008, National Biodiversity Action Plan of the Ministry of Environment and Forests has been approved by the Government of India which aims several plans, programmes and policies towards biodiversity conservation including capacity building, bio-safety, sustainable use of its components, and fair and equitable sharing of benefits arising out of their use.

Conservation and community awareness: India, being a signatory to the Food and Agriculture Organization's Code of Conduct for Responsible Fisheries, the provisions of conservation of fish stock and sustainable fisheries should sincerely be implemented. In a huge country like India with diverse ecosystems where enforcement of law is a difficult task, it has been amply proved and demonstrated that in addition to enforcement of relevant Acts; the most effective way of tackling the problem is to arouse mass consciousness on the issue when people themselves would come forward to protect the fish genetic resources. Participation and involvement of the community are an integral part of fish conservation programme. This can be done by creating awareness among different stakeholders and the local people and solicit their commitment to conservation and wise use of the nation's fish resources. Education and public awareness to promote mutual understanding of the problems of the diverse sectors involved with management and conservation of natural resources are done through training programmes. Awareness-raising should be fostered within fishing communities that are fishing within, adjacent to the water-bodies.

The fish genetic diversity conservation as a concept may sound simple but its realization and implementation is not an easy task. It is particularly so in a developing country like India with more than 119 crores of people, on-going agricultural revolution, industrial modernization and where majority of the people are fish eaters and 14 million fishers and farmers earning their livelihood from fishing and its ancillary vocations. It thus calls for well-investigated scientific data for effective planning and implementation through creative approaches. The country has diverse fish germplasm, which if effectively managed can increase biological wealth. Prospects for the conservation of fish germplasm and future strategy have to be drawn up based on past growth and the potential for future expansion, taking into consideration likely availability of funds, infrastructure, and trained manpower, the impact of research data monitoring on fish germplasm and resource conservation. Maintaining the genetic health of the fisheries wealth is equally important for up-scaling aquaculture production and sustaining the fish yield from natural waters. Therefore, conservation needs must be aimed towards preserving existing biodiversity and also the evolutionary processes that foster biodiversity. The conservation of fish diversity and aquatic resources of the country requires concerted efforts by integrating capture, culture fisheries and environmental programmes using latest technological innovations. Producing around 5% of the world's fish, India trades to the extent of 2.5% in the global fish market. There are however, concerns regarding the stagnating capture fisheries yields. The issues in inland and marine fisheries that need to be addressed pertain to biodiversity loss and depletion of fish stocks, excess coastal fishing, oceanic and deep-sea fisheries, impact of climate change on fisheries, issues, inland and coastal pollution, large-scale sedimentation of rivers, estuaries and lakes/wetlands and effective compliance of code of conduct of responsible fisheries. Suitable programmes must hence be formulated to build in resilience in fisheries including regulated fishing and capacity reduction in mechanized sector, FADs, diversified fishing in deep sea and oceanic resources; culture-based fisheries in reservoirs with stocking of advanced fish fingerlings, and implementing code of conduct of responsible fisheries. It is expected that research programmes on the

priority areas in consortia mode involving different research organizations, planners, conservationists, developmental agencies, voluntary organizations and community and stakeholder participation will certainly generate more results with respect to sustainable utilization of fish genetic resources.

3. Pelagic Fisheries

India has been one among the top 10-fish producing countries of the world since 1960 with its position oscillating between the third and the sixth rank. Currently India occupies the third position contributing about 5% (7.6 million tonnes, including inland and marine fish production) to the world fish production of about 143.6 million tonnes (2008-09). The marine fish production in India reached a record of 3.2 million tonnes in 2009 owing to mechanization of the crafts, motorization of the country crafts, commencement of stay over fishing at deeper areas, improvements in gears and related infrastructure facilities which were introduced at different periods since the late 1950s. Almost 90% of the production was obtained from within 70 m depth covering an estimated area of about 100,000 km^2.

Among the countries bordering the Indian Ocean, India endowed with 2.02 million km^2 of EEZ along a coastline of 8129 km and 0.5 million km^2 of continental shelf with a catchable annual marine fishery potential of 3.93 million tonnes occupies a unique position. Besides, there are vast brackishwater areas spread all along the coastline, which offer ideal sites for seafarming and coastal mariculture. Among the Asian countries, India ranks second in aquaculture and third in capture fisheries production, and is one of the leading nations in marine products export. The development of Indian marine fisheries from a traditional subsistence-oriented one to industrial fisheries through Five-Year Plans has been phenomenal. However, the present scenario is characterized by over capacity, declining yields from the inshore waters and increasing conflicts among different stakeholders, whereas the increasing demand for fish in domestic and export markets indicates good prospects for large-scale exploitation of oceanic and deep sea resources. The production from marine capture fisheries is stagnating since 1997 around 2.9 million tonnes/annum, threatening to decline, and warranting effective management of the exploited stocks. The Indian experience with the small-scale fisheries sector is similar to that in any other tropical developing country. The multitude of species exploited by a large variety of fishing fleets makes the management of marine fisheries a difficult proposition. An attempt is made here to bring out the historic and current status of the pelagic fisheries and to focus attention on their sustained development through appropriate management plans.

The marine fisheries resources are mainly constituted by the pelagic finfishes (all those fishes which live most part of their life in the surface or subsurface waters) numbering about a dozen major groups and species (Table 3.1), the demersal finfishes (those fishes which live most part of their life on bottom or sub column layers) contributing by about 15 major groups and species, crustaceans comprising about 5 groups, and cuttlefishes and squids. The introduction of purse-seine in seventies and ring-seine in eighties, and motorization of traditional crafts in early eighties had enhanced

pelagic fish production from the currently exploited 0-50/100 m depth zones at different stages.

Crafts and gears

Conventional canoes, Pablo-type boats and catamarans are the fishing crafts used in the exploitation of pelagic resources. They are navigated either manually or mechanically by fitting inboard/outboard engines. Besides, different sizes of trawlers, gillnetters and purse-seiners are being engaged in this fishery.

Table 3.1. Major taxonomic categories of pelagics and their species diversity

Family	Group/species	Species number
Clupeidae	Oil sardine*	1
	Lesser sardines* (including rainbow sardines)	14
	Hilsa spp. and other shad	15
	Whitebaits*	24
	Thryssa and *Thrissocles* spp.	10
	Wolf herrings	2
	Other clupeids	40
Scombridae	Coastal tunas	5
	Oceanic tunas	4
	Seerfishes and Wahoo	5
	Mackerels*	3
Trichiuridae	Ribbonfishes*	8
Carangidae	Scads*	12
	Jacks	4
	Black pomfret	1
	Trevallies	25
	Runners	1
	Pilot fishes	1
	Leather jackets	4
	Pompanos and darts	6
Harpodontidae	Bombay-duck*	1
Stromateidae	Pomfrets	2
Coryphaenidae	Dolphin fishes	2
Rachycentridae	Cobia	1
Mugilidae	Mullets	22
Sphyraenidae	Barracudas	7
Exocoetidae	Flyingfishes	10
Bregmacerotidae	Unicorn cod	1
	Others	19
	Total pelagics	250

*Major pelagics.

There is a wide array of gears employed in the pelagic fisheries. The gears used are the shoreseine, boatseine, gillnet, drift gillnet, hooks and line, pole and line, *dol* net, etc. Among these, the shoreseine has gradually disappeared and the *Rampani* of Karnataka has been replaced by purseseine and ringseines. Purse-seine, ringseine, gill net of various mesh sizes and pelagic fish- trawl were introduced later for pelagic resources exploitation. Over and above, considerable quantities of pelagic fishes are being landed in high-open trawl nets operated from the shrimp trawlers.

Trends in production

The annual average marine fish production of India for 1998 to 2008 was 2.62 million tonnes of which the pelagic contributed 1.5 million tonnes against an annual catchable potential yield of 1.92 million tonnes from the Indian EEZ. During last decade pelagic finfish resources contributed 46 to 56% (average 51%) of the total marine fish production. Almost 70% of the production was obtained from within 50 m depth zone. As per the revalidation, annual potential yield from the EEZ of India is 3.93 million tonnes, out of which 2.21 million tonnes are from within 50 m depth zone and 1.69 million tonnes are from beyond this. The current yield from 0 to 50 m depth zone is at the optimum level, and hence does not offer any scope for increasing the yield and this zone requires regulatory management for sustaining the yield. Therefore, the region beyond 50 m depth has to be the focus of expansion. Comprehensive account on the pattern of development of pelagic fishery, based on historical data (the status, prospects and management of the small pelagic fishes) and results of stock assessment of major pelagics, is available. The share of the pelagic groups in the overall production remained very high with a constantly increasing trend from 54% in 1950s to 71% in 1960s, and thereafter, at around 65% till early seventies. The pelagic catches increased from 309,000 tonnes in 1950 to 1,685,001 tonnes in 2008 registering more than a five-fold increase.

In early years of development of marine fisheries, the growth rate of pelagic fish production had been conspicuously higher than overall marine fish production. In 1970-79 this trend reversed due to rapid expansion of commercial trawling for shrimps for exports by the industrial sector. Commercial trawling resulted in significantly high production of demersal fin fishes also, besides shrimps, crabs, lobsters and cephalopods. Although pelagic fish catches increased by 22%, the trend in the overall production was set by demersal finfish and crustacean catches. The next decade (1980-89) witnessed a growth of 27% in the pelagic catches as well as in the overall production (Table 3.2). During this decade there was rapid motorization of traditional fishing craft, particularly in the latter half of the eighties. As a result, the stagnation in marine fish production witnessed in first half of the eighties gave way for accelerated production in latter half. Intensive motorization of traditional fishing crafts resulted in a remarkable increase in the annual production, especially of the total pelagics, which increased from 769,000 tonnes in 1985 to 1,685,001 tonnes in 2008, registering a 119% increase.

Table 3.2. Growth in the average annual overall and pelagic fish production through the five decades from 1950 to 2008

Period	Production (tonnes)		Relative growth (%)	
	Pelagics	Overall	Pelagics	Overall
1950-59	362,648	618,501	-	-
1960-69	527,211	814,721	+ 45	+ 31
1970-79	643,142	1,243,707	+ 22	+ 27
1980-89	819,093	1,579,836	+ 27	+ 27
1990-99	1,116,792	2,258,674	+ 36	+ 43
2000-08	1,358,578	2,617,236	+22	+16

Pelagic fishery resources

The pelagic fishes are highly migratory and generally show shoaling behaviour. Pelagic comprise different taxonomic groups, which contribute to their rich species diversity and abundance. The important varieties belonging to pelagic group are the clupeids, formed by wolf herring, oil sardine, lesser sardines, *Hilsa*, anchovies (*Coilia*, *Setipinna*, *Stolephorus*, *Thrissina*, *Thryssa*) and others; Bombay-duck, halfbeaks, and full beaks, flying fishes, ribbon fishes, carangids (horse mackerel, scads, leatherjackets), Indian mackerel, seer fishes, tunas, billfishes barracudas, mullets and unicorn cod. Among these, the groups contributing to more than 0.1 million tonnes are the oil sardine, lesser sardines, anchovies, mackerel, Bombay-duck, carangids and ribbon fishes. The increase or decrease in the annual marine fish production of the country, by and large depends on the success or failure of these groups. From the available information on the distribution of marine fishes along the Indian coast, it could be inferred that there are about 250 species of pelagic (Table 3.1). A few species of pelagic enjoy wide geographical distribution while the others such as the shads (*Hilsa* spp.), golden enchovy (*Coilia dussumieri*) and Bombay duck (*Harpadon nehereus*) have a restricted distribution.

Sector-wise landings

State-wise contributions to pelagic fish production during 2008 showed that Kerala ranked first among the maritime states of India contributing about 29% to total pelagic fish catch, followed by Tamil Nadu contributing to 13%. The contributions by other states were: Karnataka 11%, Gujarat 10.4%, West Bengal 10%, Andhra Pradesh 8%, Maharashtra 7%, Goa and Odisha 5.5% each and Puducherry 0.5%. This shows that the south-west region comprising the maritime states of Goa, Karnataka and Kerala continued to be the highly productive area (45%) followed by south-east covering Tamil Nadu, Puducherry and Andhra Pradesh (22%), the north-west covering Gujarat and Maharashtra (17%), and north-east regions covering West Bengal and Odisha (16%).

Mechanized sector contributed 54% of the total pelagics, followed by motorized (39%) and non-motorized (traditional) units 7%. The sector-wise average effort expended, catch and catch per hour of pelagics landed from 1999 to 2008 is given in Table 3.3. A comparison of average annual production of major pelagic fin-fishes from initial stages of mechanization in 1960s to 1993-94, through early and late 1980s, showed an increasing trend with respect to all groups (Table 3.4). Substantial increase was noticed in anchovies, Bombay-duck, tunas and billfishes till 1992 and that of ribbon fishes and mackerels till 1993-94.

Table 3.3. Sector-wise effort, catch and catch/hr of pelagics in respect of different units in India (1999-2008)

Items	Mechanized	Motorized	Non-motorized (traditional)
Catch/hour (kg)	37.93	25.59	10.16
Total catch (tonnes)	748.144	540,518	101,965
Effort (AFH)(hr)	19,722,666	21,123,780	10,039,011
Effort (Units number)	1,059,184	4,417,079	2,451,107
Contribution (%)	53.8	38.9	7.3

Compared to 1960s, in 1980s production almost doubled or even trebled for many groups, excepting oil sardine and mackerel; which showed only marginal increase. Increase in production in early eighties could be attributed mainly to purse-seine fishing, while that of late eighties and nineties to the motorization of country crafts, introduction of innovative gears like ringseine and commencement of stay-over fishing.

Table 3.4. Average annual landings of major pelagic finfishes in initial stages of mechanization 1998-2008 (catch in tonnes)

Major pelagic groups	1961-65	1981-85	1988-92	1993-97	1998-2003	2004-08
Oil sardine	173,457	182,920	190,378	106,611	304,690	415,344
Lesser sardines	29,326	63,069	83,379	106,143	97,205	91,813
Anchovies	22,783	57,073	145,197	136,449	122,031	117,983
Bombay-duck	84,375	11,0064	116,287	98,190	108,328	113,865
Ribbonfishes	24,153	50,056	82,910	116,043	156,811	149,453
Mackerel	38,622	40,595	165,504	226,535	136,423	153,034
Seerfishes	10,155	30,206	37,521	41,611	48,883	51,321
Tunas and billfishes	4,222	17,789	41,236	41,485	46,210	69,674
Carangids	22,027	46,769	152,142	150,509	150,903	154,863

Major pelagic stocks

Out of 250 species that contribute to pelagic fisheries along the Indian coast, only 60 species belonging to 7 groups, oil sardine, lesser sardines, anchovies, Bombay-duck, ribbonfishes, carangids and Indian mackerel form major fisheries. Annual average production of these during 1990-2008 was 1.05 million tonnes; forming 82.6% of pelagics and 42% of total marine fish landings. The other pelagic groups, which include the wolfherrings, shads, barracudas, unicorn cod, mullets, seerfishes and tunas, formed only 17.4% of pelagic fish landings. The groups, which exceeded an average production of 0.1 million tonnes/year (1990-2008), were oil sardine (2.6), mackerel (1.6), carangids (1.6), anchovies (1.3), ribbonfishes (1.3) and Bombay-duck (1.1). Oil sardine and mackerel were most predominant, contributing 11 and 7% to overall marine fish landings. Carangids formed 6% followed by anchovies and ribbonfishes (5% each), lesser sardines (4%), Bombay-duck (5%), tunas and seerfish (2% each), *Hilsa* shad (1%), and barracudas (0.6%) in the overall marine fish landings during 2008.

The percentage contribution of pelagics ranged from 1.2 of barracudas to 20.6 of oil sardine (Table 3.5).

The major single-species fisheries of pelagic resources, oil sardine (*Sardinella longiceps*), Indian mackerel (*Rastrelliger kanagurta*) and Bombay-duck (*Harpadon nehereus*) showed wide inter-annual fluctuations in their availability for exploitation. This fluctuation is due to fishery independent factors such as spawning success, recruitment strength and environmental factors, affecting resources. The distribution, production, biology, utilization and status of the stock of the major pelagics are summarized here.

Table 3.5.The average landings of pelagic finfishes and their percentage contribution during 1990-2008

Groups	Catch (tonnes)	Per cent
Oil sardine	262,098	20.6
Mackerel	164,844	13.0
Carangids	155,573	12.2
Ribbonfishes	134,304	10.6
Anchovies	127,749	10.0
Bombay-duck	111,067	8.7
Lesser sardines	94,422	7.4
Other clupeids	49,248	3.9
Tunas and Billfishes	46,452	3.7
Seerfishes	45,246	3.5
Hilsa shad	28,669	2.3
Wolf herring	15,572	1.2
Barracudas	14,891	1.2
Other pelagics	21,419	1.7
Total pelagics	1,271,554	

Indian oil sardine

Distribution: This is a major inshore small pelagic, distributed in narrow belts extending to a distance of 3 to 20 km from the coast. Along the Indian peninsula, there is greater concentration of oil sardine stock in Malabar upwelling zone along the south-west coast between 8° N and 16° N latitude. A fishery for this resource has emerged along the southeast coast from 1985. The oil sardine fishery has been most strikingly characterized by wide fluctuations in the annual landings; variability in abundance of oil sardine is cyclic.

Production trends: During the last 50 years, all-India production of oil sardine ranged from 14,000 tonnes in 1952 to an all-time high of 0.497 million tonnes in 2007; contributing 0.1 to 17.3% to the total marine fish landings in India. The oil sardine catch increased from 78,000 tonnes in 1986 to 279,000 tonnes in 1989 but declined to 47,000 tonnes in 1994. The resuscitation of the oil sardine stock after an ever-lowest landing in 1994 manifested from heavy recruitment that followed, which culminated in a highest production of 4.97 lakh tonnes in 2007. The average (1999 to 2003) annual landings of the oil sardine along the west coast were 147,989 tonnes (73 %) and were 53,984 tonnes (27%) along the east coast. However, during 2008, oil sardine landings along the west coast were 369,847 tonnes (83%) and 71,844 tonnes (16%) along the east coast. The success of oil sardine fishery depends on rainfall, food availability, migratory pattern, survival of eggs and larvae, intensity of upwelling and availability and accessibility of shoal to gear in operation.

Means of exploitation: Till close of 1970s, mainly boat and beach seines, cast nets and small meshed gill-nets were the major gears operated along the south-west coast. With introduction of mass-harvesting gears like purse seines in late 1970s and ring-seines in late 1980s along with a steady rise in motorization of traditional fishing crafts, many of these traditional fishing methods have become obsolete. Along the east coast mainly boat seines (*karavala, peddavala*), gill-nets (*chalavalai*) and bag nets (*edavalai*) dominate. In Tamil Nadu coast, pair trawlers are operated at

12 to 60 m depth in Pampan–Rameswaram area while ringseines have been introduced in the Palk Bay.

Fishing season: Along the south-west coast, the oil sardine fishery commences soon after outbreak of monsoon in June and continues till March-April. Along Kerala coast catches are fairly high throughout the year excepting from March to May, while in the Karnataka-Goa belt, the season sets in September/October with peak fishing from October to January. On the south-east coast, the fishing season is from April to December with peak catches during April-June on the Tamil Nadu coast and July-October along the Andhra Pradesh coast.

Biology: The success of oil sardine fishery along the south-west coast depends mainly on the recruitment strength of early juveniles of 80 to 100 mm during the post-monsoon months. Juveniles appear in the fishery in late August in southern region and form mainstay of the fishery whereas in the northern region it appears in late September. The beginning of the fishery is marked by the entry of the large-sized fish in the advanced stage of maturity, followed by the 0-year class. Commercial fishery is supported mainly by 0- and 1-year classes.

Oil sardine grows rapidly during first few months and matures early within its life span of about 2 years and 6 months. The age at first maturity occurs at less than one year, at about 150 mm size. Maturation is controlled by temperature and intensity of rainfall experienced by the pre-spawners. On the west coast peak spawning occurs during June-August, and on the east coast, intense spawning activity has been observed during December-February, April-June, and August-October. Through collections of spawners in oozing condition and planktonic eggs, spawning grounds are located off Quilandy, near Kozhikode, Tanur-Tellicherry belt, Quilon and Mangalore at depths of 20 to 30 m and about 15 km from shore. Seasons of feeble or severe rainfall cause recruitment failure, while a daily rainfall of 20 to 30 mm during June-August along south-west coast indicates a good recruitment to fishery. As the success of commercial fishery for each season is determined by the number of juveniles recruited at the beginning of the same season, rainfall, which affects spawning success, has been used to forecast the strength of juvenile brood entering fishery.

The oil sardine is a planktivore where diatoms, dinoflagellates and copepods are the favoured food items. The abundance of diatom *Fragilaria oceanica* is said to indicate abundance of oil sardine in coastal waters. The optimum temperature and salinity ranges for distribution and abundance of oil sardine are 27° to 28°C and 22.8 to 33.5 ppt, respectively, although occasionally they have been observed to enter estuaries along the south-west coast.

Utilization: Along the south-west coast, the fish has good demand in local and distant markets, and fishery is fully exploited. On the east coast, demand for local consumption is low and most of the catch is marketed outside the state, particularly in Kerala. During periods of heavy landings, they are also sun-dried and supplied to manufacturers of poultry feed.

Management: Fisheries of small pelagics like oil sardine is characterized by high inter-annual and decadal variability that makes their management difficult. There was an unprecedented failure of oil sardine fishery during forties which had disastrous effects on industries based on it, which provoked British administration to introduce restrictive legislation in 1943 to prevent capture of juveniles and spawners. Under Marine Fishing Regulation Act, 1980s by various maritime states, fishing by mechanized vessels, especially purse-seines during monsoon is banned to protect spawners, but the implementation of the same is not uniform in all states. Moreover, traditional motorized crafts continue to engage in seining operations using extremely small meshed mass harvesting nets like ringseine during this period, which destroy both spawners and young fish. Any fishery which allows uncontrolled exploitation of both juveniles and adults from a stock is likely to experience stock decline. Therefore, it is imperative that destructive fishing practices using small meshed seines are effectively controlled by enforcing mesh size regulation (minimum 18 mm), closed season and restricted fishing (June–September), besides strict licensing and optimum deployment of fishing units especially ringseines and purse-seines.

Lesser sardines

Distribution: The lesser sardines, which comprise several species of *Sardinella* other than *S. longiceps*, show wide distribution in tropics, and are one of the major pelagic fishery resources of India. Though occurring in the landings of all the maritime states, they particularly contribute to a lucrative fishery along the south-east and the south-west coasts. Of the 15 species of lesser sardines in the Indo-Pacific region, 12 occur in Indian waters. The species that constitute fishery are *Sardinella albella, S. gibbosa, S. fimbriata, S. sirm, S. dayi, S. sindensis, S. melanura, S. clupeoides* and *S. jonesi*. The resource contributed 3 to 5% to the total annual marine fish production of the country from 1990 to 2008.

Production trends: The average landing of lesser sardines from 1990 to 2008 was 94,422 tonnes. The east coast contributed 65% with an average annual production of 67,172 tonnes from 1986 to 2000. During 2008 the annual landings along the east coast was 88,290 tonnes comprising 76% and the west coast was 27,808 tonnes forming 24% of the total lesser sardine production. Among maritime states, Tamil Nadu with an average landing of 41,508 tonnes, contributing 36% of the catch stood first in lesser sardine production.

Means of exploitation: Along the south-east coast, the small meshed gill-nets are effectively used to exploit lesser sardines. The seines (shore seines, boat seines and ringseines) are popular along the south-west coast. The canoes and plank-built crafts with outboard engines operate boat seines (*ranibale, mattubale, kotibale*) and ringseines at depths up to 30 m. The purse-seines are operated from mechanized units at depths up to 60 m. The trawlers operating in the near-shore waters also land sardines in considerable quantities along the Karnataka coast.

Biology: The size at first maturity, spawning season and fecundity differ from species to species, but most of them become sexually mature before completion of 1 year and the commercial fishery is supported by 0 and 1+ year classes. *S. sirm, S. jonesi* and *S. clupeoides* grow to larger size when compared with other species and 1 to 2-year classes dominate fishery. Lesser sardines feed mainly on a variety of plankters. The *Sardinella gibbosa* feed on copepods, Mysis, *Lucifer*, larvae of prawns and crabs, fish eggs, *Acetes*, etc., while *S. albella* feed mainly on copepods, *Lucifer, Acetes, Mysis*, fish and bivalve larvae, etc.

Utilization: The lesser sardines are a source of cheap protein for rural poor in coastal regions. They are consumed fresh in coastal regions and transported with ice to interior markets by road and train. Salted and sun-dried sardine products are sold in hinterland states in India. Smaller sardines are dried and used as important protein-mix in preparation of cattle, poultry and shrimp feeds.

Management: The total annual stock of the lesser sardines is estimated at 280,000 tonnes comprising 20,000 tonnes in Andaman waters, 30,000 tonnes in north-east, 140,000 tonnes in the south-east, 80,000 tonnes in the south-west and 10,000 tonnes in the north-west coasts. The maximum sustainable yield (MSY) was estimated at 140,000 tonnes. The average annual production was 80,328 tonnes during 1986-90; 94,387 tonnes during 1991-95; 122,243 tonnes during 1996-2000 and 91,813 tonnes during 2004-08, and it is still below estimated MSY. Stock assessment on *S. gibbosa* indicated that its yield along the south-west coast is considerably lower than the maximum sustainable yield and hence there is further scope of increasing the catch from this region.

Anchovies

Distribution: The anchovies are widely distributed along the Indian coast. The Indian anchovies include 5 genera, *Stolephorus, Coilia, Setipinna, Thryssa* and *Thryssina*, that constitute seasonal fisheries almost along the coasts of Andhra Pradesh, Tamil Nadu, Kerala, Karnataka and Maharashtra.

Production trends: The average annual catch during 1990-2008 was 0.130 million tonne, constituting 10% of the total pelagic fish production in India. The annual landings ranged from 0.105 million tonnes in 1987 to 0.166 million tonnes in 1991. Among anchovies, white baits were the most important with current (1990 to 2008) average annual landings of 55,415 tonnes forming 43% of the overall anchovy production of 0.127 million tonnes, grenadier anchovy *Coilia dussumieri* and *Thryssa* formed 27% each and *Settipinna* 3%. The whitebaits formed 60% of the south-east coast and 80% of the south-west coast anchovy production. The grenadier anchovy dominated anchovy fishery in north-west and north-east regions with an average landings of 34,107 tonnes from 1990 to 2008.

Whitebaits

The whitebaits are the dominant component of anchovy landings in India. The whitebaits that comprise a group of small pelagic fishes belonging to genus *Stolephorus* and *Encrasicholina* are widely distributed in our waters. This resource contributed on average 55,415 tonnes (1990 to 2008) forming 2% of the total marine fish landings in the country. Ten species of whitebaits, viz. *Encrasicholina devisi, E. heterolobus, E. punctifer (Stolephorus buccaneeri), Stolephorus andhraensis, S. baganensis (S. macrops), S. commersonii, S. dubiosus, S. indicus, S. insularis* and *S. waitei (S. bataviensis)*, have been found to occur in our seas. Among these species, *E. devisi, E. punctifer, S. waitei, S. commersonii* and *S. indicus* support the fishery.

Means of exploitation: The major gears employed for exploiting whitebaits are boat-seines, shore-seines, bagnets and gill-nets operated mainly by the catamarans and other small country crafts; many of them fitted with outboard motors. Purse-seine, ringseine and trawl nets are also effectively used in fishery. In the south-east and the south-west coasts, the most common gears exploiting whitebaits include boat-seines (cod-end stretched mesh size: 10 mm) and shore-seines (cod-end stretched mesh 10-20 mm). On the south-west coast gill-net known as *Netholivala* (mesh 15 mm), is specially employed for whitebaits during main fishing season. The purse-seines (common stretched mesh at the bund, 14-8 mm) are operating in Karnataka and Kerala from mechanized boats since 1970s and ringseines (mini purse-seines with a mesh of 8 mm) are operating from plank-built boats and dugout canoes fitted with outboard motors since mid-1980s in the southern Karnataka and northern Kerala. The operational depth of these gears ranges from 15 to 50 m. The fishing season for whitebaits differs from place to place like October-March in Karnataka, July-December in Kerala, April-December in Tamil Nadu and October-March in Andhra Pradesh. They also exhibit seasonal migration along the west coast moving southwards in April-May and concentrate in the Gulf of Mannar during August-September.

Biology: The whitebaits fishery is supported by fishes of the '0' year class and their mean age is 0.5 year. They also spawn at this age. They are multiple spawners with an extended spawning season starting from November and lasting till July. The distribution of their schools generally coincides with areas of high density of zooplankton, which is their major food item.

Utilization: Most of the whitebaits catch is consumed fresh except in times of glut when surplus is dried and sent to interior markets. A small fraction of fresh fish is used as baits in hooks and line fishery. Improvements in cold storage facilities, introduction of artificial dryers and canning in tomato sauce are some of the ways by which better utilization of anchovies could be ensured.

Management: Whitebaits are annually renewable resources and hence their periodic harvest during seasons of abundance is important to make full use of the fisher. Increasing fishing pressure during peak seasons of availability may be a practical option to enhance whitebaits' production in the country. Being a non-target species in most of the gears (except the *Choodavala* operated by ringseine units), the effort required to obtain the maximum sustainable yield of whitebaits could be decided only in consideration with stock position of the other resources caught in gears. A potential yield of 240,000 tonnes was estimated for whitebaits in the EEZ of India, of which the share of west coast, east coast and Andaman and Nicobar Islands is in the proportion of 69%, 29% and 2%. This indicates scope for a three-fold increase over the present yield of whitebaits.

Golden anchovy

Distribution: The golden anchovy (*Coilia dussumieri*), like Bombay-duck, is an endemic resource in Maharashtra and Gujarat along the north-west coast of India. The species exhibits discontinuous distribution and constitutes a fishery in West Bengal and Odisha along with another species (*C. ramcarti*). It is an important pelagic resource found in association with Bombay-duck and non-penaeid prawns.

Production trends: The golden anchovy (*Coilia dussumieri*) landings ranged from 36,200 tonnes (1990) to 30,795 tonnes (2008) with an average of 34,107 tonnes. Analysis of gear-wise data indicates that prior to 1980 *dol* net was the sole gear that contributed to entire catch. The incursion of trawlers commenced in 1985 in *dol* net zone and since then the contribution of trawl catch is on the increase. During 1986-90 trawl and *dol* contributed 38% and 60%, while during 1996-2000 contribution by the former increased to 70% of the total catch. Time series analysis of the data on the landings of golden anchovy during the last 15 years together with co-existing species like *H. nehereus* and non-penaeid prawns indicated that decline in landings of Bombay-duck coincided with that of *Coilia dussumieri*. However, the landings of non-penaeid prawns showed an increase during the same period.

Management: The management strategies of *C. dussumieri* cannot be considered in isolation. This species is one among the many components exploited by the *dol* net; the other resources being non-penaeid prawns, Bombay-duck, unicorn cod and juvenile pomfrets. In a multi-species fishery, it would be rather difficult to suggest optimum mesh size for each species. However, the resource is currently underexploited and can sustain increased fishing effort.

Indian mackerel

Distribution: The Indian mackerel, *Rastrelliger kanagurta*, distributed widely in the Indo-Pacific region, constitutes the mainstay of the mackerel fishery in this region. In India, *R. kanagurta* is widely distributed along both the coasts, with very high concentrations along the south-west coast. The Indian mackerel, *R. brachysoma*, occurring in Andaman waters contributes very little to fishery, while *R. faughni* was reported to occur very rarely along the south-east coast. Nearly 90% of the world's production of Indian mackerel is contributed by India. About 77% of the annual catch of the Indian mackerel come from the west coast and 23% from the east coast.

Production trends: The annual production of the Indian mackerel is also characterized by wide fluctuations as evident from the catch records of the past 50 years. During the last 20 years, the production ranged from 113,000 tonnes in 1991 to 290,000 tonnes in 1989. The mackerel fishery showed a declining trend from 1999 (0.21 million tonnes in 1999) to 2001 (0.09 million tonnes), and showed improvements during 2007 and 2008, when the catch increased to 0.178 million tonnes and 0. 177 million tonnes respectively.

Means of exploitation: The major fishing craft engaged in mackerel fishery includes motorized and non-motorized catamarans, plank-built boats, dugout canoes, purse-seines and trawlers. The common gears employed include the shore-seines, boat-seines, gillnets, hooks and lines, ringseines, purse-seines and trawls. Along the Malabar upwelling zone from where bulk of the catch is made, the exploitation is largely by large seines. Ring-seines dominate in Kerala and purse-seines in Karnataka-Maharashtra. These gears contribute 62% to the total mackerel catch in India. In other states, these gears are not operated and the dominant gear is gill net. Trawl net is slowly emerging as an important gear in mackerel fishery. Along the Kerala-Maharashtra area, the fishery season starts by August and lasts till December. Along the east coast where gill-nets are the major gear, exploitation starts by December and lasts till May with peak catches in March-April.

Biology: The Indian mackerel feeds primarily on zooplankton at the juvenile stages and mainly on the phytoplankton in adult stages. The most common food items are diatoms, dinoflagellates, copepods, cladocerans, mysids etc. The intensity of feeding is very high in maturing and spent mackerel, but low in spawners.

The size at the first maturity ranges from 184 mm to 225 mm in total length, depending on the locations and annual variations in maturation. The intensity of spawning of mackerel starts by April/May and continues till around July. Surveys by the UNDP/FAO Pelagic Fishery Project found mackerel larvae in great abundance from March to August along the south-west coast. Along the east coast, spawning extends from October-November to April-May. The occurrence of mackerel larvae all along the Indian coast suggests that spawning occurs along the entire coast. The commercial catch depends mainly on 180 to 240 mm size fish and the bulk of it is formed by 0-1 year classes. Success of the fishery in a season depends on the recruitment of 0-year class into the fishery.

Utilization: A good quantity of mackerel is consumed fresh along the coastal and nearby areas. During glut, the surplus catch is salted, sun-dried and sent to interior markets. Export of frozen mackerel to the south-east Asian countries seems possible, considering surplus catches in certain years.

Management: There are no signs of any serious decline in mackerel catches in spite of constant increase in exploitation pressure. The large-scale exploitation of the juveniles along the south-west coast is the key factor, which limits yield from mackerel stock. Fishes below 150 mm form about 42% of the catch from west coast. Increasing the size at first capture from 140 mm to 160 mm by controlling exploitation during the major recruitment period (July-September) or increasing mesh size of the larger seines to minimum of 35 mm can be employed to control growth over-fishing.

Tunas

Tunas, being highly valued food fishes, are targeted by coastal as well as distant-water fishing nations throughout the Indian Ocean with varying intensity of exploitation. Tunas occur in coastal, neritic and oceanic waters and are caught using diverse types of crafts and gears. Tuna fishing and fisheries have become a focal point while addressing issues of development, utilization and management of fisheries in Indian Ocean in the light of EEZ regulations and other international conventions. In India, tuna-fishing is mainly an artisanal activity excepting for a brief phase of chartered and joint venture tuna fishing by long-liners in 1990s. However, tuna catches substantially improved by nearly 107% from 2001 to 2008 compared to early eighties, mainly owing to motorization of traditional crafts, distant water multiday gill-net fishing, monofilament long-lining, targeting oceanic tunas and adoption of progressive and innovative fishing techniques by the mainland fishermen.

Production trends: Tuna production fluctuated between 30,285 tonnes (1987) and 87,100 tonnes (2008) with an annual average production of 46,450 tonnes forming only 2% of the total marine fish production. Of the 8 major species of tunas occurring along the Indian waters, five are coastal and three are oceanic and highly migratory. The tuna fishery in India is limited to small-scale sector with negligible inputs from industrial sector. The commonly occurring coastal tuna species in small-scale fisheries are *Euthynnus affinis* (little tuna), *Auxis thazard* (frigate tuna), *A. rochei* (bullet tuna), *Sarda orientalis* (oriental bonito), *Thunnus tonggol* (long-tail tuna), and the oceanic species *Katsuwonus pelamis* (skipjack tuna), *T. albacares* (yellowfin tuna), *E. affinis* and *A. thazard* constitute the major species along both the coasts and *T.tonggol* and *T. albacares* along the north-west coast.

Since 2000, troll line fishing targeting oceanic tuna has been initiated by deep sea shrimp trawlers of Colachel in Tamil Nadu at 150 to 300 m depths, as a supplementary effort to trawling. Country crafts along the south-west coast were being motorized and fishing activity was extended to deeper and distant waters for multi-day gill netting/ hooks and line and tuna long lining. Of late deep sea trawlers of the region are operating different types of gillnets and hooks and line supplementary to trawling for exploiting large oceanic fishes. Off Visakhapatnam coast, traditional fishermen are operating hooks and line from non-mechanized crafts at depths greater than 250 m for oceanic tunas. Along the north-west coast fishing effort has increased by introduction of FRP canoes and OB fitted plank built boats for targeted fishing of long tail tuna, *T.tonggol*. Trawlers at several centres were also being permanently (south-east coast) or temporarily modified for multi-day gillnetting. Success reports of such efforts by traditional sector in the exploitation of oceanic resources prompted many to venture for promising oceanic tuna fishing. As a result along the mainland coast, at several centres, hundreds of fishing vessels were being modified for multi-day deep sea tuna long lining with Institutional support like financial subsidy and man-power training. Currently 224 such long liners are in operation. These developmental activities increased effort inputs substantially contributing to the tuna production since 2006. During 2007-08, India exported 35, 226 tonnes of tuna and tuna products, earning 53.22 million US $ .The rapid development of tuna fishery in the Indian seas now needs constant monitoring to know the impact of exploitation on the stocks.

Means of exploitation: The drift gill-net is operated all along the Indian coast, the purse-seine in the south-west and the hooks and line off Vizhinjam. The pole and line and troll lines are operated in Lakshadweep Islands.

Biology: The size range of *Euthynnus affinis*, the dominant species in the fishery, is 10-78 cm, *A. thazard* 16-52 cm, *A. rochei* 15-34 cm, *T. tonggol* 30-100 cm, *T. albacares* 50-180 cm and of *K. pelamis* 35-80 cm. The major length groups that support fishery are 30 56 cm, 34-42 cm, 22-26 cm, 46-108 cm and 48-60 cm respectively.

Tunas are carnivores and their major food items include crustaceans (larvae, juveniles and adults especially of shrimp and crabs), cephalopods (juveniles and adults), eggs, larvae and juveniles of fishes, whitebaits and other small pelagics.

Spawning periods of different species have been found to vary considerably. The *Euthynnus affinis* spawns during pre-monsoon (April-May) and post-monsoon (October-November). The spawning period of *A. rochei* was observed during post-monsoon in September-October. A spawning peak during January-April has been observed for skipjack tuna.

Utilization: On an average about 58% of the total tunas landed are iced and marketed for fresh consumption. About 10% of the landings are utilized for maximum production; 25 % are frozen, chilled and exported; 4% utilized for canning and 3% are salt-dried for interior market.

Management: Tunas of oceanic region largely remain under-exploited in the Indian EEZ. Since 1983, the Fishery Survey of India has undertaken long-line surveys to study spatial distribution and abundance of these highly migratory species in Indian EEZ. Among the resources identified, yellowfin tuna constitute major species in all regions. Bigeye tuna is dominant in equatorial region, while skipjack tuna is abundant in the north-western region. Extension of fishing to offshore and oceanic waters through multiday drift gill-netting, pole and lining, purse-seining, long-lining and intensification of troll lining and hand lining may help to augment tuna production from Indian waters.

Seerfishes

Seerfishes are one of the commercially most important pelagic finfish resources of India. The seerfish catch of 50,376 tonnes in 2000, which was just 1.85% of the marine fish production, was valued at ₹ 4.03 billion. Owing to high unit value and economic returns, seerfishes support artisanal fisheries and are a major source of income for gill-net and hooks and line fishermen. Out of the four species the king seer (*Scomberomorus commerson*), the spotted seer (*S. guttatus*), streaked seer (*S. lineolatus*) and the wahoo (*Acanthocybium solandri*), the fishery is sustained by the first two species. During 1985-2003 the all India seerfish catch was constituted by the kingseer (60%), spotted seer (39%) and the rest by streaked seer and wahoo. The king seer was dominant along the mid-eastern (Odisha, Andhra Pradesh), south-eastern (Tamil Nadu), south-western (Kerala) and mid-western (Karnataka, Goa) coasts. The spotted seer is more abundant than king seer along the north-east coast (West Bengal) and the north-west coast (Maharashtra, and Gujarat).

Production trends: The annual seerfish catch during 1990-2008 showed an increasing trend during past five decades with fluctuations ranging from mere 4,505 tonnes in 1953 to an all-time peak of 62,171 tonnes in 2007. Though production increased along both the coasts over the years, the increase along the west coast was remarkable.

Means of exploitation: Among a variety of gears employed for capture of seerfishes, gill-nets are the most popular along the east and west coasts. Presently, trawls are emerging as one of the important gears for juvenile seerfish exploitation. Gill-nets with larger mesh size of 120 to 170 mm have been found very efficient for seerfish exploitation. The gear contributed 65% to total seerfish catch of the country. Hooks and line are also found efficient and highly selective. The seerfishes are also taken along with other fishes by shore-seines, boat-seines, long-lines and surface trolling. Purse-seines along the west coast also land them as incidental catch.

During 1995-99, the production was highest during first quarter in Andhra Pradesh, third quarter in West Bengal, Tamil Nadu and Puducherry and fourth quarter in Odisha. Along the west coast, the fourth quarter was more productive in Kerala, Karnataka and Maharashtra, and fourth and first in Gujarat.

Biology: In kingseer, juveniles (< 17 cm), young fish (< 35 cm) and virgin immature fish (< 71 cm) formed 2.2%, 46.5% and 51.3% of the total estimated numbers of fish caught by all gears along the Indian coast. For spotted seer, juveniles (< 9 cm), young fish (< 18 cm) and virgin immature fish (< 35 cm) accounted for 0.02%, 1.7% and 33.6% respectively.

The length at the first maturity of *Scomberomorus commerson* is 75 cm, and the spawning season extends from January to September during which a weak brood is released during January-February, a strong brood during April-May and another weak brood in July-August. The frequency and time of brood releases is same for *S. guttatus* and *S. lineolatus* also. The *Scomberomorus commerson* is known to be a migratory species. The young ones, which are abundant in the south-west coast from June to September, seem to move to the south-east coast and afford a fishery. Spawning season of *Scomberomorus guttatus* extends from January to August, and January to May is the spawning season for *S. lineolatus*.

The *S. commerson* feeds mainly on teleosts, *S. guttatus* feeds on teleosts, squids and prawns and *S. lineolatus* feeds exclusively on fishes such as sardines, anchovies and silverbellies.

Utilization: Seerfishes are the most sought after table-fish, on a par with pomfrets, and are in great demand all-over the country. They are relished mostly in fresh and to some extent in cured form (salt-dried). Because of their high quality meat value, they fetch high unit value.

Carangids

Carangids occupy a dominant position with a production of 0.173 million tonnes, constituting 6% of the total marine fish production during 2008. There are 54 species of carangids occurring along the Indian coast, but fisheries comprised mainly of horse mackerels, round scads, selar scads, queenfishes, trevallies, leatherjackets and pompanos. Their distribution is confined mostly to shallow coastal waters up to a depth of 80 m. The resource has emerged as one of the important pelagic fish groups especially in mechanized sector.

Means of exploitation: Carangids are extensively exploited by a multitude of gears like trawls, drift gill-nets, bottom-set gill-nets, hooks and line, shore seine, ringseines, purseseine etc. The catamarans, plank-built boats and trawlers are major fishing crafts exploiting carangids.

Trends of production: The landings increased from a meagre 24,560 tonnes in 1969 to a phenomenal 0.197 million tonnes in 1995, but decreased to 0.111 million tonnes in 2000. The average annual production of carangids from 1990 to 2008 was 0.155 million tonnes of which scads alone constituted 55,163 tonnes (36%) followed by horse mackerel (23,808 tonnes; (14%). Many species support carangid fishery, and the species composition in the catch depends on the selective properties of the gears employed. The non-selective trawls exploit scads, viz. *Decapterus russelli, D. macrosoma, Selar crumenophthalmus, Megalaspis cordyla*, and trevally *Caranx para, C. carangus, Selaroides leptolepis*. The peak season for scads along the Kerala coast is August to October, corresponding with monsoon and post -monsoon.

Biology: The carangids are carnivores, feeding predominantly on fishes and crustaceans. The *Megalaspis cordyla* feeds mainly on clupeids and crustaceans. The young ones measuring about 8 cm in length feed on post-larval fish, juvenile prawns and other crustaceans. The *Decapterus russelli* feed on clupeids, diatoms, copepods and other crustaceans. The juveniles of 4 cm to 12 cm size feed on *Acetes*, copepods and other crustaceans.

The *Megalaspis cordyla* size at first maturity is 250 mm. The spawning is prolonged, resulting in recruitment almost round the year. In the east coast, peak spawning occurs from March to May, followed by peak recruitment from April to May. In the north-west and the south-west coasts, recruitment takes place in two different peaks. In the north-west coast, there is a minor recruitment in October and a major one in January, whereas in the south-west coast, the minor recruitment occurs in April and the major in July. The spawning peak was found around July in the north-west coast, while along the south-west coast, the peak was in January.

Utilization: The carangids are high quality table-fish in great demand and marketed mostly in fresh or iced condition because of the quick transportation facilities that exist in most places between production and consuming centres. During peak landings, surplus catch is deep-frozen and stored for lean season, which ensures steady price and supplies. Larger species, viz. *C. malabaricus, C. melampygus, C. ignobilis, Atule mate*, and *Alepes djedaba*, are being exported in frozen form.

Ribbonfishes

The ribbonfishes, also known as hair-tail or cutlass are widely distributed along the Indian coast and form major pelagic fishery resources of Indian seas.

Production trends: The ribbonfish landings showed an increasing trend with considerable annual fluctuations. From 1990 to 2008 (Table 3.6), landings fluctuated between 73,570 tonnes in 1995 and 235,045 tonnes in 2006 with an average landing of 134,304 tonnes. The trend showed a 5- to 8-

Table 3.6. The average annual landings of ribbonfishes in different decades with percentage of growth rate

Periods	Average landings (tonnes)	Percentage growth
1956-60	30,741	-
1961-70	28,171	-8.4
1971-80	57,147	102.9
1981-90	65,360	14.4
1991-2000	120,461	84.3
2001-08	158,407	31.5

year cycle in the landings. Ribbonfishes formed 3.3 to 8.7% (in 1995 and 2006 respectively) of the total fish landings and 6.9 to 15.8% (in 1995 and 2006 respectively) of total pelagic fish landings. On an average it formed 5.4% of the total fish landings and 10.6% of the pelagic landings.

The *Trichurus lepturus* is the dominant species among ribbonfishes and supports fishery all along the Indian coast. It forms more than 95% of the total ribbonfish landings. Other species in catches are: *T. russelli, Lepturacanthus savala, L. gangeticus, Eupleurogrammus muticus* and *E. glossodon*. The ribbonfishes are exploited all along the coast and bulk of the landings is from Gujarat and Maharashtra followed by Kerala, Tamil Nadu and Andhra Pradesh.

Means of exploitation: The fleets employed in ribbonfish fishery include trawlers, motorized and non-motorized catamarans, plank-built boats and dugout canoes while the principal gears include trawls, boat-seines, *dol* nets, shore-seines, hooks and line and gill-nets. Among the major gears, trawls contributed 70% (68,051 tonnes), the bag nets (including the *dol* nets of the north-west coast) 7%, gill-nets 3% and purse-seines 2.2% to the all India ribbonfish landings.

Biology: The ribbonfishes are carnivores, feeding predominantly on fishes and to a smaller extent on shrimps and other items. While young ribbonfishes feed on smaller fishes and shrimps, adults prey upon much larger items. Huge shoals of ribbonfishes are commonly noticed in coastal areas, chasing sardines, anchovies and scads.

The ribbonfishes (*T. lepturus, L. savala, E. glossodon* and *E. muticus*) spawn more than once a year. Three batches of ova (immature, maturing and mature) are found in ovaries. The maturing and mature groups of ova are so sharply differentiated in mature ovaries of all species that their spawning seems to take place at short intervals of time in quick succession.

Utilization: Nearly 64% of the ribbonfish landed annually in India are exported in frozen form to China, Japan and other South-East Asian countries. Only undamaged fresh fish are considered for export. They are graded size-wise and are frozen intact without removing the gut or fins. The local people consume large-size fresh fish while under-sized are sun-dried.

Bombay duck

The Bombayduck (*Harpadon nehereus*), which inhabit waters up to 50 to 70 m isobath, forms a major single species fishery along the north-west coast from Ratnagiri in Maharashtra to Gulf of Kachchh in Saurashtra coast. It forms a seasonal fishery along the coasts of West Bengal, Odisha and northern part of Andhra Pradesh.The Bombay-duck is inconspicuous or totally absent in the south-west and south-east coasts.

Production trends: As in oil sardine and Indian mackerel, the Bombay-duck along the north-west coast also exhibits wide annual fluctuations in production. The landings contribute about 5% of the all India marine fish landings. Annual Bombay-duck production ranged from 67,392 tonnes in 1988 to 136,442 tonnes in 1991. The average annual catch of Bombay-duck was estimated at 105,087 tonnes by traditional and mechanized sector (trawlers) along the north-west (88%) and north-east (12%) coasts of India. The annual catchable potential yield along the north-east coast is estimated as 0.116 million tonnes. During 2005 catch from West Bengal (36,024 tonnes) has surpassed the catch from traditional Maharashtra coast (22,508 tonnes). In 2008, Gujarat contributed 46% (48,688 tonnes) of the total Bombay-duck landings followed by West Bengal (27,936 tonnes) and Maharashtra (24,038 tonnes). Though *Harpadon nehereus* was the sole contributor along the north-east coast, another species, *H. squamosus* (195-214 mm, recorded at Kakinada) accounted for 56% of Bombay-duck landings at Kakinada. The fishing season shows two distinct phases of productivity: (*i*) September to January, which is more productive, with predominance of adults over juveniles, and (*ii*) February to March, which is less productive, with juveniles forming a major part of the catch.

Means of exploitation: Fishing for Bombay-duck is traditionally carried out by a stationary bag net called *dol* net along Maharashtra and Gujarat coasts. It is a traditional labour-intensive stationary bagnet, made of synthetic filaments, highly specialized in design, working entirely by the forces of tide. Gill-nets, boat-seines and trawls are also employed in this fishery.

Utilization: Bombay-duck is very soft fish of low quality, is highly perishable because of high water content, and hence requires to be disposed quickly for fresh consumption. The bulk of the catch is sun-dried and sold in the interior markets while a small portion is converted into manure. Laminated Bombay-duck are in good demand in some foreign markets.

Management: In the past Bombay-duck stock had been exploited with a mix of success and failure. Large-scale landings of indeterminate and immature fish have been a source of concern since long. The only possible method by which age or size at first capture can be adjusted is by regulating the mesh size at appropriate size. The *dol* net fishery is multi-species. The optimum mesh size for each species or group is different. Therefore, it is not easy to evolve a new single optimum mesh size. The mesh size currently under operation with seasonal shifts appears to be most appropriate for maximization of yield. The National Bureau of Fish Genetic Resources (NBFGR) has reported that the stocks of Bombay-duck from north-east and north-west coasts of India are genetically distinct based on morpho-meristic and molecular genetic markers. This points out the need for separate management strategies for the stocks from both the coasts.

Pomfrets

Pomfrets, belonging to the family Stromateidae, enjoy wide distribution in depth up to 150 m. They are highly relished table-fishes in internal and export markets and command high unit value. The annual average catch of 38,000 tonnes forming about 1.4% of all-India marine-fish landings, comprises silver pomfret (*Pampus argenteus*) and Chinese pomfret (*Pampus chinensis*). Most of their production is from Gujarat and Maharashtra in the north-west and Odisha in the north-east coasts. The principal gear exploiting adult pomfrets are drift gillnet of 140 to 155 mm mesh size while the *dol* net exploits essentially juveniles in the north-west coast. The maximum sustainable yield of the silver pomfret (*Pampus argenteus*) in Indian waters has been estimated at 38,194 tonnes. As fishery had collapsed in the north-west coast during the 1990s, restriction of *dol* net operations to minimize recruitment overfishing and regulation of gillnets to minimize growth overfishing have been prescribed as management measures.

Shads

The hilsa shad [*Hilsa (Tenualosa) ilisha*] forms a prominent fishery in the north east coast. They are known to spend most of their life in the inshore areas and migrate into estuaries and rivers for breeding. From 1999 to 2008, the annual catch of shad increased from 19,456 tonnes in 1999 to 59,864 tonnes in 2008 with an average production of 40,810 tonnes. The *H. ilisha* alone contributed 82% (average: 33,307 tonnes). The gill-netters contributed the bulk of the shad catches in the north-east coast. The bulk of the fishery is constituted by fish in the size range of 260 mm to 480 mm. The shads other than hilsa shad form fisheries in all regions, particularly in the south-east and north-west regions.

Barracudas

Barracudas, otherwise known as sea-pikes of family Sphyraenidae, are important food and sport fishes of the tropical and subtropical waters, which are caught in sizable quantities along the Indian coast. Though they form shoals, the larger ones prefer to be solitary. The annual catch improved remarkably from a meagre 4,000 tonnes in 1986 to 21,049 tonnes in 2008. The *Sphyraena obtusata, S. barracuda, S. jello* and *S. forsteri* constitute the barracuda fishery in India, though more number of species occur in Indian waters. The larger fishes were caught in hooks and line, bottom-set gill-nets and drift gill-nets, while the smaller ones are caught in trawls in fairly good quantities. The barracudas are top predators, feeding voraciously on other pelagic fishes.

Flying fishes

The flying fish fishery is limited to Coromandel coast in Tamil Nadu. The average annual catch of flying fish was 2,749 tonnes during 1990-2008. The seasonal fishery is supported mainly by the *Hirundichthys coromandelensis*. The annual catches are taken almost exclusively by scoop nets, and fluctuate considerably from year-to-year, contributing only about 0.1% to the total all-India landings.

Other clupeids

Among the other clupeids, the wolf-herring (*Chirocentrus dorab*) forms a fishery, and contributes about 0.7% to total all-India landings (20,688 tonnes during 2008) of which about 45% comes from north-east coast. Clupeids consisting of species of *Dussumiera, Escualosa, Ilisha, Nematalosa, Opisthopterus, Pellona, Reconda, Dorosoma* and *Chanos* together accounted for an annual average of 49,248 tonnes during 1990-2008; 1.8 % of the total all-India landings.

Mullets

Among the other pelagics, the mullets (*Mugil cephalus, Liza parsia, L. tade, L. macrolepis*, and *Valamugil seheli*) form a fishery mainly in the north-west region, which contributed an annual average of 5,168 tonnes during 1999-2008.

Unicorn cod

The landings of unicorn cod (*Bregmoceros mclellandi*) is restricted to Maharashtra coast. The landings decreased from 6,880 tonnes from 1950 to 834 tonnes in 2008.

Common features of pelagic fisheries

From foregoing account, it is evident that the pelagic fisheries of India are characterized by: (*i*) dominance of Indian oil sardine, Indian mackerel and Bombay-duck; (*ii*) highly fluctuating nature of their fisheries; (*iii*) area-specific distribution of dominant species; (*iv*) crucial role of environment; and (*v*) unique biological characteristics. Interactions among these vital features determine abundance of pelagics.

Dominance of three species: Though over 200 species of pelagics occur along the Indian coast, only 3 species, the oil sardine (*S. longiceps*), the Indian mackerel (*R. kanagurta*) and the Bombay-duck (*H. nehereus*) play a very dominant role, not only in the pelagic fisheries, but also in the entire Indian marine fisheries. These three species together form 25% (682,239 tonnes) of the total marine fish landings (2004 to 2008). Adverse effects of any fishery dependent or independent factors on any of these 3 species would seriously affect the landings of pelagics, which are, therefore, highly vulnerable and subject to fluctuations.

Highly fluctuating fisheries: The landing pattern of pelagics could be categorized as: (*i*) fisheries which have fluctuated very widely (oil sardine, Bombay-duck and Indian mackerel); (*ii*) fisheries which have increased landings fairly consistently (lesser sardines, *Hilsa* spp., whitebaits, *Thryssa* spp. *Coilia dussumieri*, carangids and ribbonfishes); and (*iii*) the only fishery which has declined (unicorn cod). The landings of unicorn cod (*Bregmaceros mclellandi*), which are restricted to the Maharashtra coast, decreased from 6,880 tonnes in 1950 to 834 tonnes in 2008. In view of the consistently declining fishery, the unicorn cod may have to be listed as vulnerable, and strategies need to be devised to restore its population.

Area-specific distribution of the dominant species: Another important characteristic of pelagics is the area-specific abundance of dominant species. The fisheries for oil sardine, Bombay-duck, flyingfishes and unicorn cod are restricted to coastal waters of a single geographic zone, i.e. oil sardine to south-west coast between 8°N and 16°N latitudes (92.6% of the total oil sardine landings) and the Bombay-duck to the north-west coast between 18°N and 22°N latitudes (90% of the Bombay-duck landings), and their abundance in the other coastal zones is quite meagre. Four groups/species (Indian mackerel, lesser sardines and whitebaits in the southwest and south-east coasts; and the grenadier anchovy in the north-west and north-east coasts) form fisheries in two zones. The remaining groups exhibit much wider range and form fisheries in all the zones.

A full understanding of reasons why the distribution and abundance of a few species are restricted to certain well-defined sea areas is yet to emerge. Differences in temperature, salinity and food regimes are thought to be important factors. However, thermal and salinity profiles in the coastal areas of the northern and southern latitudes are not different from each other. Though these factors may be important, these do not appear to be the basic factors that bind Bombay-duck to the northern latitudes. High tidal amplitudes of about 5 m are characteristic of the northern latitudes. Neither strictly pelagic nor demersal, the Bombay-duck effectively utilizes tidal oscillations for less energy demanding movement for foraging on the sergestid shrimps and the grenadier anchovy, which are also associated with the tidal oscillations. The reasons for abundance of the oil sardine and mackerel populations in the south-west coast are vivid. Regular upwelling along the south-west coast leads to dense plankton blooms. Being plankton feeders, the oil sardine and mackerel, which form large shoals and require huge quantities of food, find the southwest coast as an ideal location to forage.

An inverse relationship between the abundance of the oil sardine and mackerel has often been reported along the south-west coast. The periods of maximum landings of the oil sardine (e.g. 1998-2008: average annual yield = 354,987 tonnes) were periods of least abundance of the mackerel (1998-2008: average annual yield = 143,414 tonnes). As both the species are harvested by the same gears, the decade variations may not be due to the effect of fishing effort expended.

Role of the environment: Several environmental parameters are considered to be the determinants of abundance of oil sardine and mackerel. The onset and intensity of monsoon, sunspot activity, surface temperature, and variations in the pattern of coastal currents, sudden increase in salinity, dissolved oxygen, sinking of offshore waters, sea level, and availability of nutrients in coastal waters are some of the causative factors believed to play crucial roles in determining abundance of oil sardine along the south-west coast.

Unique biological characteristics: Though represented by different taxonomic families, pelagics, as a group, are characterized by certain unique combination of biological features which include formation of large schools, feeding on plankton or nekton, fast growth rate, short longevity and late maturation in relation to $L\infty$ (at about 70% of $L\infty$). Most species of pelagics are either continuous spawners or have prolonged spawning periods with high fecundity. The pelagics such as sardines, whitebaits and mackerel feed mainly on plankton. Occupying a low trophic level, these groups are advantageously placed to get continuous food supply. The exploitation of pelagic resources has reached optimum/near optimum level and hence constant monitoring fisheries and evolving suitable management measures, preferably with a participatory approach is warranted.

Research priorities in the management of pelagic fisheries

Impact of environment on pelagic fisheries: Year after year, the success of pelagic fisheries is a delicate balance between physical oceanographic factors and effects of fishing on stock. Numerous studies conducted so far have confirmed that seawater temperature, dissolved oxygen levels, salinity, phytoplankton and zooplankton concentrations play a vital role in controlling the distribution and abundance of pelagic fishery resources. Thus fishery environment data have become crucial to addressing productivity of fishing grounds, annual/long-term fluctuations in fish catches and making fishery forecasts. Today, parameters like Sea Surface Temperature (SST) and phytoplankton pigments (Chlorophyll *a*) using satellites are available from agencies like the Indian National Centre for Ocean Information Services (INCOIS) and are used in prediction of Potential Fishing Zones (PFZ). Dissemination of information of PFZ's among the fishermen in Kerala and Lakshadweep had been facilitated by the Central Marine Fisheries Research Institute (CMFRI), Kochi, for locating fish shoals and feedback received indicated considerable reduction in cost of fishing by saving time and fuel. This technology requires further strengthening through refinement and validation. Creation of maps indicating spatial and temporal distribution patterns of pelagic fishes and their prediction on a Geographical Information System (GIS) platform is another potentially powerful technology that can be developed.

Fish migration behaviour: Most of the pelagic finfish species move in large shoals and exhibit certain characteristic migratory patterns. Small pelagics like sardines and anchovies perform migrations along the coast and mackerels, scads and coastal tunas migrate fairly long distances between inshore and offshore waters. Oceanic tunas undertake even longer migrations (transoceanic) and stocks are frequently shared by many countries. Therefore understanding migratory patterns of pelagics, especially highly valued large pelagics like tunas is crucial for planning a successful fishery and its management. Tagging and recovery is the best way to study migration and growth of pelagic fishes, and sophisticated acoustic and telemetric tags have been developed to allow continuous observation of movement of a single fish. Tagging studies for small pelagics like oil sardine and mackerel have been conducted in Indian waters.

Development of predictive models: Reliable estimation of stock size is required to formulate any fisheries management policy, but pelagic fish stocks are known for their unpredictable catch fluctuations. Pelagic fish stock estimation using classical models have many limitations as these fishes have highly variable recruitment pattern and complex environmental – biological interactions. Therefore appropriate new stock assessment models using time series data on phytoplankton, zooplankton, fish catches, hydrography and climate data that will bridge the interface between physics and biology will have to be developed. Our scientists have made attempts to understand dynamics of these fisheries through mathematical modeling of fishery dependent and independent factors. Predictions for oil sardine fishery along the Indian coast based on sunspot activity, rainfall intensity, sea level change and duration and upwelling indices have proved successful and could be attempted for other pelagic species also.

Resource conservation

Many of the world's greatest fisheries particularly for pelagics like sardines have collapsed due to recruitment failures caused by high fishing pressure on the spawning stock. Hence, there is a need to study stock-recruitment relationship. However, such studies are complicated due to the fact that there is significant influence of environment in determining recruitment success of pelagic species every year. Hence, it is imperative that a precautionary approach whereby spawners are protected and allowed to replenish population is in place. Most of the pelagic species move in large shoals and exhibit certain characteristic migratory pattern to inshore, offshore or deeper areas for the purpose of feeding or breeding. In course of such migration, large schools enter coastal waters and constitute seasonal fishery along the coastal belt. Towards the close of the season a part of the stock that escapes from heavy fishing probably migrate away from the fishing ground to offshore or deeper areas and thus becomes unavailable in traditional fishing grounds resulting in an off-season for fishery. This emigrant part forms the broodstock that contributes to new recruits to the coastal fishery in the subsequent years. Any attempt to exploit these broodstocks from their protected areas, under the disguise of increasing production from the offshore may hamper inshore fishery in longrun. Therefore conservation of these broodstocks is essential for a sustainable yield from inshore areas. Fishing-vessel-based stripping of ripe spawners of oil sardine and mackerel captured in nets and releasing eggs in the fishing grounds has been tried on an experimental scale. Such programmes in addition to existing restrictions on fishing for spawners and in spawning grounds will have to be strengthened. Fishing by ringseine and purseseine causes over-fishing to stocks of oil sardine and mackerel, which cause huge economic losses, especially during monsoon, when young recruits enter the coastal waters. The mesh size of ringseine and purseseine is normally 14 to 18 mm and at times as small as 8 mm. Though the 8 mm meshed net is meant for fishing whitebaits, young recruits of sardine and mackerel measuring 50 to 80 mm are also caught in large quantities. This negatively affects these fisheries in the subsequent years, as these stocks are not allowed to grow, mature and reproduce. Similar is the case with the *dol* net where the mesh size is small (10 to 50 mm) and is employed in Bombay-duck fishery along the Maharashtra and Gujarat coast causing large-scale growth over-fishing of the stock. So mesh size regulation with respect of ringseine, purseseine and *dol* net is inevitable, and the minimum size should be fixed as 20 mm. Fishery with 8 mm meshed ringseine should be restricted solely to exploit whitebaits (*Stolephorus* spp.) and not for any other pelagic fish stocks. Further proliferation of ringseiners needs to be checked urgently. It is therefore vital to make periodic assessments of the pelagic stocks, fishing practices adopted and juvenile and spawner's components of catches. Based on this, need-based management measures can be formulated either as input controls (restriction of fleet size, mesh size, closed season) or output control (restriction on fishery for certain species, size of fish caught, etc.). Awareness creation among all stakeholders against non-sustainable fishing practices with a participatory management approach has become inevitable in fisheries management.

Though a progressive trend is noticed in production of most of the pelagics, many of them, especially oil sardine, mackerel, Bombay-duck, seerfishes, ribbonfishes and coastal tunas have reached optimum level of exploitation in conventional fishing ground. The stock assessment studies conducted for 19 species of exploited pelagic finfishes have shown that the present effort expended is close to or in some cases has even exceeded the level of maximum sustainable yield and further increase in effort in the coastal sector would be detrimental to sustain yield. Under these circumstances, it is imperative to evolve suitable management measures for judicious exploitation so as to ensure a long-term sustainable yield from the 0-50/100 m depth zone. The groups, which are expected to contribute significantly to additional yield from beyond conventional belt, where the rate of exploitation is limited at present, are whitebaits, carangids, ribbonfishes, oceanic tunas and pelagic sharks. The options available for exploitation of these potential resources from the 50 to 200 m depth zone are extension of operational range of crafts, introduction of combination vessels (drift gillnetting and long-lining) for multiday target fishing, widespread employment of light-luring purse-seiners, conversion of trawlers for offshore drift gill-net and tuna longline fishery, providing chilling and cold storage facility on-board of the vessel and development of suitable post-harvest and value-addition technologies for utilizing the products for domestic as well as export markets. The use of high-opening fish trawls beyond traditional grounds indicates good scope of enhancing production of carangids and ribbonfishes. Besides the above groups, the deeper areas of the oceans contain non-conventional mesopelagic resources, such as file fishes and lantern fishes that can be converted into fish-meal. According to a recent observation, the mesopelagic fish fauna in the Arabian Sea is dominated by myctophid fishes. Among them, one species *Benthosema pterotum* is arguably the largest single species population of fish in the world, with stock estimates ranging up to 100 million tonnes/year. Similar populations, but of lesser magnitude, may be available in the Bay of Bengal also. Economically viable technologies could be developed for their commercial exploitation, handling, processing and utilization. However, the fishing activities in the offshore and in the high seas are at present limited since such activities are capital-intensive and require offshore fishing vessels (long-liners, purse-seiners and mid-water trawlers), infrastructures, shore facilities, expertise and skilled manpower. Development of the above facilities for offshore fishing operations, coupled with value-added product development, marketing and export would provide the necessary impetus for further development of pelagic fisheries in the country.

4. Demersal Fisheries

Demersal finfishes are one of the major components in the marine fish landings along the Indian coast. Demersal fish groups such as the sharks, groupers, snappers, threadfins, pomfrets and Indian halibut are commercially valuable and contribute substantially to the economy of Indian marine fisheries. Some of these groups, especially of large size, are targeted by the fishermen by employing different craft and gear combinations. However, several other demersal finfishes are not targeted, but are landed as by-catch by shrimp trawlers. Compared with the pelagics, the demersal finfishes are less affected by the changes in the environment, such as changes in temperature, speed and direction of currents. Hence, the biological characteristics of the demersals are relatively stable. Consequent upon the increase in the number and efficiency of trawlers, the demersal landings have increased in the last 40 years. However, indiscriminate trawling in the last one decade has affected the bottom habitat and the demersal resources as well. Now there are evidences of decline in the stocks of few demersal groups and shift in the composition of the landings.

Demersal finfish

Based on their vertical distribution, fishes are broadly classified as pelagic or demersal. Those species that are distributed from the seafloor to 5 m depth above, are demersal and those distributed from a depth of 5 m above the seafloor to the sea surface, are called pelagic. However, frequent movements of pelagic and demersal populations take place through the entire water column across various vertical hydrographic boundaries. In inshore fishing below 50 m depth, occurrence of pelagics like the mackerel, carangids, ribbonfishes and seerfishes in bottom trawls and demersals like the catfishes, perches and penaeid prawns in purse-seines in commercial quantities is quite common. The trawl landings along the Indian coast generally consist of 76% demersal groups, which include demersal finfish (38%) and invertebrates (38%). The remaining 24% are pelagic and column-water fishes. Vertical migration of fish populations takes place on account of feeding, shelter, spawning, and differential behaviour to light or hydrographic limitations. In general, most pelagic fishes rise to the surface waters before sunset and sink into deeper layers by sunrise. Demersal fishes also exhibit vertical migration, resulting in diurnal differences in the habitat. Comparison of bottom trawl catches off Chennai by day and night fishing showed a marked variation with day : night catch rate ratio of 1 : 10, 1 : 7.5, 1 : 7 and 1 : 5 in respect of catfishes, rays, eels and flatfishes, respectively, i.e. these groups spend the night in the bottom and disperse in the water column during day. On the other hand, the day : night catch rate ratio was 1 : 0.8, 1 : 0.5 and 1 : 0.3 in respect of the squids, carangids and perches, i.e. these groups spend the day in the bottom and disperse in the water column during night. Besides the diurnal vertical migration, many species

undertake seasonal vertical migration for spawning. The presence of larvae and post-larvae of the pelagic fish, the Indian mackerel in the depth zone of 30 to 80 m in the south-west coast, which inferred that the fish migrate to the deeper shelf waters for spawning. Hence, many groups of fish are benthopelagic with considerable overlap in their depth distribution. Nevertheless, depending on their dominance in the landings of pelagic or demersal gear, it is possible to identify the major habitats where fishes spend most of their life.

Landings

The demersal finfish landings increased by four times from an annual average of 174,356 tonnes from 1961 to 1965 (pre-trawl period) to 784,524 tonnes during 2007-08 (trawl-dominant period) along the Indian coast (Table 4.1).

Table 4.1. Annual average landings along the Indian coast during 2007-08

Category	Landings (million tonnes)	%
Pelagic finfish	1.65	54.8
Demersal finfish	0.78	25.9
Shellfish	0.58	19.3
Total	3.01	100.0

However, the contribution of demersals to the total marine landings, which was 31.8% during 1974-88, decreased to 25.9% during 2007-08. Among the four coastal regions, the landings was maximum (265,169 tonnes; 33.8% of demersal landings along the Indian coast) along the north-west coast (Gujarat and Maharashtra) during 2007-08 (Table 4.2). However, the catch/km^2 was maximum (3.5 tonnes) along the north-east coast (West Bengal and Odisha) which is 2-fold higher than that of average catch from the entire continental shelf of the Indian mainland.

Table 4.2. Annual average demersal finfish catch (tonnes) along the four regions during 2007-08

Regions	Continental shelf area ('000 km^2)	Catch (tonnes)	Catch (tonnes/km^2)	% of all India demersal catch
North-east	41	145,137	3.5	18.5
South-east	73	180,440	2.5	23.0
South-west	75	193,777	2.6	24.7
North-west	276	265,169	1.0	33.8
Total Indian mainland	465	784,523	1.7	100.0

Several factors contribute to the differences in the catches between the coastal regions. The benthic biomass is one of the most valid parameters for estimating the productivity of demersal fishery resources. Compared to the studies on the correlation between phytoplankton, zooplankton and tertiary production, information pertaining to benthic standing crop as an indicator of the potential fishery resources is limited. Based on the benthic biomass, it has been estimated that the potential demersal fishery yield in the continental shelf as 1.20 million tonnes, which is lower than the exploited catch of 1.34 million tonnes (including demersal finfish and shellfish) between 2007 and 2008.

Major demersal fish groups

The demersal fisheries exploited 21 major fish groups of different biological characteristics occupying a variety of ecological niche. The fishery included viviparous, slow-growing sharks, rays and guitarfish, crevice-dwelling eels, mouth-brooding catfish, protogynous groupers, reef-associated other perches, near-shore sciaenids and mullets, and flatheads and soles, which bury themselves inches below the bottom. All these groups are intensively exploited by employing different craft and gear combinations. The contribution of each species/group to the demersal landings along the four coastal regions during 2007-08 is given in Table 4.3. Of the 22 species/groups, sciaenids contributed maximum (21.1%) to the demersal landings along the Indian coast, followed by threadfin breams (15.4%). Each region is characterized by dominance of specific demersal fish groups. Whereas the north-east coast is characterized by the dominance of sciaenids, catfish and pomfrets (together contributing 67.9% to the demersal landings), the south-east coast is characterized by the dominance of silverbellies and sciaenids, the south-west coast by the threadfin breams, lizardfishes and soles, and the north-west coast by the sciaenids, catfishes and threadfin breams.

Table 4.3. Major demersal finfish groups and their contribution (%) to the demersal landings of the respective coast during 2007-08

Groups	North-east	South-east	South-west	North-west	India
Sharks	3.9	1.8	1.6	4.0	2.9
Skates	0.4	0.4	0.2	0.6	0.4
Rays	1.7	6.1	0.7	0.9	2.2
Eels	2.3	1.3	0.3	1.4	1.3
Catfishes	18.0	5.7	2.8	16.4	10.9
Lizard-fishes	2.0	6.1	13.7	3.5	6.4
Groupers	0.1	1.4	5.0	2.4	2.4
Snappers	0.4	2.7	1.2	0.2	1.0
Pigface breams	0.0	5.7	0.2	0.2	1.4
Threadfin breams	1.8	4.8	34.9	15.8	15.4
Other perches	3.5	10.0	11.6	12.9	10.2
Goatfish	5.2	7.0	0.0	0.3	2.7
Threadfins	2.4	0.8	0.0	1.6	1.2
Sciaenids	34.9	9.7	7.9	31.0	21.1
Silverbellies	3.0	28.3	5.6	0.1	8.5
Whitefish	1.5	0.3	2.3	0.4	1.0
Black pomfret	5.4	2.1	1.5	1.3	2.3
Silver pomfret	7.6	2.7	0.6	3.6	3.4
Chinese pomfret	2.0	0.2	0.0	0.2	0.5
Halibut	0.0	0.3	0.0	0.1	0.1
Flounders	0.0	0.1	0.0	0.0	0.0
Soles	3.8	2.4	9.8	2.8	4.6

Analysis of data on the landings pertaining to a time series of 48 years from 1960 to 2008, revealed that the landings of a few groups along the Indian coast have declined whereas those of others have increased. After the introduction of bottom trawlers in the mid-1960s, the landings of three demersal groups increased substantially. The landings of lizardfishes (*Saurida* spp.) increased from a mere 900 tonnes in 1960 to 52,439 tonnes in 2008, major perches (groupers, snappers and pigface breams) from 9,000 tonnes to 39,919 tonnes, and threadfin breams from 38,571 tonnes in 1985 to 126,943 tonnes in 2008. Consequently, the contribution of these three groups to the total demersal landings increased. For instance, the contribution of lizardfishes to the demersal landings increased from 0.6% in 1961 to 6.4% in 2008. On the other hand, the landings of four groups, namely the elasmobranchs, catfishes, silverbellies and whitefish, did not increase, and their contribution to the total demersal landings decreased. For instance, the contribution of elasmobranchs to the demersal landings decreased from 20.6% in 1961 to 5.5% in 2008. Though the contribution of other groups to the demersal landings remained stable, a clear shift in the composition of the landings is evident during the 48 years. Within the demersals, the pooled contribution of elasmobranchs, catfishes, silverbellies and whitefish to the demersal finfish landings decreased considerably from 47.6% during 1961-65 to 25.9% during 2007-08. On the other hand, the percentage contribution of lizardfishes, major perches and threadfin breams increased from 10.3 to 36.8% during the same period. Considering the landings as an index of abundance, it could be inferred that fishing has inflicted changes in the composition of demersal fish populations. The shift could be attributed to the increase in trawling intensity, changes in the exploitation pattern (such as introduction and increase in the number of multiday trawlers, extension of trawling grounds and introduction of high opening trawlnets etc), and biological vulnerability or adaptability of fish to fishing.

Species richness and characteristics of a few demersal fish groups

Sharks

Species diversity: Sharks and their relatives, called elasmobranchs, are characterized by having skeletons composed entirely of cartilage. These fishes have been around for a very long time, more than 400 million years. Of the 48 species of sharks known from the Indian waters, 23 do not form fishery, 19 contribute minor fisheries and only 6 species contribute major fisheries. The Order Carchariniformes is represented by 33 species and the remaining 115 species represent 4 taxonomic orders (Table 4.4). It is believed that, in addition to the 48 species, a number of deep-water species may exist in the Indian waters without proper record on occurrence.

Distribution: Sharks are primarily marine organisms, but a number of species enter bays, lagoons and estuaries. A few species, viz. *Carcharhinus leucas* and *Glyphis gangeticus*, migrate far up into the rivers and freshwater lakes which have connections to the sea. In the sea, a few are pelagic (e.g. *Sphyrna lewini* and *S. mokkaran*), a few others are epipelagic (e.g. *Carcharhinus longimannus* and *Alopias vulpinus*) and the rest are demersal (e.g. *Scoliodon laticaudus* and *Chiloscyllium griseum*). There are also species which are known to occur in waters up to 1,000 m depth (e.g. *Echinorhinus brucus* and *Iago omanensis*).

Table 4.4. Number of shark species occurring in the Indian waters

Order	Family	Common name	Occurrence	
			Genus	Species
Hexanchiformes	Hexanidae	Cowsharks	1	1
Squaliformes	Echinorhinidae	Bramble sharks	1	1
	Squalidae	Dogfish sharks	1	2
Orectolobiformes	Hemiscyllidae	Bamboo sharks	1	4
	Stegostomatidae	Zebra shark	1	1
	Ginglymostomatidae	Nurse sharks	1	1
	Rhiniodontidae	Whale shark	1	1
Laminiformes	Alopidae	Thresher sharks	1	3
	Laminidae	Mackerel shark	1	1
Carcharhiniformes	Scyliorhinidae	Catsharks	2	3
	Proscyllidae	Finback catsharks	1	1
	Leptocharidae	Barbeled hounds	2	2
	Triakidae	Hound sharks	1	1
	Hemigaleidae	Weasel sharks	2	2
	Carcharhinidae	Requiem sharks	9	20
	Sphyrnidae	Hammerheaded sharks	2	4
Total			28	48

Source: Compagno L J V (1984). *Sharks of the world.* FAO Fish. Synop. 125, 653 pp.Froese R and Pauly D (2001). FishBase. www.fishbase.org.Raje S G *et al.* (2007). *An Atlas on the Elasmobranch Fishery Resources of India.* CMFRI Special Publications **95**: 253 pp.

Life pattern: The sharks, in essence, have evolved a life-history strategy very similar to that of the marine reptiles and mammals. The life of sharks is characterized by slow growth during the adult phase, late reproduction and the production of a few but well developed young ones. This pattern is quite different from the one found in the teleosts. Unlike most other fish, all elasmobranches copulate and have internal fertilization.

Different species of sharks exhibit very large variations in their life, which is larger than those observed among the teleosts. A few of the variations in the life patterns among the different shark species are outlined here: (*i*) The size difference is very large. One of the smallest sharks, *Eridacnis radcliffei* reaches a maximum length of only 24 cm. The largest shark, the whale shark *Rhincodon typus*, which is by far the largest fish in the world, reaches 1,400 cm. The largest shark is thus nearly 60 times longer that the smallest. However, most of the sharks are near the small end of the spectrum. Of the 48 species occurring in the Indian waters, 16 attain maximum length ranging between 24 and 100 cm, 13 attain 101 to 200 cm, 6 attain 201 to 300 cm, 9 attain 301 to 400 cm, 3 attain 501 to 600 cm and one species attains the maximum length of 1,400 cm. The maximum length of 6 species that contribute major fisheries along the Indian coast range from 60 to 309 cm; (*ii*) females of several species of sharks grow to a larger size than the males; (*iii*) there is great variation in the reproductive pattern among the sharks. Among the sharks occurring in the Indian waters, 34 species are viviparous, 8 are ovoviviparous and 6 are oviparous. Unusual patterns like oviphagous (egg eating) embryos exist in a temperate shark.

Despite the variations in the life pattern, there are a few common features. All the viviparous sharks produce limited number of well-developed young ones. The tiger shark *Galeocerdo cuvieri* and the hammer-head shark have the capacity to produce more than 80 and 30 young ones/brood, respectively. But, most sharks produce limited number of young ones; the carcharinids produce only 2 to 4 young ones/brood once or twice in a year. However, compared to the fragile early life stages of the teleosts, the young ones of sharks are released in a well-developed state, with better chances of survival individually. The bull shark, *Carcharhinus leucas* release young ones of 56 to 81 cm length, which is about 20% of the maximum length of the shark. Even the smallest shark, *Eridacnis radcliffei*, produce only one or two young ones/brood but releases them at a length of 11 cm only, which is 45.8% of the maximum length. Analysis of the relationship between L_{max} and the length at birth of the litters for 30 species of sharks ranging in L_{max} from 24 cm (*Eridacnis radcliffei*) to 1,400 cm (*Rhincodon typus*) revealed that the small-sized sharks release comparatively large-sized young ones in terms of percentage of their maximum length.

Oviparity in sharks is considered to be a primitive mode of reproduction. Oviparity involves deposition of ova enclosed in a capsule outside the maternal body. In contrast, viviparity involves retention of internally fertilized ova in the uterus where the embryonic development is completed. There are several oviparous species whose mode of reproduction represents a transitional phase from oviparity to viviparity. In several species, the mode of reproduction is still a puzzle. The whale shark, which is considered to be ovoviviparous, is an example. It is not clear whether the whale shark retains the egg cases in the uterus until the embryo hatches or the egg cases are retained in the uterus during most of the development of the embryos and then rejected at a later stage of development. Sharks mature late in their life to facilitate proper nursing of the litters. The length at first maturity ranges from 52.2 to 85.4% of the maximum length of different sharks.

Information on the growth of sharks occurring in the Indian waters is available for only three species. Compared to the teleosts, the sharks have slow growth rate. Growth data on *Scoliodon laticaudus*, *Rhizoprionodon acutus* and *Carcharhinus sorrah* indicated that the annual growth (K) of the sharks ranges from 0.33 to 1.08. The relationship between the stock and recruitment is quite direct in the sharks owing to low fecundity combined with well-developed young ones. In general, the number of young ones that can be produced is strictly restricted and is dependent on the number of adults in the stock. Thus, the relationship between the parental stock and recruitment success must be of prime consideration for developing a rational strategy for the exploitation of the sharks.

Since every body part fetches attractive price, the sharks are subjected to target fishing in recent years. The meat is consumed either in fresh, frozen or dried form, liver is used for oil, fins for soup preparation, hide for the manufacture of bags and garments, jaws as curios and teeth as ornaments. Shark fins, highly appreciated in oriental cuisine, are one of the most expensive fish products in the world. In 2006, about 250 tonnes of dried shark fins were exported from India, valued at ₹ 150 million.

Besides, 273 tonnes of frozen shark meat valued at ₹ 23 million, squalene valued at ₹ 40 million, shark skin valued at ₹ 8 millions and dried shark bones valued at ₹ 4 million were exported.

During January-March every year, the whale shark, *Rhincodon typus*, migrate towards Saurashtra coast and were subjected to harpoon fishing. The harpoon fishery flourished in the 1990s, causing great concern since the number of surviving whale shark was believed to be too few. Moreover, due to their biological characteristics, the elasmobranchs in general, are vulnerable to fishing pressure. In 2001, to protect the elasmobranchs the Government of India placed four species of sharks (the whale shark *Rhincodon typus*, the Pondicherry shark *Carcharhinus hemiodon*, the gangetic shark *Glyphis gangeticus* and the speartoothed shark *G. glyphis* under Schedule I of the Wildlife (Protection) Act, 1972. Besides sharks, two rays (*Himantura fluviatilis* and *Urogymnus asperinus*), three sawfishes (*Anoxypristis cuspidatus, Pristis microdon* and *P. zijsron*), and one guitarfish (*Rhynchobatus djiddensis*) are also placed under Schedule I.

Major perches

Species diversity: The group of fishes popularly called the perches (Order Perciformes) include more than 20 families, viz. the Serranidae (rockcods/groupers), Lutjanidae (snappers), Lethrinidae (pigface breams) (called major perches because of their large body size); and Nemipteridae, Priacanthidae, Sparidae, Acanthuridae and Siganidae (called minor perches because of their smaller body size). There are at least 42 species of rockcods/groupers, 18 species of snappers and sea-perches and 10 species of pigface breams, which contribute to the fisheries in one or more areas along the Indian waters. The L_{max} of the groupers ranges from 20 cm (= 400 g; *Epinephelus boenack*) to 231 cm (= 350 kg; *E. lanceolatus*) and 270 cm (= 400 kg; *Promicrops lanceolatus*).

Distribution: The major perches are bottom dwellers and they usually inhabit rocky and coral areas. The 100 km long Wadge Bank coast extending from Kovalam (south-west coast) to Kanyakumari is rocky and the crevices and outcrops in this area provide a congenial habitat for many species of major perches. The *kalava* (grouper) grounds are located in the depth range of 75 to 100 m along the 1,000 km long south-west coast between 8°N (Kanyakumari) and 13°N (Mangalore). These *kalava* grounds are small areas of hard bottom with shallow ridge-like outcrops, which rise 2 to 5 m from the ground level and have very irregular profile. The rocky grounds of Wadge Bank (area: about 12,000 km^2) and Quilon Bank (area: about 3,300 km^2 off Quilon) are found to be rich for the major perches.

Life pattern: Based on the species for which reproductive biology has been studied, it is evident that the groupers are protogynous hermaphrodites. After spawning for one or more years, the female groupers change sex and function as male. At sexual transition, the oocytes degenerate, the spermatogonia proliferate and the ovary is transformed into a functional testis. Evidences of the ovarian origin of the testis are the remnants of oocytes and the ovarian lumen. Females of *Epinephelus coioides* mature at 25 to 30 cm total length (2 to 3-year- old) and sexual transition occurs at 55 to 75 cm length and the fish attain a maximum of 95 cm total length. Fecundity is 0.85 million ova for a fish of 35 cm length and 2.90 million ova for a fish of 62 cm. The eggs are pelagic. The *E. akaar* mature as female at 45 to 50 cm length and transform as male at about 74 cm length (weight: >11 kg) and develop ripe testes. An intersex condition can be found at 66 to 72 cm length, with transitional gonads containing female as well as male gonadal tissues. The fish remain as female for more than 5 years and then become a functional male. The groupers spawn several times in a year.

This protogynous mode of reproduction poses several problems in the aquaculture of groupers as well as in fishery management practices. Some large females do not change sex and some small males mature at the same size as the females. Exogenous (behavioural) inducement of sexual transformation has also been suggested, as opposed to an endogenous (size) threshold, which is indicated by : (*i*) sexual transition occurring over a broad range of size (age), and (*ii*) the presence of females older than the age at which transition is completed for the population. As the male groupers are usually larger and older than the females, the males are less numerous than the females in the population. Hence, the capture of even a small number of males would result in the exploitation of a greater proportion of males from the stock. Thus the impact of fishing on the grouper population is different compared to the effect on other fish populations, which do not transform sex. Estimates on the stocks of the major perches along the Indian coast are not available. Considering the vulnerability of the adult population, especially of the male population, and the export-oriented target fishing, it is important that the biological characteristics and the stocks of the major perches are assessed for the Indian coast.

The groupers feed on a variety of fishes, large crustaceans and cephalopods. The large head and mouth of the groupers enable them to gulp a large volume of water and prey. The numerous inwardly depressible sharp teeth are well adapted for seizing large prey and preventing their escape from the mouth. In the nurseries, the fry and fingerlings are fed on mysids and tiny shrimps. In production cages, they are fed on trash fishes, minced or chopped to suit each size group. The feeding rate in the production cages is 5% body weight.

The major perches are high-value fishes and are exported to different countries. It is possible to export them in live condition as live fishes command very high price in the foreign markets. A live grouper fry (usable for aquaculture) commands a price of 1 US $, a fingerling 3 $ and a 600 g adult 20 $/kg. India exported a few consignments of groupers in live or fresh-chilled condition through cargo vessels during 1996-97, but discontinued the export due to various constraints. Before export the groupers were held in captivity in floating framed net-cages off the Tuticorin coast and fed regularly.

Threadfin breams

Species diversity: The threadfin breams belong to the Family Nemipteridae of the Order Perciformes. The following 6 species occur in the commercial catches in India:

Nemipterus japonicus, N. mesoprion, N. delagoae, N. tolu, N. luteus and *N. metopias*. Among the 6 species, the first 2 are the most abundant and contribute to the bulk of the catches.

Distribution: The threadfin breams occur on muddy and sandy bottoms in the coastal inshore as well as offshore shelf waters. Although they occur mostly in shallow waters between 5 m and 80 m depth, they are recorded up to about 300 m depth. In the shallow waters up to the 40 m depth, the resource is dominated by *Nemipterus japonicus* whereas in the deeper zones (beyond 40 m depth), *N. mesoprion* is the dominant species. However, *N. japonicus* is recorded in the deeper areas up to the 300 m depth. The resource appraisal surveys indicated that the stocks occur in the 100 to 200 m depth contour off Kerala from December to April and below the 100 m depth between July and October. They appear to move into shallow waters during the monsoon. Immature individuals of *Nemipterus japonicus* inhabit <20 m depth and sexually mature large females and males move to deeper areas where spawning takes place beyond 40 m depth.

Life pattern: The threadfin breams are fractional spawners, releasing ripe eggs in two spawning acts. The *Nemipterus japonicus* breed over a short and definite period and after 3 months, spawn for the second time. The spawning season varies from locality to locality and among different species. For instance, *N. japonicus* spawn season is from June to September along the north-west coast, and from November to April along the south-east coast. The *Nemipterus mesoprion* spawn season is during November-March, and *N. delagoae* and *N. tolu* spawn season is during February/ March and August-October along the south-east coast. The *N. japonicus* spawn season is when it is about 1year old. The annual fecundity (two batches) ranges from 23,000 to 139,200 eggs.

The threadfin breams are carnivorous and feed mainly on crustaceans, small fishes and cephalopods. The *Nemipterus japonicus* prefer to feed on large number of small-sized crustaceans like the penaeid and non-penaeid shrimps. Large individuals (total length: >25 cm) diversify their feeding habit and depend on fishes and cephalopods as the secondary prey. The *Nemipterus japonicus* are asynchronous cyclic feeders, i.e. there is no particular feeding time in a day for the population but individual fishes may follow a cyclic pattern of active feeding followed by cessation in feeding. In a continuum between opportunistic and selective feeding, the *Nemipterus japonicus* tend towards opportunistic feeding.

Sciaenids

Species diversity: The fishes of the family Sciaenidae are represented by 17 genera and 34 species in the Indian waters. The richness in species diversity among the sciaenids, although characteristic of the tropical ichthyofauna, is matched only by a few families such as the Clupeidae and Carangidae. The maximum size of different species of sciaenids ranges from 16 to 160 cm. Based on the maximum length that they are known to attain, the sciaenids can be grouped into the following three size classes: (*i*) 25 species of small sciaenids, which are less than 45 cm in length (for example, *Johnius aneus, J. belangeri, J. dussumieri, J. carutta, Johnieops sina, Otolithes cuvieri, Nibea maculata, Kathala axillaris,* and *Atrobucca nibe*); (*ii*) 6 species of medium-size sciaenids ranging from 45 to 80 cm length (for instance *Johnieops dussumieri, Otolithes ruber,* and *Nibea soldado*); and (*iii*) 3 species of larger sciaenids of >1 m total length (the koth *Otolithoides biauritus, O. brunneus,* and the ghol *Protonibea diacanthus*), which have great commercial value along the north-west coast.

Distribution: The sciaenids have restricted distribution and are confined mainly to the inshore waters up to 50 m depth. Only a few species like *Protonibea diacanthus* inhabit depths up to 70 m. The sciaenids are active swimmers in the coastal waters. They possess well-developed swim bladder, which is used as a hydrostatic organ during swimming. The swim bladder is of closed type (unlike those of the sardines, which are open type) and the exchange of air is through the wall of the swim bladder.

Life pattern: The sciaenids exhibit 2 general patterns in respect of their spawning season: one in which the spawning season is restricted for 3 or 4 months, as exemplified by *Johnius sina* and *J. dussumieri,* which spawn during June-September and November-February along the south-west coast; the other type is prolonged spawning for 6 or 7 months as in *Johnius carutta* (January-August), *J. aneus* (January-July) and *N. maculata* (March-August) along the south-east coast. The sciaenids are highly fecund. The relative fecundity of *Otolithes ruber* and *J. dussumieri* is 44,621 to 179,659 ova and 142,000 to 225,988 ova respectively.

The post-larvae and juveniles of the sciaenids feed mainly on copepods, amphipods, prawns and *Acetes*. The adults of small-and medium-sized sciaenids feed predominantly on benthic crustaceans and polychaetes, and to a smaller extent on gastropods, fishes and detritus. Occasionally, pelagic crustaceans, pteropods and salps are also consumed. The adults of the larger sciaenids, viz., *P. diacanthus* and *O. biauritus,* feed mostly on fishes (65%); crustaceans and molluscs form the rest of the diet.

Silverbellies

Species diversity: About 19 species of silverbellies belonging to 3 genera, viz. *Leiognathus*, *Gazza* and *Secutor*, occur along the Indian coast. The species are: *Leiognathus bindus, L. brevirostris, L. dussumieri, L. jonesi, L. splendens, L. equulus, L. berbis, L. blochii, L. daura, L. elongatus, L. fasciatus, L. interruptus, L. leuciscus, L. lineolatus, L. smithursti, L. novaehollandiae, Gazza minuta, Secutor insidiator* and *S. ruconius*.

Distribution: The silverbellies are mostly demersal and are restricted to the coastal areas, up to a depth of about 40 m. However, *Leiognathus equulus* occur in deeper waters, up to 120 m. Some of the species enter estuaries occasionally.

Life pattern: Along the Indian coast, the silverbellies are abundant only along the south-east coast, especially in the Gulf of Mannar and Palk Bay. Due to the large number of species in the restricted area of their geographical distribution, the silverbellies have adopted the following strategies for species compatibility and sustainability:

(i) The feeding habit of the silverbellies is governed by the nature of their mouth.

For *Secutor* spp. and some species of *Leiognathus*, whose mouth is protrusible upwards, the food is mainly plankton. For other *Leiognathus* spp. with mouth protrusible downwards, benthic organisms like the gastropods, bivalves, polychaetes and crustaceans form the major food. *Gazza minuta*, by virtue of the presence of canine teeth, is a carnivore and feed on crustaceans and small fishes. Thus, the silverbellies, to a very large extent, have avoided competition for food.

(ii) Several species of silverbellies spend at least part of their life in estuaries, thereby further reducing the competition for food.

(iii) Species like *Leiognathus jonesi* undertake diurnal vertical migration. The 0-year class (<60 mm) of *L. jonesi* occupy the column water in daytime and descend to the bottom in the night. The adults (>60 mm) remain in the bottom during daytime and ascend to the column in the night. When at bottom, they feed on benthos and when at column/surface, they feed on plankton. The three dimensional feeding strategy (benthic, column and estuarine) is a strategy to evolve into a successful group.

(iv) Predation on the silverbellies is negligible compared to pelagic predation on clupeids. The nektonic predators such as the sharks, tunas and seerfishes predate predominantly on the clupeids. For their food requirement, the kingseer, for instance, ingests 67% sardines and only 0.3% silverbellies. The stomach content analyses of several benthic predators, viz. the rays, catfishes, sciaenids and perches also have not revealed large-scale predation on the silverbellies. Rays feed predominantly on shellfishes, catfishes on macrobenthic invertebrates, and sciaenids and perches on crustaceans. Thus the silverbellies are spared of very high predation mortality to a large extent. In the absence of effective predation, the silverbellies have flourished in a restricted area utilizing plankton and benthos and have accumulated as large biomasses.

The silverbellies are short-lived fishes, living for not more than 2 years and rarely for 3 years. They are small-size fishes barring *L. equulus*, which attain maximum length of 260 mm. The size of the different species in the fishery ranges from 30 to 145 mm. They attain first maturity when they are 10 to 12 months old. Some species spawn throughout the year (*L. splendens, L. dussumieri*) with two distinct peaks. Others have a rather prolonged spawning season with a single peak (*G. minuta*: August to January; *L. bindus*: December to February). Unlike many teleosts, which prefer inshore waters for spawning, the silverbellies move to deeper waters for spawning and the young ones move to the inshore nursery grounds. The fecundity ranges from 7,000 to 27,000 in *Leiognathus splendens*, 5,000 to 13,000 in *Secutor insidiator*, and 12,000 to 27,000 in *Gazza minuta*.

The silverbellies are low quality fishes. Some species like *Leiognathus equulus* (L_{max}=260 mm) and *L. jonesi* (L_{max}=160 mm), which attain comparatively larger size, are consumed fresh or sun-dried. All the other small-sized species are used as fishmeal.

Demersal fishes in the marine food web

It is being increasingly realized that fisheries should be viewed from an ecosystem perspective. Demersal fish populations do not live by themselves. Rather, they are embedded in ecosystems where they perform their roles as consumers and prey of other organisms. For describing the ecosystem impacts of fisheries, it is necessary to concentrate on the impacts that fisheries have on food webs, i.e. on the network of flows of matter (= biomass), which in ecosystems, links the plants with herbivores, and the latter with their predators. These networks of flows are affected directly by fishing, which removes predatory fish, or competes with them for their preys, in either case affecting the web within which predators and preys are embedded.

The consolidation of available data on the trophic level (the position of each functional group within the web) of 707 species of pelagic and demersal finfishes and shellfishes collected from FishBase and several other sources was completed. Of these, 417 species are demersal finfishes. The trophic level of demersal finfish ranged from 2.42 (mullets) to 4.40 (Indian halibut, Table 4.5).

Table 4.5. Trophic level of commercially important demersal fish groups along the Indian coast

Groups	Species* (number)	Trophic level	Standard error	Coefficient of variation (%)
Mullets	11	2.42	0.157	6.5
Silverbellies	12	3.17	0.163	5.1
Whitefish	1	3.20	0.000	0.0
Pomfrets	2	3.20	0.000	0.0
Minor perches	114	3.20	0.043	1.3
Unicorn cod	1	3.30	0.000	0.0
Soles	18	3.39	0.039	1.2
Flounders	10	3.42	0.050	1.5
Catfishes	14	3.44	0.085	2.5
Sciaenids	32	3.50	0.086	2.5
Threadfin breams	14	3.53	0.008	0.2
Goatfishes	5	3.54	0.150	4.2
Threadfins	7	3.55	0.163	4.6
Rays	28	3.58	0.102	2.8
Pigface breams	14	3.61	0.089	2.5
Eels	9	3.84	0.140	3.6
Snappers	60	3.88	0.055	1.4
Groupers	18	3.90	0.083	2.1
Sharks	42	4.00	0.066	1.7
Lizardfishes	4	4.30	0.196	4.6
Indian halibut	1	4.40	0.000	0.0

*Number of species for which information on diet and/or trophic level estimates are available

Source: Vivekanandan E, Gomathy, S, Thirimilu, P, Meiyappan, M M, Balakumar, S K (2009). Trophic level of fishes occurring along the Indian coast. *J. mar. biol. Ass. India* **51**: 44-51.

Nearly 50% of the demersals are mid-level carnivores (trophic level: 3.01 to 3.50) and 47% are high-level carnivores (trophic level: 3.51 to 4.00). There are too few demersal omnivores and top predators. Thus 97% of the demersal finfish have resorted to carnivory and occupy a narrow horizontal spread in the food web, consuming mostly small finfishes and crustaceans that are low in trophic level, and form the food of top predators, many of which are large pelagics. Hence, the demersal fish stocks cannot be understood, quantified and managed without a thorough knowledge of their associates in the sea, especially of their prey and predators.

Bottom trawl fishery

Considering the quantity of catch landed, only a few fishing methods are of interest to commercial demersal fisheries, Trawling is one among these methods. Recognizing the importance of trawling to inshore and offshore fisheries, fishing companies and scientists have improved the methods of trawling not only by increasing the length of the trawler but also by increasing the winch power for improving the efficiency in towing. Power winches achieve the shooting and hauling of the net, which once required much labour and time. The development of trawling is traced below in chronological sequence, (*i*) experimental trawling followed by pilot scale trawling in the late 1950s using 8.5 to 10 m vessels; (*ii*) expansion of commercial trawling since the mid-1960s using mainly 10 m vessels; (*iii*) introduction and growth of Mexican trawlers of 22 to 25 m length since the mid-1970s for shrimps in the Sandheads grounds off West Bengal; (*iv*) increase in trawling efficiency since the mid-1980s by the introduction of 12-16 m vessels (or even up to 17 m vessels as in Veraval with multiday fishing extending for a week or more); and (*v*) industrialization and expansion of the trawler fleet in the 1990s. In 1998, there were 30,979 trawlers ranging from 9 to 17 m overall length with engine horsepower of 40 to 220. The few offshore steel trawlers operating at present are of 17 to 30 m length with 150 to 400 HP engine.Trawlers exceeding 13 m with 100 to 220 HP engine were introduced in the 1990s to facilitate sea endurance lasting for 5 days or more. The shift in the size and number of trawlers during 1980 to 1998 and the estimated efficiency of the trawlers operating along the Indian coast is given in Table 4.6. While the number of trawlers increased twice, the estimated efficiency (engine horse power) increased by nearly 4 times, from 9,51,200 HP (1980) to 34,48,570 HP (1998). From 1999, the trawlers are also employed for deep sea fishing up to 400 m depth by modifying the winch drum and trawlnet.

Many improvements have been made to increase the efficiency of the trawlnets too. HDPE twine has become popular for trawls in view of its low specific gravity, good strength and low cost. Thin twines have helped to reduce the tow resistance. The height of the headrope has been increased to extend the sweep area without increasing the resistance. The high opening trawlnets, which were introduced in the early 1980s, were instant success commercially. Due to higher vertical opening, the net had the capacity to sweep considerably larger volumes of water compared to the conventional trawlnets. This innovations resulted in remarkably higher catches of mid-water stocks like the squids, cuttlefishes, carangids and ribbonfishes. Fishing trials conducted in the Palk Bay revealed that the catch rate of high opening bottom trawl (158 kg/hr) was 50% higher than that (103 kg/hr) of the traditional trawlnet. To catch more shrimps, several other modifications were introduced. As most of the shrimp species remain very close to the sea bottom or buried just beneath the seafloor, the weight of the sinkers of the trawlnet was increased so as to touch and disturb the bottom while dragging the net. The codend mesh size of the net was reduced to <15 mm bar or 25 mm stretched so as to prevent the escape of the tiny shrimps. These nets, called the shrimp trawls, exploit huge quantities of small fishes and juveniles of large fishes.

Table 4.6. Comparison of overall length, number and horsepower (HP) of trawlers operating along the Indian coast in 1980 and 1998

Overall length (m)	Number of trawlers 1980	Number of trawlers 1998	Mean (HP)	Estimated total (HP) 1980	Estimated total (HP) 1998
< 9	2,890	950	40	115,600	38,000
10 - 11	7,460	8,605	60	447,600	516,300
11 - 13	4,850	8,309	80	388,000	664,720
13 - 17	0	13,115	170	0	2,229,550
Total	15,200	30,979		951,200	3,448,570

The combination of the following four factors paved the way for substantial increase in demersal fish landings during 1961-94: (*i*) increase in effort, (*ii*) extension of trawling grounds along and off the coast by increasing the size and efficiency of the vessels, (*iii*) increase in the mouth opening of the trawlnet, and (*iv*) reduction in the codend mesh size. In the last ten years, however, the annual demersal landings by the trawlers did not increase and stagnated at around 460,000 tonnes along the Indian coast. The catch rate of demersals decreased from 17.3 kg/hr in 1994 to 13.6 kg/hr in 2004.

Another disturbing aspect of the trawl is the size of the coded mesh, which is very small at < 15 mm, although the optimum prescribed for a sustainable fishery is 35 mm. Adverse effects of use of small mesh size are: (*i*) exploitation of large number of juveniles of economically important finfishes (It is estimated that about 40 million juveniles of the threadfin bream *Nemipterus japonicus* are exploited annually off Chennai, which forms 60% of the landings of the species in terms of number and 40% in terms of biomass); (*ii*) exploitation of huge quantities of small-sized adult finfishes and crustaceans, which fetch very low price; (*iii*) discard of trash fish in the sea due to inadequate space and lack of freezing and processing facilities onboard. It was estimated that 2,671 tonnes of trash fish (7.3% of the trawl landings) worth ₹ 0.50 million was discarded by the trawlers based at Chennai in 1995. Little has been done technically to prevent discards. The discards along the Kerala coast has been estimated at about 15% of the trawl catch in 2002. Selection of proper mesh size and increasing the fish hold capacity would minimize the problem of discard.

The other concern often expressed about trawling is the damage it is alleged to cause to the seabed and to the plants and animals associated with the seabed (algae, polychaetes, bivalves, gastropods, echinoderms, etc). It is likely that the mere passage of the trawls may not damage larger and active nekton, but may affect the sessile, sedentary or slow moving invertebrates. The biological effects of trawling on the seabed may differ with the variations of the physical nature of the seabed. The trawl is observed to transform marine habitats from places of rich and complex with invertebrate life, to muddy or sandy wastelands. In China, bottom trawling since the 1960s has led to exploitation of low-value and low trophic level species and immature fish since the 1990s. The catch rate has declined by 75% in 35 years although more than half of the total marine production of China was from bottom trawling in 1995. Investigations on the effect of bottom trawling on the benthic fauna off Mangalore revealed that trawling made significant changes in the total suspended solids, turbidity and organic carbon content, reduction in the clay content of the sediment, and negative impact on the biodiversity of benthic organisms. One of the main tasks of the Indian fisheries scientists is to correlate the impact of trawling on the physical and biological deterioration of the seabed with tertiary productivity.

In spite of the detrimental effects of trawling on the various marine resources, trawling has been primarily responsible for the increase in marine fish production and for the effective exploitation of a wide range of demersal stocks, which remained underexploited prior to the introduction of trawlers. Trawlers have become the mainstay fishing craft used for bulk fisheries, but the fleet has been allowed to grow without proper management interventions.

Sustaining the demersal resources

Studies have indicated that the stocks of several demersal fishes are on the decline and the scope for increasing the catch from the inshore waters along the Indian coast is limited. For example, the annual stock of 7 major demersal fish stocks, namely threadfin breams *Nemipterus japonicus* and *N. mesoprion*, silverbellies *Leiognathus bindus* and *Secutor insidiator*, goatfishes *Upeneus taeniopterus* and *U. sulphureus*, and lizardfish *Saurida undosquamis* decreased from 4,954 tonnes from 1980 to 1984 to 3,704 tonnes from 2000 to 2004 off Chennai, i.e. a substantial decline of 25% in 20 years. The decline is evident in spite of extension of trawling to distant grounds along and off the coast. However, the decrease in the stock is masked by increase/fluctuations in the landings. Similar situation prevails in several other fishing grounds along the Indian coast and calls for implementation of an effective management instrument for sustaining the resources.

One of the restrictions that is being followed under the Marine Fishing Regulation Acts is closure of trawling by mechanized vessels for 45 to 60 days during south-west monsoon along the west coast, and during April-May along the east coast. Analysis of the impact of seasonal trawl ban has indicated that the ban has helped reduce the annual fishing effort. However, reduction in fishing effort alone may not enhance the fish stocks or increase the catch. For higher catch, the recruitment to the fishery should improve. The number of young ones that survive and eventually grow big enough to be caught by the fishery is called recruitment. There was good recruitment to the fishery immediately after the ban period, but the increased recruitment did not last for more than 2 to 3 months. It is not clear whether the seasonal trawl ban, in the present form, has helped long-term recovery of the stocks.

A non-selective gear such as the bottom trawl captures 40 to 50 species of target as well and non-target fish and shellfish species in every haul, which are in different stages of exploitation. For instance, some of the stocks that are landed from a single haul are in over-exploited status whereas some others are in under-exploited status. Under this situation, evolving a common management package for optimum utilization

of all the resources may not be possible. Should the management option concentrate on the dominant species, and hope that the ecosystem will somehow adjust to management measures aiming to generate high catches of that species? Or should the option try to consider ecological redundancies, that is, group the fishes into guilds of similar species or similar states of exploitation and try to manage the guilds as if they are single species? These uncertainties are an enigma for evolving effective management priorities for the multispecies fisheries. It is increasingly being realized that temporal ban and restrictions on craft and gear will be effective under a larger, holistic management regime which should include spatial ecosystem-based fishing restrictions, mesh size regulations, capping the capacity of fishing craft in major harbours, etc. It has been demonstrated that fishing down the marine food web occurs along the south-east coast (Andhra Pradesh, Tamil Nadu and Puducherry) of India @ 0.04 trophic level/ decade. The concern about this trend is that due to intense fishing, large and valuable predatory fish are being gradually replaced by smaller fish lower down the food web. This may not only affect the value of fisheries, but may cause serious problems in the structure and function of marine ecosystems. This result underlines the need for a shift toward "ecosystem-based marine fisheries management".

An ecosystem approach is an effective tool since it takes into account the complexity of marine and coastal ecosystems and it is now believed that such an approach could provide a lasting solution to the problems of declining fish stock biomass. An ecosystem approach takes into consideration models that estimate the carrying capacity of the ecosystems and the biomass at each trophic level. It also quantifies the number of craft and gear required for sustainable harvest of pelagic, mid-water and demersal finfish and shellfish from the given ecosystem. One of the effective options under the ecosystem-based fisheries management is creation of No-Fishing Zones. A plethora of studies in several developed countries has convincingly demonstrated that the creation of marine reserves allows rapid build-up of spawning stock biomass. When the fish are protected from fishing, they live longer, grow larger and produce an exponentially increasing number of eggs. Overall (multi-species) levels of biomass per unit area can increase several fold. Within three years, commercially important fish stocks are reported to double in the seas adjacent to the reserves, resulting in higher catches.

Demersal finfishes substantially contribute to the quantity and value of marine fish landings along the Indian coast. The contribution of demersal landings to the total landings is decreasing, and there are also evidences of stock decline in the inshore waters due to intensive trawling. The demersal resource is constituted by a number of fish groups with a variety of biological characteristics. The trophic level of most of the species is restricted to a narrow range of 3.01 to 4.00, indicating their severe dependence on other resources, especially on the crustaceans for food. Trawl is the major gear exploiting the demersals. For sustaining the resources, however, managing the trawl fishery alone may not yield the desired results. Considering the dependence of the demersals on other ecological groups and habitats, management of the ecosystem *per se* will be more effective in sustaining the components, which includes the demersal finfishes as well.

5. Oceanic and Deep-sea Fisheries

Marine fish production in India has increased from 0.5 million tonnes (mt) in the early fifties to a whopping 3.2 mt in 2008–09 (*Source:* CMFRI). Mechanization/motorization of crafts, modernization of existing vessels, introduction of better fish capturing techniques like the introduction of purse- seines, trawls, resource specific gillnets etc., improved gear materials and designs, improved fish preservation techniques, distribution, marketing and utilization systems contributed to increased fish production over the years. These technological developments increased the fishing pressure in the coastal waters up to a depth of 100 m and led to over-capitalization in certain fisheries (for example, trawl fishery); overfishing of a few fish stocks (for instance, sharks, catfishes and whitefish) and led to the stagnation of marine fish production to around 2.9 mt during the last decade. It was estimated that 90% of the major resource groups that formed 75% of total Indian marine fish production in 2004 were either in mature or senescent stage indicating that the coastal waters was fished heavily leaving no scope for further expansion in the present fishing grounds. However, diversification and fishing to exploit the deep sea resources in the last five years by bigger well-equipped vessels or by modifying the existing larger vessels increased the marine capture fish production to more than 3.2 mt in 2008. The production is still short of the Revalidated Potential Fish Yield of 3.93 mt estimated by the Working Group constituted by the Government of India to revalidate the fishery potential in the Indian Exclusive Economic Zone (EEZ). Fisheries carried out in waters deeper than about 400 m are generally considered to be deep-sea fisheries. In general, the resources exploited by deep-sea fisheries have biological characteristics that pose challenges for their sustainable utilization and exploitation. These include: (*i*) maturation at relatively old ages; (*ii*) slow growth; (*iii*) long life expectancies; (*iv*) low natural mortality rates; (*v*) intermittent recruitment of successful year classes; and (*vi*) spawning that may not occur every year. Hence they can sustain very low exploitation rates, and if these resources are depleted, recovery is expected to be slow and not assured. Assessment and management of these deep-sea resources involve higher costs and are subject to greater uncertainty.

History of deep-sea fishing in India

However, it was known that oceanic and deep-sea fishing should be given due consideration for improving marine capture fish production, large-scale commercial deep-sea fishing has not progressed as envisaged owing to certain constraints. The history of deep-sea fishing in India dates back to the early seventies when two Mexican trawlers imported from the United States of America were introduced to operate in Indian waters. By 1982, there were 110 chartered and joint venture deep-sea fishing trawlers based at different fishing harbours operating all along the Indian coast.

Unfortunately, most of these Taiwanese vessels rarely fished beyond 50 m depth and thus exploited huge quantities of inshore demersal fishes. Further more, these vessels retained and marketed only high value fishes (prawns, pomfrets and seerfishes) in Singapore and discarded huge quantities of fish and shellfish. In 1983, the Government of India enforced the depth limitation of 80 m and all the chartered vessels left the country and the foreign vessel-chartering programme was terminated. In the mid-1980s, the Government of India prepared several schemes and projects to diversify and strengthen the deep-sea fishing industry and large industrial houses. Multinational companies were permitted to undertake deep-sea fishing through joint venture arrangements in the early 1990s. Under these schemes, 33 stern trawlers and 22 pair trawlers operated in 50 to 100 m depth from 1990 to 1993, and 23 tuna longliners from 1990 to 1995. It is estimated that the total catch of trawlers was about 31,000 tonnes from 1990 to 1993. As the trawlers could not get the expected quantities of shrimps, the operations were gradually reduced since 1993. The tuna long-liners landed a total catch of 19,904 tonnes valued at ₹ 80 crore and earned a foreign exchange of ₹ 6 crore from 1990 to 1992. The yellowfin tuna contributed 79.1% to the catch followed by the bigeye tuna (3.1%), marlin (6.7%), swordfish (2.8%), skipjack tuna (0.3%) and sharks and other fishes (8.0%). However, due to high operational and maintenance costs, only 10 tuna long-liners and 5 stern trawlers operated in 1994 and 1995, which too ceased operation by the end of the 1990s.

Meanwhile, Visakhapatnam Fisheries Harbour was developed as an important base for large Mexican and other trawlers [Length Over All (L_{OA}/ OAL): 22 to 25 m; engine capacity: 380 to 500 HP], owned exclusively by Indian companies. Though these vessels were deep-sea fishing vessels by definition, they operated in the inshore waters, mostly off Sandheads and targeted the shrimps but also exploited finfishes and cepahalopods. The number of these trawlers gradually increased from 37 in 1978 to 180 in 1994, which was far above the recommended number of trawlers for the region.The catch rate for shrimps which was 30 kg/hr in 1980 declined to 14 kg/hr in the 1990s. Out of the total 180 vessels, only 60 seem to be under operation now.

Strategies for sustenance and promotion of fisheries

Since 2000, there has been renewed interest on the part of the Government as well as the fisher folk to venture into deep-sea fishing to harvest the deep-sea fishes/ shell fishes as well as the large oceanic pelagic fishes (tunas, sharks etc.). With the establishment of cold chains, fish meal plants and Surimi plants, a good domestic/ export market for the formerly non-conventional resources like deep-sea prawns, lobsters and fishes has been developed to cater to different tastes. The threadfin breams and groupers are considered delicacies by the Chinese in Hong Kong, Singapore and Malaysia. Fillets of the bull's eye *Priacanthus macracanthus* and *P. hamrur*, species closely allied to New Zealand's orange roughy (*Hoplostethus atlanticus*), could possibly compete with the latter in the flourishing market for this species in the USA. Fresh, chilled red snappers, breams and groupers find ready market in many countries. Smoke-cured shark meat is a delicacy in several far- eastern countries. Frozen shark meat is a product in demand in Spain and France. Squid and cuttlefish export potential to Japan is high. Tuna meat in different forms (sashimi, loins, fillet, caned steaks etc.) is highly sought after in the south-eastern countries. Since 2002, traditional fishermen from a few coastal villages in Andhra Pradesh have been exclusively operating hooks and line to exploit the yellowfin tuna *Thunnus albacares* occurring in the oceanic waters. Catches from these traditional non-mechanized crafts have been encouraging and the operation highly cost effective. High demand for tunas in the international market has induced the interest of several boat owners both on the east and west coasts of India. In Andhra Pradesh, several existing mechanized trawlers have been modified suitably to operate long-lines for catching yellowfin tuna. The MPEDA has financially aided the private boat owners from maritime states to modify and convert their large trawlers into long-liners. There are about 175 such modified trawlers at Visakhapatnam. Besides, 30 private trawl boat owners (Sona boats, OAL>42 ft or 12.8 m) have also modified their crafts to operate long lines manually. The area of operation is beyond depth of 200 m. The catch from the identified fishing grounds along the upper east coast consists of yellowfin tuna, billfish, dolphin fish and large seerfish. These fishes are commercially important and fetch a good price both in the domestic and export markets.

Apart from these, about 2,000 catamarans (the world's most safe traditional craft) operate around Visakhapatnam on daily basis to catch yellowfin tuna by hand-held hook and lines. They use sails to use wind power and operate between 100 and 200 m depth line and operate almost 9 months in an year.

Deep-sea fishing in India

Oceanic tuna fisheries: *Tunas* form an important oceanic fishery resource of our country. Several species of oceanic tuna's, viz. *Thunnus albacares*, *T. obesus*, *Kastsuwonus pelamis* and *T. tonggol*, have been recorded along the Indian coast. Oceanic tuna resources of the Indian EEZ have been provisionally estimated as 2.14 lakh tonnes of which 15 to 25 thousand tonnes are harvested annually at present. The traditional fishermen of Andhra Pradesh initiated fishing for oceanic tunas as early as 2002 and now around 2,000 canoes (non-mechanized/motorized) and 175 mechanized units are involved in exploiting this resource. Exploitation of oceanic tunas is only by hooks and line – either long line or trolling. Both methods of fishing are popular along the Andhra Coast. The traditional fishermen use catamarans/wooden or fibre canoes. These canoes do not have any special fish hold to store the fish and no preservative technique is adopted. The bigger units used in tuna fishing are the converted mechanized trawlers. These are again of two types: the medium wooden trawlers having an OAL up to 42 m and large trawlers (mostly steel) having an OAL of above 56 m. Both these units have been modified to operate the long-line to fish exclusively for oceanic tunas. However, the smaller converted trawlers do not have a winch system and the lines which are stored in boxes are laid manually on reaching the fishing ground. Fish-hold too has been suitably modified to store large-size tunas. These units operate for 2 to 4 days. The larger units are equipped for skilled mechanical long lining. The fish-hold

is more spacious and these units have an endurance of 6 to 9 days. Fishing is carried out during the day and night depending on the weather and water conditions.

Fishing for oceanic tunas is done at water depths of 200 m msl and above. The lines are baited and kept adrift for 60 min or more. The number of hook per line ranges from 250 to 800. Large-size barbed hook (hook number 1, 2 or 4) is traditionally used. The larger vessels generally use imported steel hooks. Mackerel is the most popular bait used in tuna fishing along Andhra coast. In the absence of mackerel, lesser sardines, flying fish, squids and small-size coastal tunas are used. Mullet is a popular bait among the traditional fishermen especially those who use troll lines. The traditional fishermen carry a small ice box to store the baits on board the canoe.

A rapid survey was undertaken during 2006-07 by the Central Marine Fisheries Research Institute on the oceanic tuna landings at Visakhapatnam (Andhra Pradesh; central east coast of India). The oceanic tuna catch was represented only by the yellowfin tuna (*Thunnus albacares*). Besides Visakhapatnam, fishermen from several villages along the Andhra Pradesh coast are also exclusively involved in exploiting yellowfin tunas and land an estimated >20,000 tonnes of yellowfin tuna annually. The larger converted units also land an equal quantity of tuna along Andhra coast.

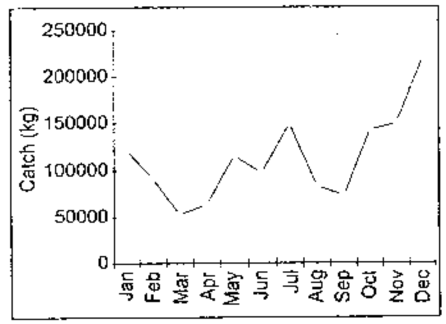

Fig. 5.1. Month-wise landing of *Thunnus albacares*.

Fishing is done throughout the year but depends a lot on the prevailing wind and sea water conditions. However, landing of yellowfin tuna by all sectors was at its peak from October to January. A second peak was observed between May and July (Fig. 5.1).

The fork length *Thunnus albacares* landed by the hook and line along Andhra coast ranged from 30 to 190 cm with major modes at 90 cm and 130 cm and the mean length at 106 cm. Smaller fishes (30 to 70 cm) were more abundant from June to July and larger fishes (>100cm) during November-January. The wet weight ranged from 0.423 kg to 103 kg. The length weight relationship of the yellowfin tuna was estimated as:

$$W= 0.017077L^{2.976}$$

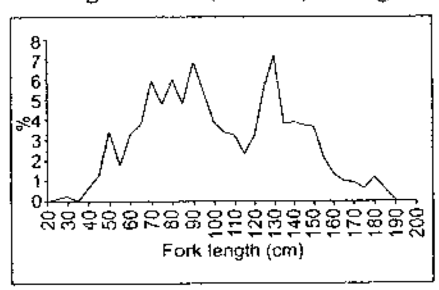

Fig. 5.2. Length frequency distribution of yellowfin tuna at Visakhapatnam.

The catch comprised both males and females but having uneven distribution. The male : female ratio was 1:0.58.

Sex in yellowfin tunas can be distinguished when the fish attain a fork length of 40 cm and gonads in mature condition were observed when the fish attained a fork length of 75 to 80 cm. However, 50% of fishes reached maturity at a fork length of 85 to 90 cm and above.

Food contents mainly consisted of crustaceans (42.5%), fishes (34.7%) and cephalopods (15.5%) which generally constituted the macro- nekton part of the Deep Scattering Layer. Fully digested matter comprised 7.3 % of the food contents.

Marketing and disposal of tunas brought by the traditional crafts are done at major landing centre. The catch is mainly purchased by processors and retailers. The processors gut the fish and keep it chilled until further processing. Most of these chilled tunas is then made into loins or canned. A very small percentage is also exported as whole fish to South-East Asian countries. The retailers sell the fish in local markets or send to adjacent states where there is good demand for tuna meat. The converted vessels adopt certain post-harvest procedures to retain the quality of the fish. Tunas are generally bled and gutted on board and then chilled till it is brought to the landing centre. These fishes are directly exported by the processing agents. The price of tuna at the landing centre varies from ₹ 40/kg to ₹ 120/kg depending on the quality of the fish. The annual exports of tuna from India reached an estimated 16,627 tonnes valued at US$15.68 million during 2005-06. The export is expected to grow with more trawl boats slated for conversion to longline fleet.

The highly-skilled deep-sea fishermen hailing from Colachel, Kanyakumari district in Tamil Nadu operate hooks and large meshed gill nets in the oceanic waters to exploit tunas and other large pelalgics These fishermen generally follow the tuna movement and land the catch either in Tamil Nadu, Kerala or Gujarat. The establishment of floating fish aggregating devices in the oceanic waters off Nagapattinam (Tamil Nadu) is reported to attract large number of tunas.

Emerging problems

A good potential for yellowfin tuna fishery exists along the Andhra coast. This has attracted and induced fishermen to focus on tuna fishing and presently both traditional as well as mechanized converted units are operating off Andhra Pradesh. Unfortunately, it is reported that both types of crafts are operating in the same area. This is leading to conflicts among the traditional tuna fishers and the recently introduced mechanized crafts. The larger vessels have the endurance to fish in deeper waters and therefore should not fish in the area where the traditional units are operating for several years. A similar situation may arise at Nagapattinam where fish aggregating devices were established. Guidelines have to be set to avoid conflicts between different sectors while the resource is harvested optimally.

There is price difference between tunas landed by the traditional and mechanized boats owing to difference in quality of the fish. Training the traditional fishermen on processing of the tunas will ensure better quality and thus fetch a better price. This will also reduce the ill feeling between the fishermen of the two sectors to a great extent. Furthermore, adequate support for the traditional fishermen groups from Andhra Pradesh and Tamil Nadu by facilitating marketing can increase tuna production and international trade earning valuable foreign exchange.

There is an urgent need for the Government to provide proper mother boat facility/ concept to the traditional catamarans to collect the tuna almost within 1 hr of catching and freezing at required temperature, so that they fetch a sashmi grade product offering better price to the traditional fishermen also.

Hooks and line fishing is a low cost, eco-friendly method of harvesting the existing resource and has been encouraged world over. However, tuna fishing along this coast is still in its early stage. The fishery has to be closely monitored and appropriate steps be taken to optimize the effort as well as catch with an aim to conserve this rich resource.

Oceanic sharks

Targeted fishery for deep-sea sharks by select drift gillnet-cum-hooks and line units operating at depths beyond 400 m has emerged lately at Cochin Fisheries Harbour. The catch of these units consists mainly of sharks, skates, rays and chimaeras. Besides, certain species of deep-sea sharks occur as by-catch in the deep-sea trawlers. Most of the multiday deepwater shark fishermen are from Chinnathura, Irayuminthura, Puthanthura, Thengapatanam, Thoothur and Colachal areas of southern Tamil Nadu. Fishing days range up to 30 days and fishing grounds extend along the entire west coast from Kerala to Gujarat. The major gears used are long-lines, bottom gillnets, drift gillnets, trawlers and hooks and lines. Major species landed are oil sharks (*Centrophorus* spp.), chimaeras (*Neoharriotta pinnata*), thresher sharks (*Alopias* spp.) and bramble shark (*Echinorhinus brucus*) (Table 5.1). The market value for oil sharks (*Centrophorus* spp.) or *mullan* as known in landing centres can reach up to

Table 5.1. Species observed in the deep-sea chondrichthyan landings at Kochi fisheries harbour

Family	Species	Length range (T_L) (cm)	Occurrence in landings
Rhinochimaeridae	*Neoharriotta pinnata*	55-147	Seasonal fishery/occasional in trawl by-catch
Hexanchidae	*Hexanchus griseus*	90-260	Rare
	Heptranchias perlo	80-107	Rare
Echinorhinidae	*Echinorhinus brucus*	42-300	Seasonal fishery/common in trawl by-catch
Centrophoridae	*Centrophorus squamosus*	70-80	Seasonal fishery/occasional in trawl by-catch
	C. moluccensis	60-90	
	C.granulosus	35-90	
	C.uyato	35-70	
	Centrophorus sp.	60-66	
	Deania profundorum		
Somniosidae	*Centroselachus crepidator*	74-76	Occasional
Squalidae	*Squalus* spp.		Rare
Carcharhinidae	*Galeocerdo cuvier*	106-140	Rare in deep-sea landings/ common in gillnet fishery
Triakidae	*Iago omanensis*	60-65	Rare
Scyliorhinidae	*Apristurus* sp.		Rare
Alopiidae	*Alopias pelagicus*	100-221	Fishery
	A. superciliosus	112-235	
Rajidae	*Raja miraleatus*		Rare
	Dipturus sp.		

₹ 300/kg and, the deep-sea chondrichthyan landings exceeded two tonnes a day on several days.

Other finfishes

Finfishes belonging to several diverse families; viz. *Cubiceps* spp. (Nomeidae), *Neoepinnula* spp. and *Rexea* spp. (Gempylidae), *Zenopsis* spp. (Zeiidae), *Gepheoberyx* spp. (Berycidae), *Chlorophthalmus* spp. (Chlorophthalmidae), *Psenopsis cynaea* (Stromateidae), occur mainly as by-catch in the deep-sea trawl fisheries. Certain species, viz. *Neoepinnula orientalis*, are sold in the domestic market also. Most of the other deep sea species landed are still considered non-conventional and do not fetch a price in the fresh fish market. However, these fishes are presently used for preparation of fish meal.

Deep-sea shrimps

Until the late 1990s, it was considered that deep-sea resources could be exploited only by large trawlers. These resources were considered to be beyond the reach of small and medium trawlers operating in the coastal waters. From November 1999, the fishermen of Kerala, and from 2000, the fishermen of Karnataka are engaged in deep- sea fishing by employing conventional trawlers (OAL: 12 to 18 m; engine power: 100 to 150 HP). The conventional winches were modified by increasing the diamater of the drums and the length of the shaft to accommodate up to 1,800 m length of wire rope. The diameter of the wire rope was increased to 10 mm. The length of the headrope was increased to 45 m. By minimizing the number of floats on the headrope and by reducing the trawling speed, these boats operate successfully up to 400 m depth. In 2000, these trawlers targeted deep-sea shrimps and lobsters and realized about 50 kg/hr and 1 kg/hr respectively The major deep-sea pandalid shrimps landed at Kochi Fisheries Harbour are *Heterocarpus woodmasoni* (33.4%), *H. gibbosus* (16.6%), *Plesionika spinipes* (25.6%), *Aristeus alcocki* (14.4%), *Metapenaeopsis andamanensis* (7.7%), *Solenocera hextii* (1.8%) and *Penaeopsis jerryi* (0.4%) (Table 5.2). The catch rate and species composition are in agreement with the findings of the exploratory surveys carried out off the south-west coast of India by the Indo-Norwegian Project during 1967-69 and by FORV *Sagar Sampada* in 1988 and 1989. The pandalids *H. woodmasoni* and *P. spinipes* fetch about ₹ 50/kg, and larger-sized *H. gibbosus* and *A. alcocki* fetch ₹ 80-100/kg. In Karnataka the deep-sea shrimps mainly comprised *Aristeus* sp. and *Heterocarpus* spp.

Table 5.2. Crustaceans landed by the deep-sea trawlers at Kochi Fisheries Harbour

Family	Species	Depth range (m)	Size range (mm)
Pandalidae	*Plesionika spinipes*	190-320	70-117
Pandalidae	*Heterocarpus gibbosus*	240-380	106-125
Pandalidae	*Heterocarpus woodmasoni*	280-400	71-125
Pandalidae	*Plesionika martia*	170-400	65-102
Aristeidae	*Aristeus alcocki*	380-550	80-140
Penaeidae	*Metapenaeopsis andamanensis*	160-300	71-130
Solenoceridae	*Solenocera hextii*	190-320	103-145

The deep-sea lobster fishery in Kerala is supported by a single species, viz. *Puerulus sewelli*. Distributed along the west coast between 7° N and 18° N at 150-400 m depth, there is good concentration of *P. sewelli* off Quilon. The price of the deep-sea lobster *P. sewelli* ranged from ₹ 100 to ₹ 150/kg. In Karnataka the deep-sea lobster fishery was supported by *Puerulus* sp. and *Nephropsis* spp.

Constraints, requirements and considerations for fishing in offshore/ deep-sea regions

The revival of deep-sea fishing since the early 2000, in the Indian waters, has been marked by gradual development of an indigenous fleet of vessels which have been suitably modified and equipped to fish in deeper waters to harvest the oceanic tunas, sharks, billfishes, cepahalopods as well as the deep-water shrimps, lobsters and demersal finfishes. Certain post-harvest preservation methods and marketing needs have been addressed to facilitate and encourage deep-sea fishing, but a lot more need to be done for growth and sustenance of deep-sea fishing venture. The important areas which need to be addressed relate to:

- Inadequate information/data on the distribution in time and space, and abundance of exploitable fishery resources in the deep seas; proper assessment of deep-sea resources is necessary before introduction of more deep-sea trawlers.
- Over-fishing leads to conflicts between different fleets and sectors and finally to law and order problem.
- Diversification of fishing to harvest the presently under-exploited deep-sea resources like yellowfin tuna and deep-sea squids by suitably modifying and redeploying the existing crafts.
- Lack of reliable information on the economics of deep sea and oceanic fishing operations.
- Poor marketing strategies and non-availability of organized market oriented economics promoting deep-sea enterprises.
- Entrepreneurship problems relating to investment and equity participation in case of joint venture and chartering arrangements.
- Constraints regarding indigenous construction of larger fishing vessels and berthing/dry docking facilities.
- Financing of deep-sea fishing vessels.
- Inadequate trained/experienced manpower in India for undertaking deep-sea fishing.
- Inadequate infrastructure facilities for onshore vessel management and , processing, distribution and marketing for the domestic market.
- Targeted interest for the exploitation of prawns rather than fishes.
- Lack of market promotion for non-conventional resources.

- Stipulate legislative measures to control and prevent operation of poaching fleets in the Indian EEZ. Coast guards may be provided with adequate facilities. Failure to formulate pragmatic programmes for judicious exploitation and proper utilization is believed to be the main cause for India's loss of fish yield each year.

Future prospects

In view of the stagnating catches from the traditional fishing grounds and coastal waters, the fishermen are targeting high unit value species such as tunas, oceanic sharks, deep-sea shrimps and squids. However, it is to be ensured that this exploitation is within sustainable limits. While on one hand, development of a deep-sea fishing fleet is essential to effectively tap the resources of the Indian EEZ in conformity with the Article 62 of the United Nations Convention on the Law of the Sea (UNCLOS), it is also to be ensured that it adheres to the Code of Conduct for Deep Sea Fishing which was approved in 2007. It states that deep-sea fishing should be rigorously managed throughout all the stages of their development– experimental, exploratory and established. In recognition of the potential vulnerability of the deep-sea resources and their ecosystem, the State should ensure that harvest rates are kept low initially and increased gradually as knowledge of the resources and management capacity increases as well as monitoring, control and surveillance mechanisms are put in place.

6. Crustacean Fisheries

The crustaceans (Crustacea) belong to diverse group members of arthropods, comprising almost 52,000 species. They include crabs, lobsters, crayfish, shrimp, krill and barnacles. Crustacea is the only group of arthropods that is primarily marine, though there are several aquatic species. A few groups have adapted to life on land, such as terrestrial crabs, terrestrial hermit crabs and woodlice. The crustaceans are abundant in the oceans as insects and also on land. From the fishery point of view, the species belonging to order Decapoda (class Malacostraca) is an important group, comprising numerous edible species of shrimps, lobsters and crabs, which inhabit different ecosystems forming a significant portion of aquatic food resources of the world. This order comprises about 1,100 genera with about 8,321 species. Faunistic record of Indian decapod crustaceans showed that there are more than 117 species of shrimps, 17 species of lobsters, and 700 species of crabs that inhabit marine and contiguous estuarine areas. At present, as many as 150 species of edible crustaceans form part of the commercial catches either on a regular basis or as occasional landings. The number of species entering into faunistic list is ever on the increase as a consequence of the extension of fishing activities to deeper water and capture of non-conventional species. A retrospect of India's marine fisheries development during the past four decades has revealed phenomenal increase in exploitation of important crustacean varieties, namely shrimps and lobsters, on account of their high export value. Enhancement of fishing effort in units as well as fishing hours in deeper grounds, modernization of craft and gear and intensive fishing have resulted in enormous fishing pressure on edible crustacean resources.

India has ever remained as one of the major contributors of marine crustaceans to the world production. Apart from freshwater shrimps and mud crabs, majority of the crustacean capture fishery of India is exclusively consisting of marine species. Crustaceans are landed in all the maritime states of India, but the volume of landings varies from state to state. The landings from east coast of India form only about 19% of the total crustacean landings, whereas the balance is landed on the west coast of India. Average annual crustacean catch in India during 2003-07 was 0.43 million tonnes, which forms 15% of the total marine fish production. Important resources include penaeid shrimps (47%), non-penaeid shrimps (34%), and crabs (11%), stomatopods (7%) and lobsters (1%). Apart from stomatopods all the other groups are edible. Stomatopods are used for fish-meal preparation in India. In China and in South-east Asian countries, the 'squilla meat' is a delicacy and some of the stomatopod species from India are also exported in frozen form. In our country Maharashtra ranks first in crustacean production by contributing about 29% of the total crustacean landings followed by Gujarat which contributes 23%. The major penaeid shrimp producing states of India are Maharashtra and Kerala that are contributing 28% and 27%, respectively, and Karnataka ranks first in the stomatopod landings (30%). The penaeid shrimps fetch good price in the export market, next to live lobsters.

Craft and gear

In the backwaters and estuaries shrimp juveniles are caught in large quantities in stake nets, cast nets, drag nets, dip nets, and small scoop nets operated by traditional fishermen. In the inshore marine fishery, the principal types of gear employed for captures of shrimps are boat seines and shore seines and for deep water fishing trawl nets are used. Small drag nets, dip nets and barrier nets are used in Hooghly estuary and in Chilka lake traps are extensively used for catching shrimps. On the west coast of India, small dug-out canoes (4 to 6 m long) are the principal craft used in the backwaters whereas larger dug-out (6 to 10 m) canoes and catamarans are used in inshore fishery. On the east coast, plank-built canoes and catamarans are used for shrimp fishing. The shrimp trawls are operated from 7 to 11 m long Pablo type wooden boats powered with 10 to 30 HP diesel engines. A few large boats such as Mexican trawlers and Sona boats were also operating shrimp trawls. The traditional *dol* nets are operated mainly along the north-west coast and Bengal coast to fish non-penaeid shrimps and smaller varieties of penaeid shrimps. The mini-trawl and thalluvalai (smaller version of shrimp-trawl) are regularly operated by indigenous plank-built and wooden small crafts in near-shore waters (4 to 9 m depth range) along the Kerala and Tuticorin-Pamban (Tamil Nadu) coast, respectively, to catch mainly shrimps. Trammel net along the Vizhinjam-Manakudy coast and bottom-set gill-net and disco-net along the south-east coast are operated regularly for exploitation of shrimps, lobsters and crabs. In the offshore fishery, trawl net is the most effective gear to exploit shrimp resources. Mostly medium-sized vessels (38 ft to 48 ft or 11.4 m to 14.4 m) operate trawl net to exploit marine crustaceans from inshore to deep-sea grounds, mainly targeting shrimps. From mid-eighties, most of the trawl units switched over to multiday fishing operations up to 80 to 100 m to exploit mid-shelf grounds, combining both day and night fishing. During 1999 onwards, some of the trawlers having higher engine power with modified winches and addition of wire ropes (up to 1,800 m) have begun operation in deep-sea grounds off Kerala and South Canara coast in the depth range of 175 to 450 m to fish deep-sea shrimps and lobsters.

Shrimps

Among crustaceans, shrimps are the most commercially exploited group by virtue of its importance and are the most valuable seafood commodity traded world-wide. Globally, annual exports of shrimp average more than 1.6 million tonnes, fetching a value of over 11 billion US$, and are a major source of employment, income, and revenue globally. Frozen shrimps are the most important marine fishery commodity exported from India in terms of value. In 2007-08, 136,000 tonnes of frozen shrimps worth ₹ 39,400 million were exported from India. As in most of the countries of tropical region, the shrimp fishery of India is also of multi-species in nature. The common species supporting the shrimp fisheries of India belong to two major categories, namely the 'penaeid shrimps' and the 'non-penaeid shrimps'.

Penaeid shrimps

The penaeid shrimps form the backbone of the sea food industry of the country and are major foreign exchange earner as well as a source of livelihood to millions of fishermen. Average annual penaeid shrimp catch in India was 186,000 tonnes contributing 7.2% to the total marine fish production from 2003 to 2007 (Table 6.1). Farmed shrimps also contribute to the total shrimp production in India. The inshore shrimp fishery is restricted to 15 m depth zone. The mechanization of some of the craft has helped in extending the fishing zone farther. Since introduction of trawlers the depth of operation extended from 15 to 40 m and fishing hours around 5 hr/trip. Night trawling and multi-day trawl fishing in the deeper waters began during the early 1980s. In the initial stage, the fishing was extended up to 3 days and later the number of fishing days was gradually increased even up to 12 days owing to higher profitability of fishing operations in the distant waters and on finding new resources in the far off fishing grounds. The technological advancements in navigational aids and fishing gear materials have paved the way for multi-day trawl fishing for the high-valued shellfishes such as shrimps.

Table 6.1. Penaeid shrimp landing (tonnes) in different maritime states between 1985 and 2007

Year	WB	OR	AP	TN	PO	KE	KA	GO	MH	GJ	Total
1985	246	2,597	7,680	11,304	754	26,685	4,483	3,496	51,793	12,636	123,659
1986	412	2,883	11,609	15,640	547	37,188	5,016	4,610	46,341	14,382	140,614
1987	299	2,164	6,765	18,185	508	52,866	9,192	5,795	49,630	16,094	163,485
1988	220	1,794	7,739	16,461	389	67,498	8,665	3,963	30,207	15,808	154,732
1989	529	2,451	7,598	16,886	442	53,317	8,566	4,618	37,403	14,645	148,444
1990	2,556	3,621	8,743	19,110	915	45,483	6,688	1,886	55,668	19,867	166,527
1991	1,223	1,972	10,759	18,523	654	60,318	9,170	3,231	57,984	26,376	192,201
1992	2,677	2,738	10,797	20,286	400	51,068	10,882	2,997	58,076	29,980	191,893
1993	2,754	2,986	16,200	19,833	146	47,988	4,528	2,202	56,416	20,151	175,197
1994	1,247	2,520	15,513	30,176	785	71,871	8,418	2,617	52,413	39,063	226,617
1995	3,352	5,350	13,863	28,038	458	43,224	7,753	1,853	40,450	34,533	180,869
1996	3,799	3,557	15,138	27,528	361	46,143	7,168	3,178	52,984	27,935	189,787
1997	3,030	2,966	14,193	27,284	104	56,131	9,470	2,914	49,819	42,629	210,537
1998	3,123	2,281	19,011	28,348	702	58,523	6,508	1,726	45,832	50,289	218,341
1999	2,704	4,323	24,967	23,443	368	42,133	8,893	986	31,840	34,414	176,070
2000	4,272	6,911	22,657	22,004	339	56,462	6,593	1,668	47,613	35,759	206,278
2001	8,780	4,105	16,221	16,202	154	45,864	8,928	2,161	51,501	22,532	178,449
2002	9,434	4,947	16,391	21,266	653	42,217	17,701	2,628	66,804	21,760	205,803
2003	12,705	5,641	17,911	15,711	84	42,862	12,040	3,039	73,170	31,617	216,783
2004	7,480	9,769	17,128	14,912	315	30,577	9,122	1,896	56,768	23,674	173,645
2005	7,281	13,148	13,487	14,413	90	31,516	21,507	1,541	45,023	16,606	164,612
2006	5,170	10,523	20,951	17,860	388	39,011	11,147	2,126	41,726	23,558	172,460
2007	11,224	16,394	25,056	16,854	339	41,002	13,895	899	48,884	27,506	202,053

WB, West Bengal; OR, Odisha; AP, Andhra Pradesh; TN, Tamil Nadu; PO, Puducherry; KE, Kerala; KA, Karnataka; GO,Goa; MH, Maharashtra; GJ Gujarat.

Distribution: The prawns/shrimps include about 33 genera with about 2,500 species, of which less than 300 species are of economic interest throughout the world. Most of these species fall under 5 penaeidean families, viz. Solenoceridae, Aristidae, Penaeidae, Sicyonidae and Sergestidae; and three caridian families, viz. Pandalidae, Crangonidae and Palaemonidae. The species belonging to *Penaeus* genus are the bigger size shrimps and out of the 28 valid species of the genus, only 8 are represented in Indian waters. These species were later classified under sub-genus/genus: *Penaeus, Fenneropenaeus, Melicertus* and *Marsupenaeus.* All the 8 species recorded from India are listed as shrimps of economic value and are *Fenneropenaeus indicus* (Indian white shrimp), *F. merguiensis* (banana shrimp), *F. penicillatus* (red-tail shrimp), *Penaeus monodon* (giant tiger shrimp), *P. semisulcatus* (green tiger shrimp), *Melicertus canaliculatus* (witch shrimp), *M. latisulcatus* (western king shrimp) and *Marsupenaeus japonicus* (kuruma shrimp). Practically all of them are marine although some are known to spend a part of their life in the brackishwater and even in freshwater. Among other penaeids, *Metapenaeus dobsoni* (flower-tail shrimp), *M. monoceros* (speckled shrimp), *M. affinis* (jinga shrimp), *M. kutchensis* (ginger shrimp) *M. brevicornis* (yellow shrimp), *Parapenaeopsis stylifera* (kiddi shrimp), *P. hardwickii* (spear shrimp), *P. sculptilis* (rainbow shrimp), *P. uncta* (uncta shrimp), *Trachysalambria curvirostris* (rough shrimp), *Metapenaeopsis stridulans* (fiddler shrimp), *Parapenaeus longipes* (flamingo shrimp), *Solenocera crassicornis* (coastal mud shrimp) and *S. choprai* (coastal mud shrimp) are commercially important.

Conventional resources, viz. *P. stylifera, M. dobsoni, M. monoceros, F. indicus* and *S. crassicornis*, were major constituents of penaeid fishery between 1995 and 2004 along the west coast. With the extension of trawling operations and night fishing, non-conventional resources , viz. *T. curvirostris, M. stridulans, S. choprai, M. canaliculatus* and *M. japonicus*, were added to the fishery. *P. stylifera* dominated the fishery at all centres. However, *S. crassicornis* had emerged as a prime contributor to fishery in Gujarat and Maharashtra. Along North Kanara and Kerala *M. dobsoni* and *P. stylifera* are the major contributors and during last decade dominance of the mid-shelf shrimp *S. choprai* was noticed from south Karnataka and north Kerala coasts. Along the south-east coast, *P. semisulcatus* dominated the fishery in south Tamil Nadu region along with *M. stridulans*. At Chennai, *M. dobsoni, F. indicus* and *M. monoceros* were the major species observed in shrimp landings. Along the Andhra Pradesh coast, *M. monoceros* was the main contributor to the penaeid shrimp fishery. *Metapenaeopsis andamanensis, Aristeus alcocki, Penaeopsis jerryi* and *Solenocera hextii* constituted the deep-sea shrimp landings along the south-west coast of India since 2000.

Fishery: The different aspects of penaeid shrimp fishery (Table 6.2) are discussed here.

Fenneropenaeus indicus: This species is subjected to commercial exploitation at different stages of their life-cycle from both estuarine and marine environments. The entire backwater fishery, therefore, are constituted by '0' year class shrimps. Three-year classes (0, I and II) of this species are represented in the trawl fishery. In the backwater of Kerala, the species is fished almost throughout the year. On the other

Table 6.2. Species contributing to commercial fishery

Scientific name	Common name	State-wise distribution
Fenneropenaeus indicus	Indian white shrimp	Ke, Ka, Tn, Po, Ap, Wb ,Or
F. merguiensis	Banana shrimp	Gj, Mh, Ka, Go
Penaeus monodon	Giant tiger shrimp	Tn, Po, Ap, Wb, Or
Penaeus semisulcatus	Green tiger shrimp	Ka, Ke, Po, Tn
Penaeus penicillatus	Red-tail shrimp	Gj, Mh
Melicertus canaliculatus	Witch shrimp	Ka
Metapenaeus dobsoni	Kadal shrimp	Mh, Ka, Go, Ke, Po, Tn
M. monoceros	Speckled shrimp	Gj, Mh, Go, Ka Ke, Tn, Po, Ap
M . affinis	Jinga shrimp	Mh, Ap
M. kutchensis	Ginger shrimp	Gj
M. brevicornis	Yellow shrimp	Po, Mh, Tn, Ap, Wb, Or
Parapenaeopsis stylifera	Kiddy shrimp	Gj, Mh, Go, Ka, Ke, Po, Tn, Ap
P. hardwickii	Spear shrimp	Gj, Mh
P. sculptilis	Rainbow shrimp	Mh, Wb, Or
Trachysalambria curvirostris	Southern rough shrimp	Ka, Ke
Metapenaeopsis stridulans	Fiddler shrimp	Gj, Mh
Solenocera crassicornis	Coastal mud shrimp	Gj, Mh,
S. choprai	Ridgeback shrimp	Gj, Mh, Ka, Ke

Gj, Gujarat; Mh, Maharashtra; Go,Goa; Ka, Karnataka; Ke, Kerala; Tn, Tamil Nadu; Po, Puducherry; Ap, Andhra Pradesh; Or, Odisha; Wb,West Bengal.

hand, marine fishery is largely seasonal. The estuarine and backwater fishery for the juveniles of the species is carried out in very shallow waters not exceeding 10 m in depth. But the commercial fishery for adults is generally carried out in coastal waters up to a depth of 50 m along the Indian coast. In Karnataka and Kerala, the species were found to contribute significantly to the monsoon fishery. In 2007, 16% of the shrimp landing in north Kerala, and 9% of the shrimp landing in Andhra Pradesh were constituted by *Fenneropenaeus indicus* species. This species is of aquaculture importance and can grow up to 270 mm in total length.

Penaeus semisulcatus: On the east coast, the juveniles of the species were observed to spend their life from late August to middle of October in areas where sea grass is growing. After the middle of October, the species seems to be fished only from the off-shore areas, where the bottom is muddy. The species also form a significant portion of shrimp catches of 'Bheris' of West Bengal, where they attain a length of 76 to 127 mm in total length. The Tamil Nadu coast is the major fishing ground for *Penaeus semisulcatus*. At Mandapam landing centre, 67% of the landing in 2007 was constituted by *P. semisulcatus*. At Tuticorin also more than 50% of the shrimp landing was constituted by this species. It can grow up to 250 mm in total length and is suggested for aquaculture where salinity is more than 25 ppt.

Penaeus monodon: Like *Fenneropenaeus indicus*, this species is also subjected to commercial exploitation at different stages of life from both estuarine and marine environments. The entire backwater fishery is constituted by '0' year class. The species occur in the trawl catches on both the coasts of India and belong to late 0-year to early 1-year class. Specimens over 300 mm in total length are common in the trawler catches landed from relatively deeper waters of the west coast. In the backwater fishery of

Kerala, the species is caught throughout the season in small numbers. In Maharashtra and Gujarat, they are found in commercial catches from August to October. Among commercial species contributing to penaeid fishery, *Penaeus monodon* is the largest in size and grows more than 300 mm total length and is widely used in shrimp farming.

Metapenaeus dobsoni: The fishery in backwater is constituted by the '0' year and a marine fishery is represented by 1-year class. During monsoon months when the mud banks are formed in various places along the coast, shoals of *Metapenaeus dobsoni* shrimps approach the near-shore areas to make it possible for fishermen to catch them. The population caught from the backwaters and estuaries range from 30 to 70 mm in total length whereas in the marine fishery size range from about 60 to 125 mm in total length. Juveniles are fished in backwaters, estuaries and paddy fields ranging from 1 to 15 m depth. Young adults and adults are caught from sea in depths from 15 to 30 m. In marine inshore areas, the fishery is largely seasonal from June to September. The offshore fishery extends from November to June. In brackishwaters of Kerala, the fishery extends from middle of November to April. It is one of the dominant species in the marine fishery of Goa, Karnataka and Kerala.

Metapenaeus monoceros: Only '0' year class contributes to the backwater fishery of Kochi. In the trawl catches, 3-year class were recorded. The backwater fishery constitutes shrimps of 56 to 90 mm in total length and the inshore fishery is represented by sizes ranging from 40 to 120 mm in total length and is mostly juveniles. The adults are caught in the trawl fishery and the size range from 90 to 75 mm in total length. The maximum size observed on the south-west coast is 180 mm in total length but in higher latitudes shrimps as large as 200 mm in total length is common and are caught from a depth of 50 to 100 m. The species is abundant in backwaters from March to June, and in November. The fishing season in the trawl fishery is from November to December. In Mumbai waters, the fishery commences during the rainy season, July-August. In Chilka lake, it is abundant during November to June. The *Metapenaeus monoceros* contributes significantly in the offshore landings of Gujarat, Karnataka and Andhra Pradesh. From 1995 onwards the species is the major contributor in the shrimp landings of Mangalore and Vishakhapatnam.

Metapenaeus affinis: In the backwater fishery, only '0'year class (30 to 120 mm) is represented. The inshore and offshore fishery is mostly represented by 1- and 2-year class (71 to 130 mm in total length). In the trawl fishery, the 2- year class generally enters the fishery in the first half of the season, and the 1- year class in the latter half (121 to 140 mm in total length). In the backwater fishery, the species is abundant from January to June. The peak season for the species in the trawl fishery is from December to February in Kochi, January to March in Mumbai, and January to August in Calicut. The inshore fishery of the Kerala coast intensifies after the formation of mud banks (annual). In Maharashtra, *Metapenaeus affinis* contributes significantly to the offshore shrimp landing of the state.

Metapenaeus brevicornis: In Hooghly estuary, 1- and 2- year classes of the species mainly form the fishery and occasionally '0' and 3- year classes also contribute to the fishery. In the Hooghly estuary, the catches range in size between 15 and 115 mm and in the inshore fishery size range from 40 to 110 mm in total length. They occur in shallow waters ranging from 4 to 7 m in depth. The species is found throughout the year and the peak season is from January to March in Mumbai coast and July to February in Gulf of Kachchh area. In Hoogly estuary it is fished throughout the year with bulk landings during November to February.

Parapenaeopsis stylifera: In the inshore waters, the species is abundant up to 22 m especially from the depth ranges of 12 to 20 m. The population is composed of 0, 1 and 2- year classes, with a size range of 10 to 145 mm in total length. At Veraval, the species support a good fishery from October to December. On the Mumbai coast, the shrimp is caught throughout the year. The peak season for fishing is from January to May in Karnataka and Kerala. Although the species occur all through the year on the west coast of India, it abounds the inshore waters from November-December to May-June and offshore waters in September to October. In 2004-05, *Parapenaeopsis stylifera* formed 40% of the shrimp fishery at Kochi Fisheries harbour and 71% of the shrimp landing of Neendakara landing centre was represented by the species.

Parapenaeopsis hardwickii: This species forms less than 1% of the annual shrimp landing of India. On the Mumbai coast and Gujarat, the species contributes considerably to the shrimp catch, and the fishery starts in November and continues up to May, and the peak season is November and January. The size ranges between 55 and 65 mm in total length in males, and 80-100 mm in total length in females.

Solenocera crassicornis: This species forms a major fishery in Gujarat and Maharashtra. At Veraval and Mumbai, the species occur in the fishery throughout the year. Peak season of the fishery is from March to April and a secondary peak was observed from December to January. The size ranged from 35 to 110 mm in total length.

Solenocera choprai: This species was emerged as a major fishery in Gujarat and Karnataka during the last decade. In Maharashtra and north Kerala also it forms a significant fishery. Peak production of *Solenocera choprai* along the Karnataka coast is during the post-monsoon (August to September). The total length ranged from 46 to 120 mm in total length; mean length of males was 74 mm in total length and that of females 86.3 mm in total length.

Biology: The penaeid shrimps are heterosexual and females are generally larger than males. Growth rate varies in different species at different phases of life depending on the habitat and environment. Among commercial species contributing to the penaeid fishery, *Penaeus semisulcatus*, *Fenneropenaeus indicus* and *Penaeus monodon* are larger in size and grow to a total length of 250, 270 and 300 mm respectively. Length ranges of smaller species, viz. *P. stylifera*, *Metapenaeus dobsoni*, *S. crassicornis* and *S. choprai*, are 46 to 145 mm, 31 to 115 mm and 35 to 110 mm and 46 to 120 mm total length respectively. Penaeid shrimps feed mainly on animal food items and decomposing organic matter. They have high fecundity and number of eggs varies between species, mainly in proportion to size of females and ovary weight. The estimated fecundity of *F. indicus* measuring 200 mm total length was 7.3 lakh; 3.9 lakh at 163 mm total length for *M. monoceros*, 1.6 lakh at 120 mm total length for *M. dobsoni* and 1.01 lakh at 102 mm total length for *Solenocera crassicornis*. Though spawners are available throughout the year, there are species-wise peak-spawning periods, which may vary between years mainly due to environmental factors. Life span of penaeid shrimp is about 2 to 3 years and mainly '0'-year group contributes to shrimp fishery. The *Aristeus alcocki* popularly known as 'Red ring' is the most sought after deep-sea shrimp by exporters. Available in the depth range of 350 to 500 m off south Kerala coast and Mangalore, the species measure between 81 and 185 mm total length. The *Metapenaeopsis andamanensis* is the dominant species in deep-sea shrimp catch with length range of 70-130 mm total length.

Stock assessment and management options

The stock assessment of various species of shrimps for developing appropriate exploitation strategies for effective management of the fishery was carried out by research workers based on the data on fishing and population characteristics of the species collected from different fish landing centres. The stock assessment studies conducted on major commercial penaeid shrimp species of the Indian coast showed that annual yields of *Fenneropenaeus indicus*, *P. monodon* and *P. semisulcatus* on the east coast and *M. dobsoni*, *M. monoceros* and *P. stylifera* on the entire coast had reached the Maximum sustainable yield (MSY). It was suggested to fix catch quota for three major species, *Fenneropenaeus indicus*, *P. semisulcatus* and *P. monodon* for Andhra Pradesh, Odisha and Tamil Nadu for mechanized and non-mechanized gears. However, implementing such regulations is practically difficult as the fishing vessels from these states fish beyond their jurisdiction and land their catch in ports of other states. The *P. stylifera* is the most important contributor to the penaeid shrimp fishery along the west coast and mortality studies show that this species along Kerala coast is facing heavy fishing pressure. The average annual yield of *P. stylifera* along Calicut coast at the present level of exploitation is nearer to MSY and it is advisable to maintain the same level of fishing effort. In *M. monoceros*, though the average annual yield during 1985-89 was marginally lower than the MSY of 10,993 tonnes, the catch during later years exceeded the MSY level. Since increasing the effort was not economically attractive, it was suggested to maintain the existing fishing effort to obtain optimum yields. Similar results were obtained in *S. choprai* stock assessment studies from Karnataka during 2003-05. Studies on *M. monoceros* along Kerala coast have indicated that there was no adverse effect of fishing on the exploited stock of this species from south-west coast off Cochin. In the case of *M. dobsoni* it is suggested that the indigenous gears may be allowed to exploit this coastal species, especially during monsoon, as the catch consisted mainly of larger size groups, which would have spawned twice or thrice. In conclusion, in a multispecies fishery it is rather difficult to suggest harvesting strategies exclusively for each stock. Since shrimps are the most important commercial species targeted by the multi-day trawlers, to understand the impact of increase in effort on shrimp resources caught by these vessels, Catch and Effort Data Analysis (CEDA) was carried out with catch and effort of shrimps landed in Karnataka during 2002-06. In penaeid shrimps, MSY was calculated as 4,374 tonnes and fishing effort maximum sustainable yield (fMSY) as 1,864,945 hr, which is equal to 22,469 units in

terms of fishing hours per unit in 2006. By taking 2006 effort level as base line 22% reduction in effort is recommended for exploiting the resource at MSY level.

The population dynamics and stock assessment of commercial shrimps showed that the average annual yield of most of the species has reached the MSY level. It was observed that increase in fishing effort may not result in substantial improvement in penaeid shrimp yield and therefore may not be economically viable. Reduction in number of fishing vessels as well as fishing hours along with increase in cod-end mesh size of shrimp trawl to at least 25 mm are the practical management measures which can be effectively implemented to get a sustainable yield of penaeid shrimp resource.

Estuaries and backwaters are nursery grounds for many commercially important penaeid species (*Metapenaeus dobsoni, M. monoceros* and *Fenneropenaeus indicus*) and act as a source of recruitment for inshore stock. Large-scale destruction of juveniles takes place in this environment as a result of indiscriminate fishing mainly by stake nets. Today, unauthorized stake nets far exceed the licensed ones and these nets should be removed permanently. Total ban of export of shrimps below a fixed minimum size is recommended to sustain the fishery. Capture of juvenile shrimps is uneconomical and leads to national loss worth crores of revenue in foreign exchange.

Enforcement of temporary closure of the fishery is an effective option in the conservation of the shrimp resource. During the south-west monsoon closure of fishing along the west coast acts as a natural conservation measure. Ban on monsoon trawling in the first half of the monsoon season is in vogue in Kerala for the last 14 years. This partial ban has prevented the capture of undersized shrimps in June and July resulting in increased availability of larger shrimps in the post-ban period. However, the trawl ban did not benefit the shrimp fishery, as the post-ban catch of *Karikkadi*(*P. stylifera*) did not show much improvement when compared with the pre-ban period. Maharashtra and Tamil Nadu have also imposed trawling ban. Cod end mesh size of the trawl net in operation along the Indian coast is generally ranging between 15 and 20 mm, which results in large-scale capture of juveniles and under-size shrimps and these are often discarded. The regulation on minimum cod end mesh size of trawl nets is to be strictly implemented and monitored by the maritime governments. Operation of mini-trawl with a cod end mesh size of 10 mm operated along the Kerala coast and *thalluvalai* in Gulf of Mannar and Palk Bay regions cause heavy destruction of juvenile population of *karikkadi* (*P.stylifera*) and green tiger shrimp (*P. semisulcatus*) respectively. Fishing by these types of gears should be completely banned by either compensating the fishermen involved or by offering alternate jobs. Trawling within 10 m depth by commercial trawlers as well as mini-trawlers should be completely stopped to avoid exploitation of juvenile shrimps. Existing laws should be strictly implemented to avoid sectoral conflicts.

At present inshore areas are over-exploited. Extension of fishing to areas beyond conventional fishing grounds has to be encouraged by offering suitable subsidy. Marine fishing regulation laws delimit area of operation of different types of gears and vessels to safeguard the interest of different sectors. These laws are often breached than complied with. Finally, the number of trawl units operated should be restricted based on the stock assessment study. The respective state governments should stop issuing license to new trawl units for shrimp fishery in inshore waters. Natural stocks of heavily exploited shrimp species can be replenished by large-scale sea-ranching of the post-larvae.

Experimental sea-ranching for stock enhancement

During 1985-86 the CMFRI initiated experimental sea-ranching of the green tiger shrimp, *P. semisulcatus*, at the Regional Centre, Mandapam Camp with the objective of studying the impact of sea-ranching of hatchery produced juveniles on stock enhancement. *P. semisulcatus* is the most important component of the shrimp fishery in Palk Bay region of Tamil Nadu, probably due to the vast expanse of sea grasses and seaweeds which offer an ideal habitat for the early juvenile stage. This shrimp being an endemic species with limited movement was considered to be the most suitable species for sea-ranching. An experimental hatchery with 1 million production capacity/ year was established in Mandapam. Post-larvae produced in the hatchery were initially released in the Pillaimadam lagoon and were observed to move into the sea within 24 hr. Regular sea-ranching was carried out from 1985 onwards. Nearly 7 million post-larvae (PL 20-40) were released between 1985 and 2000 in Palk Bay. Though impact of sea-ranching on the shrimp population could not be delineated from studies on the commercial catches due to small quantity of post-larvae released, the data collected would serve as a base for further studies on the effectiveness of sea ranching to augment the natural stock.

To study the growth, movement and recruitment of the released stock into the fishery, tag-recovery studies were conducted between 1991-92 and 1993-94. During 1991-92, hatchery (2,964) produced and farm grown shrimp in the size range of 61 to 110 mm total length were tagged and released in Palk Bay. Wide publicity regarding release of tagged shrimp and reward for return of tagged shrimps, if found in commercial catches were given in all the coastal villages bordering Palk Bay. Within 53 days 37 tagged shrimps were recovered from catches landed by trawlers operating in shrimp grounds in Palk Bay. During 1993-94, 3,384 numbers of *P. semisulcatus* and 3,430 numbers of *F. indicus* were tagged and released of which 42 numbers of *P. semisulcatus* and 19 numbers of *F. indicus* were recovered from trawler catches. While movement of *P. semisulcatus* was restricted within the Bay, *F. indicus* moved away from the fishing grounds in Palk bay and were recovered from Gulf of Mannar. The study showed that the released shrimps were able to survive, grow and get recruited into the shrimp fishing grounds, indicating the positive impact of sea-ranching on stock improvement.

Non-penaeid shrimps

The estimated average annual landing of non-penaeid shrimps in India from 2005 to 2007 was 136,881 tonnes. About 85% of non-penaeid shrimp catch of the country was landed along the north-west coast. The Gujarat and Maharashtra contributed 48% and (37%) respectively, followed by West Bengal (7%) and Andhra Pradesh (8%)

Table 6.3. Non-penaeid shrimp landing (tonnes) in different maritime states from 1985 to 2007

Year	WB	OR	AP	TN	PO	KE	KA	GO	MH	GJ	Total
1985	2,860	274	1,161	165	8	202	100	0	55,180	7,132	69,067
1986	1,103	217	2,439	202	55	104	269	85	57,387	9,961	73,808
1987	681	136	956	34	0	259	182	0	20,234	6,813	31,282
1988	1,718	145	1,390	432	10	163	25	0	37,549	7,940	51,360
1989	1,183	11	1,462	52	19	18	2	0	41,037	32,538	78,311
1990	1,665	32	1,807	68	13	2	129	0	35,906	40,151	81,763
1991	1,382	358	1,912	639	0	277	133	0	44,031	51,876	102,599
1992	1,842	340	1,465	174	0	63	110	0	33,400	53,884	93,270
1993	2,559	380	1,198	191	25	131	2	0	28,206	33,529	71,214
1994	1,693	221	2,112	2,507	3	103	175	0	16,463	50,223	75,494
1995	3,296	373	906	677	428	182	0	0	14,886	53,251	75,994
1996	3,833	263	4,380	154	0	136	0	1	28,263	67,432	106,458
1997	1,890	622	3,509	932	0	431	420	0	59,537	86,295	155,633
1998	8,631	320	3,128	304	65	52	92	0	67,375	97,338	179,303
1999	5,241	730	5,215	49	0	2,573	1	0	44,248	89,851	149,907
2000	8,524	2,597	2,685	2,002	0	9,635	284	0	42,580	83,208	153,515
2001	12,458	1,094	1,455	5,546	27	6,947	5	0	48,501	69,199	147,233
2002	17,664	1,052	2,987	3,537	0	9,982	81	0	43,705	58,706	139,716
2003	20,792	1,490	4,445	1,940	0	10,472	32	0	54,074	43,984	139,232
2004	14,658	1,416	1,777	2,871	0	8,624	25	2	42,177	44,681	118,235
2005	20,506	2,219	2,620	1,080	0	7,236	16	7	38,747	48,676	123,112
2006	21,090	1,368	1,931	4,311	0	8,465	0	3	47,309	86,310	172,793
2007	15,148	3,883	2,160	2,187	0	5,808	0	0	38,634	71,232	141,059

WB, West Bengal; OR, Odisha; AP, Andhra Pradesh; TN, Tamil Nadu; PO, Puducherry; KE, Kerala; KA, Karnataka; GO,Goa; MH, Maharashtra; and GJ, Gujarat.

(Table 6.3). Along the north-west coast this resource is mainly caught by traditionally used bag nets locally called *dol* nets. Prior to 1988, Maharashtra contributed 78% of this resource. But thereafter, shrimp trawlers in Gujarat started commercial exploitation of *Acetes* spp. on a large- scale. Reduction of cod-end mesh size of trawl net from 25 mm to 12-15 mm and fishing operation in the coastal sea coupled with the development of fishmeal industry at Veraval were responsible for enormous landing of this resource in Gujarat. In Maharashtra, on the contrary, the trawlers catch only *Nematopalaemon tenuipes*. Owing to deep-sea shrimp fishing in Kerala from 1999, the non-penaeid shrimp catch from this state increased and amounted to 3.6% of all-India catch. Availability of deep-sea non-penaeids from Tuticorin and Chennai in 2000 resulted in contribution of 1.3% to all-India catch by Tamil Nadu.

Distribution: The non-penaeid shrimp resource is multispecies, mainly supported by tiny species of genus *Acetes* (Paste shrimp), in addition to *Nematopalaemon tenuipes* (Spider shrimp), and *Exhippolysmata ensirostris* (Hunter shrimp). There are 5 species of *Acetes; A. indicus*, *A. johni*, *A. sibogae*, *A. erythraeus* and *A. japonicus*. Among these, first 2 species support commercially important fisheries from marine waters, and the rest are exploited on a low key from estuarine and near shore coastal seas along both along the north-east and north-west regions.

Fishery: The non-penaeid shrimps in Maharashtra as well as in Gujarat showed two peaks of abundance, in October-November and in April-May, but in Andhra Pradesh only one peak is noticed in July-September. Along the Gujarat-Maharashtra coast, *A. johni* occurs in huge quantities between October and November and other species were abounding almost throughout the year. The *Acetes indicus* forms bulk of the catch in March-April, *Nematopalaemon tenuipes* in May-June and *Exhippolysmata ensirostris* during June-August and December-January. Pandalid shrimps are the major contributors to deep-sea shrimp fishery which consists mainly of *Heterocarpus woodmasoni, H. gibbosus, Plesionika spinipes* and *P.martia.*

Biology: The biology of different non-penaeid shrimps is discussed here.

Acetes indicus: This species is an epi-pelagic planktonic shrimp, which forms large shoals in coastal waters. Generally, its size ranges from 8 to 38 mm in total length, and males and females exhibit differential growth rates of 6.15 mm and 5.96 mm/month respectively. Their fishable life span is about 3 to 6 months. The species breeds almost throughout the year in shallow coastal waters showing peak spawning activity during September to January. The females lay 4,300 to 10,300 eggs. The species mainly feeds on detritus consisting of fibrous and granular materials of phytoplankton and zooplankton origins.

Nematopalaemon tenuipes: This shrimp exhibits differential growth rates with males and females reaching 57 mm and 64 mm in total length on completion of 1 year. The life-span of the species is slightly more than 1 year. Being a caridean shrimp, it carries yolky eggs attached to its pleopods for incubation. The fecundity varies from 242 to 3,648 eggs.

Exhippolysmata ensirostris: This species is the largest among the coastal non-penaeids and is a hermaphrodite. It is highly predatory and feeds on paste shrimps, polychaetes and young ones of fish and shrimps. It attains 64.8 mm in total length in 6 months and 92.8 mm in total length at the end of 1 year, and its fishable life-span is about 1 year. Being a hermaphrodite, ovo-testes produce sperms as well as large yolky eggs when shrimps attain 40 to 45 mm in total length. The fecundity ranges from 476 to 13,260 eggs in individuals varying in length from 45 to 99 mm in total length. The *E. ensirostris* breeds throughout the year with peaks from May to September, and December to January.

In the deep-sea shrimp catch, *Heterocarpus woodmasoni* and *H. gibbosus*, of length range 71 to 125 mm and 91 to 140 mm in total length, respectively, were represented. Peak breeding season of these species was January to March. The fishery of *Parapandalus spinipes*, the dominant species among pandalids in the deep sea shrimp catch, was supported by 71 to120 mm length group. Berried females were observed throughout the year, indicating continuous breeding habit.

Stock assessment and management options: Stock assessment studies showed that MSY of non-penaeid shrimp is 64,685 tonnes in Maharashtra and 76,550 tonnes in Gujarat, together forming MSY of 1.41 lakh tonnes for entire north-west coast of India. To achieve Maximum Sustainable Yield, which is only 20% higher than the present annual average catch, the required effort would be more than double (1.3-fold

of the present level). Non-penaeid shrimps are not target species for either *dol* nets or trawlers and therefore implementation of management measures is rather difficult. Being the most important group of forage organisms along the north-west coast, the non-penaeid shrimps support huge biomass of economically important fishes in the region. Therefore, one of the reasons for increase in abundance of non-penaeid shrimps leading to their increased catches in the region may be attributed to the removal of these predators by intensive trawling in Gujarat and Maharashtra that commenced in late eighties and nineties. It is evident that on account of their low commercial value but greater importance in marine food chain of important food fishes of the region, large-scale exploitation of non-penaeid shrimp will not be economically feasible.

Heavy decline in the contribution of pandalids in the deep-sea shrimp catch and abundance of juveniles with less representation of berried females indicate that this resource is exploited more than the optimal level. Unlike coastal species, deep-sea pandalids have biological limitations such as slow growth rate, less fecundity and long life-span. Hence, it is advisable to exploit this resource optimally by limiting effort in trawler units and fishing hours. Instead of concentrating on heavily exploited grounds such as Quilon Bank, the trawling should be done in new/under exploited deep-sea grounds for sustainable returns.

Lobsters

Lobsters are one of the highly priced crustaceans in India and are in great demand as a delicacy in the internal market and as a foreign exchange earner in export market. They are widely distributed along the entire coast of the country with maximum landings from the north-west coast, followed by the south-west and south-east coasts (Table 6.4). The lobster fishery along the north-west coast comprising Gujarat and Maharashtra, is constituted by palinurid lobster *Panulirus polyphagus* and the scyllarid *Thenus unimaculatus,* which forms incidental catch in trawl nets. These two species, *Panulirus polyphagus* and *Thenus unimaculatus,* dominated lobster fisheries till the early 1990s in the country, contributing to nearly three-quarters of the total landing. However, the slipper lobster fishery in Maharashtra witnessed an unusual incidence of collapse by 1994, and has showed no sign of recovery so far. The *Panuirus homarus* dominates shallow water lobster fishery along the south-west coast. Landed in small quantities are *Panulirus versicolor* and *Panulirus ornatus.* The major landing centres are at Colachel and Muttom, where indigenous gears such as gill-net, trammel-net and traps are used. The lobster fishery along the south-west coast is dominated by the deep-sea lobster, *Puerulus sewelli,* the fishing ground of which is located off Quilon in Kerala, at depths ranging from 150 m to 400 m. A small-scale fishing for *Thenus unimaculatus* was reported from Quilon from 2004 onwards, which is landing as a bycatch in trawlers operating at 50 to 70 m. The major species exploited along the south-east coast of India are *Panulirus homarus* and *Panulirus ornatus*, landed mainly by gill-nets along the southern region and *P. homarus* and *Thenus unimaculaus* by trawlers as by-catch along the northern region of Tamil Nadu. The *Linuparus somniosus* is exploited in small quantities from Andaman and Nicobar Islands. The minimum legal size law

Table 6.4 . Lobster landing (tonnes) in different maritime states between 1985 and 2007

Year	WB	OR	AP	TN	PO	KE	KA	GO	MH	GJ	Total
1985	0	2	9	442	12	94	23	23	2,504	966	4,075
1986	0	7	8	324	18	50	20	4	2.031	612	3,074
1987	0	0	4	536	16	139	4	77	662	1,051	2,489
1988	0	0	1	132	19	112	1	8	477	837	1,587
1989	0	1	1	164	9	74	2	6	386	947	1,590
1990	0	0	4	365	11	123	0	5	787	539	1,834
1991	0	0	10	362	20	496	2	4	735	923	2,552
1992	0	0	9	502	3	206	0	1	453	921	2,095
1993	0	0	3	411	4	40	13	93	237	959	1,760
1994	1	0	4	559	11	443	0	4	405	1,265	2,692
1995	11	2	5	294	0	97	0	0	288	1,226	1,923
1996	0	0	5	252	0	112	0	0	1.132	1,130	2,631
1997	6	0	0	346	0	265	47	0	818	1,305	2,787
1998	89	0	12	998	0	64	0	0	442	1,091	2,696
1999	25	9	24	254	0	513	2	0	291	976	2,094
2000	0	0	13	142	0	535	49	1	611	1,080	2,431
2001	0	0	3	160	7	264	46	0	506	403	1,389
2002	29	0	16	195	0	395	78	0	402	217	1,332
2003	21	0	13	202	0	386	55	1	385	182	1,245
2004	52	0	38	226	5	264	2	0	599	185	1,371
2005	27	102	26	305	0	45	6	0	417	184	1,112
2006	17	3	114	257	0	163	10	0	665	322	1,551
2007	91	18	15	226	6	121	6	0	639	417	1,539

WB, West Bengal; OR, Odisha; AP, Andhra Pradesh; TN, Tamil Nadu; PO, Puducherry; KE, Kerala; KA, Karnataka; GO,Goa; MH, Maharashtra; and GJ, Gujarat.

promulgated in 2003 by the Ministry of Commerce and Industry, Government of India, and lobster conservation and co-management programmes taken up by the Central Marine Fisheries Research Institute, and Central Institute of Fisheries Technology for the fishers are steps taken towards effective management of lobster fisheries.

Distribution: The slipper lobster *Thenus unimaculatus* is dominant in Gujarat; fishery of *Panulirus polyphagus* is prominent in Gujarat and Maharashtra; *Panuliarus homarus*, *Panulirus ornatus*, *Thenus unimaculatus* are found in Tamil Nadu; and *Puerulus sewelli*, *Panulirus homarus*, *Thenus unimaculatus* are distributed in Kerala.

Fishery: In India, annual lobster landings increased from 800 tonnes in 1968 to ,000 tonnes in 1975, and attained a peak of 4,075 tonnes in 1985. However, the landings declined thereafter, averaging 2,200 tonnes for about 15 years. The catches further decreased to 1,245 tonnes in 2003 and further declined to 1,112 tonnes in 2005. Average landing from 2005 to 2007 was 1,400 tonnes, with Maharashtra contributing maximum (41%) and Gujarat contributing 22%. Gujarat recorded its lowest catch of the decade, 184 tonnes in 2005. The percentage composition of catch in Tamil Nadu and Kerala was 19% and 8% respectively. In Maharashtra, the commercial fishery for *Thenus unimaculatus* was initiated in 1978, with a catch of 1.5 tonnes. The landing reached a maximum of 375 tonnes in 1982. Subsequently the catches fluctuated around 250 tonnes and reached another peak (334 tonnes) in 1986. But, thereafter the catches declined steadily, landing only 2.2 tonnes in 1994. As a

consequence, the fishery collapsed, and the species occurred only in small quantities in the following years.

Biology: The total length attained by the spiny lobsters are: *Panulirus homarus* 320 mm, *P. polyphagus* 450 mm, and *P. ornatus* 500 mm. Growth rate is identical in juveniles but differential in adults. In *Panulirus polyphagus*, 50% sexual maturity is attained at 205 mm in total length for females. Though the species breeds throughout the year, maximum number of females in berried condition is observed from August to October and recruitment of juveniles measuring < 100 mm (<50 g) generally takes place between December and January. In spiny lobsters fecundity ranges from 50,000 to 1,000,000 depending upon the species and the size of lobster. The *Puerulus sewelli* ranges in size in total length from 76 mm to 190 mm in males and from 71 mm to 205 mm in females. Occurrence of maximum number of immature females in January and smaller size classes from December to January indicate entry of young ones into the fishery during these months.

Stock assessment and management options: Maximum landing of lobster is reported from the north-west region where *Panulirus polyphagus* dominates fishery. The size ranged from 75 mm to 385 mm in total length, those between 160 mm and 230 mm forming mainstay of the fishery in 1998-2002. From the length composition of the two sexes of *P. polyphagus*, the total mortality coefficient (Z), natural mortality coefficient (M), exploitation rate (U) and E_{max} were estimated. The Z for 5-year period was 1.63 for males and females. With the mean seawater temperature at 28°C, M for males and females was 0.53 and 0.6 respectively. The relative yield/recruit (Y/R) analysis indicated that yield could be maximized when the exploitation ratios were 0.46 and 0.53 for males and females respectively. However, the present exploitation ratios are 0.65 for males and 0.63 for females are high, which may not sustain future stock.

As the trawl fishery for lobsters in India does not constitute an exclusive target fishery, optimizing trawlers for lobsters alone is not an option. Observing a closed season for lobsters during the peak breeding season (August-September) is also not practical as trawl ban is already practised based on the multi-species fishery in different states. Hence, one of the options left is to return egg-bearing females back to sea at least during the peak spawning season (August to September), so that the spawning stock is protected. Heavy recruitment of juvenile lobsters (40 to 160 g) takes place during December-February and since these under-size lobsters do not fetch remunerative price to the fishermen they can also be returned to the sea. The minimum legal size (MLS) for export of whole cooked *P. polyphagus* is fixed at 250 g with this motive. These options are possible, if it is legalized to catch lobsters only above the size at maturity (205 mm in total length or 220 g size) and returning the egg-bearing females back to the sea. The *P. polyphagus* is a hardy species which remains alive for 1 to 2 hr after it is brought on board by the trawl net. Hence, releasing back the undersized and berried lobsters is recommended. This will protect not only the new recruits but also the spawning stock ensuring future recruitment process. Mesh size regulation is not practical as *P. polyphagus* appears as bycatch in shrimp trawls. The sustainability of *P. polyphagus* fishery at a lower magnitude is attributed mainly to its high fecundity and breeding throughout the year. The long larval phase and the consequent small percentage of recruitment showed that the lobster is a highly vulnerable species biologically. The species is also highly vulnerable to fishing due to the gregarious behaviour and the peculiar aggregation during breeding season, which the fishermen are quite aware of. If regulatory measures are not strictly enforced, gradual decline and complete annihilation of the stock as in *T. unimaculatus* is possible. Intensive exploitation of juveniles of *Panulirus polyphagus* from the inshore reef area by gill nets is to be banned, if the lobster fishery is to sustain. Legal ban on fishing of juveniles by the gear is to be enforced by the state government. In *Thenus unimaculatus* which occurs only in small numbers along the coast of Maharashtra, total conservation of the remaining residual population could be achieved by a legal ban on the landing of the species.

Spiny lobster fishery is an open access fishery and any restriction imposed on fishing will be desisted by the fishermen. A part from legal implementation of fishing regulations, education and creation of awareness among the various stakeholders on the negative impact of fishing and marketing juveniles and egg-bearing lobsters may bring a subtle change in the mindset. Establishment of artificial habitats and lobster sanctuaries/reserves in identified locations is desirable.

A participatory management project initiated by the CMFRI and CIFT, and funded by MPEDA is making slow progress in changing the mindset of fishermen and traders and may inculcate a sense of responsible fishing and trade. Village-level meeting, distribution of educative posters, stickers and pamphlets, video film shows, 'V' notching and releasing of egg-bearing lobsters involving the fishermen and distribution of lobster traps to wean the fishermen away from using the destructive fishing methods are some of the activities implemented under the programme. Enforcement of minimum legal size (MLS) for export is a positive step from the Ministry of Commerce and Industry, Government of India. The MLS is arrived at considering the biological features of each species. A minimum of 80 g as tail weight for *P. polyphagus* and 90 g was fixed by the Ministry in 2003. The objective is that MLS should be above the size at first maturity so that the lobsters get an opportunity to breed at least in one breeding season. *P. polyphagus* is mostly exported as whole-cooked and as whole chilled or as tail, whereas *P. homarus* and *P. ornatus* are mostly exported as live or whole frozen/chilled. In *P. ornatus* the breeding population is mostly protected because of their movement to deeper waters for spawning. However, implementation of an minimum legal size for fishing, closure of fishery during peak spawning in the southern spiny lobster fishery and ban on trammel nets are regulatory measures to be implemented by the state governments. Lobster fishing being a socio-economic activity involving the local fishermen, any regulatory measure shall consider the socio-economic aspects so that the fishermen are not adversely affected.

The minimum legal size for export of lobsters from India is: *Panulirus polyphagus* (live/chilled/frozen, 300 g; whole cooked, 250 g; tail, 90 g), *P. homarus* (live/chilled/frozen, 200 g; whole cooked, 170 g; tail, 50 g), *P. ornatus* (live/chilled/frozen, 500 g; whole cooked, 425 g; tail, 150 g), and *Thenus unimaculatus* (live /chilled/frozen, 150 g; and tail, 45 g).

Crabs

The crab segment of fishery in India is picking up as a major fishery with abundance of edible crabs all along the Indian coast steadily. The crab meat, cut crab and live crabs are exported from India to Japan, United States of America, France, Hong Kong and Malaysia. However, there are about 700 species of crabs recorded from Indian waters, those commonly used for food belong to the family Portunidae. Three species: *Portunus sanguinolentus* (spotted crab), *P. pelagicus* (reticulate crab) and *Charybdis feriatus* (cross crab) pre-dominate fishery in the coastal waters. *Podopthalmus vigil, C. lucifera, C. annulata* and *C. natator* also contribute, though in small quantities, to the fishery. The crabs are caught as by-catch and more than 80% of the total landing is by trawlers. Indigenous gears such as gill nets and traps are also used in selected areas targeting individual species, especially *P. pelagicus*. The crabs are usually caught from a depth of about 10 to 60 m. Trawlers occasionally go up to 80 m during the post-monsoon, along the south-west coast. It is the recent advances in fishing technology that has enabled fishermen to venture into deeper waters engaging themselves in multi-day fishing. This has resulted in increased landing of edible crabs, especially *Charybdis feriatus*. Average annual landing of crabs (2003-07) was 42,851 tonnes and maximum landing was in Gujarat (32%) followed by Tamil Nadu (28%) (Table 6.5).

Table 6.5. Crab landing (tonnes) in different maritime states from 1985 to 2007

Year	WB	OR	AP	TN	PO	KE	KA	GO	MH	GJ	Total
1985	210	127	1,587	6,575	430	973	595	1,789	494	9,452	22,232
1986	93	180	3,220	5,875	326	1,400	1,868	2.872	361	4,560	20,755
1987	130	368	2.312	7,801	205	2,560	2,575	2,325	366	4,433	23,075
1988	66	230	2.116	7,039	377	2,151	762	497	211	3,973	17,422
1989	26	398	2,395	5,842	86	2,664	771	327	195	3,445	16,149
1990	24	148	2,063	6,827	310	4,704	948	569	414	7,960	23,967
1991	125	199	3,447	10,026	413	5,881	1,181	435	638	7,469	29,814
1992	27	548	3,768	8,851	282	4,864	2,069	332	674	5,434	26,849
1993	139	712	3,963	10,742	296	5,612	1,174	1,047	1,027	2,383	27,095
1994	241	267	3,278	10,067	251	4,778	1,462	451	1,660	7,077	29,532
1995	506	776	2,980	11,568	367	2,030	842	214	913	10,273	30,469
1996	228	784	2,256	9,681	152	3,581	1,263	229	1,129	9,605	28,908
1997	236	731	3,491	11,750	346	10,438	2,296	702	1,490	13,342	44,822
1998	778	436	3,326	12,913	243	6,985	797	200	455	8,330	34,463
1999	445	917	3.014	11,891	139	4,836	1,118	157	267	4,764	27,548
2000	406	1,296	2,791	13,682	110	5,894	1,854	454	843	20,923	48,253
2001	1,153	972	2,929	10,435	297	4,201	1,974	320	720	6,738	29,739
2002	1,592	1,284	4,955	14,242	347	4,735	2,852	472	1,247	4,325	36,051
2003	2,586	1,337	5,113	15,455	137	5,604	2,059	556	1,653	7,476	41,976
2004	1,715	1,315	6,877	13,332	384	5.506	1,555	378	1,572	8,266	40,900
2005	1,832	1,738	5,405	10,261	158	5,428	1,264	394	1,565	9,064	37,109
2006	1,858	1,106	6,804	12,136	1,231	3,079	1,659	431	1,282	21,481	51,067
2007	1,695	2,718	5,351	12,566	155	3,643	2,511	347	863	10,528	40,377

WB, West Bengal; OR, Odisha; AP, Andhra Pradesh; TN, Tamil Nadu; PO, Puducherry; KE, Kerala; KA, Karnataka; GO,Goa; MH, Maharashtra; and GJ, Gujarat.

Distribution: The *Charybdis feriatus* dominated the fishery for edible crabs at Veraval in Gujarat, the modal classes ranging from 56 to 75 mm carapace width. Inedible species landed often in putrefied form were used for the production of fish meal or manure. In Mumbai waters also, *Charybdis feriatus* predominated the fishery followed by *Portunus sanguinolentus* and *P. pelagicus*. The landings were generally maximum in the third quarter and minimum in the second quarter of the year. Percentage of berried females also seemed to be more in the third quarter. Towards south, in Karwar, *P. pelagicus* dominated the fishery, though further south along the south-west coast, both *C. feriatus* and *P. sanguinolentus* dominated, followed by *P. pelagicus*. Ringseines and hand trawl also landed crabs along the Malpe coast, during the south-west monsoon. In Kerala, maximum landing was reported during January-May with little landing in the third quarter of the year. At Vizhinjam in south Kerala, trammel nets were used from *Vallom* or *Catamarans* during the south-west monsoon. Bottom-set gill nets were widely used along the coasts of Mandapam and Tharuvaikkulam landing large-size *P. pelagicus*. On the other hand, the trawl landings at Chennai and Visakhapatnam were dominated by *P. sanguinolentus* followed by *P. pelagicus* and *C. feriatus*. The landing of inedible crabs at Visakhapatnam was dominated by *C. callianassa*.

The state-wise species distribution of marine crabs is: *Charybdis feriatus* and *Charybdis lucifera* in Gujarat; *Charybdis feriatus* and *Portunus sanguinolentus* in Maharashtra; *Portunus sanguinolentus*, *Portunus pelagicus* and *Charybdis feriatus* in Karnataka, Goa, and Kerala; *Portunus pelagicus* and *Portunus sanguinolentus* in Tamil Nadu, and Puducherry, and *Portunus sanguinolentus* and *Charybdis lucifera* in Andhra Pradesh, Odisha, and West Bengal.

Mud crabs: The mud crabs, *Scylla serrata* and *Scylla tranquebarica*, are in great demand in the domestic market and fetch good revenue when compared with other species of crabs. The mud crabs can be successfully marketed both in domestic and export markets in live condition. Medium and large crab of more than 14 cm CW and weighing more than 400 g are collected exclusively for export in West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra and Gujarat. The mud crabs generally do not figure in marine fisheries but is occasionally found in the fishery especially in the mouth of estuaries.

Fishery: The region-wise analysis of the landing during 2005 showed that maximum atches were reported from the south-east (15,824 tonnes) and north-west (10,629 onnes) coasts. The percentage contribution from the south-east region was 43, north-vest region 29 and south-west region 19 of the total landing, during 1994-2001. analysis of the total region-wise landings of crabs during 1985-2005 also showed hat maximum catch was from the south-east region (46%) followed by the north-vest (28%), south-west (22%) and north-east (4%) regions. Quarter-wise landings re generally better during the first quarter followed by the second and fourth quarters. nly small quantities are landed during July-October, along the south-west coast of ne country. The sizes between 63 mm and 113 mm (carapace width) formed mainstay f the fishery for *Charybdis feriatus* along the north-west coast. The percentage

composition of this species ranged from 5 to 45, followed by *Portunus pelagicus* and *Portunus sanguinolentus*. The remaining species generally came under non-edible groups which are used for preparation of fish-meal or manure. The *P. sanguinolentus* constituted about 30 to 45% of the landings along the south-west and east coasts of the country, followed by *C. feriatus* and *Portunus pelagicus*. Studies carried out along the south-west coast showed that in *Portunus sanguinolentus*, the size ranged from 71 to 160 mm, with sizes between 91 and 125 mm forming mainstay of the fishery.

Biology: Studies on the food and feeding habits of *Portunus sanguinolentus* and *P. pelagicus* showed that they generally feed on smaller crustaceans, fishes and molluscs. Detritus, bits of plant and other organic materials are also noticed in stomach contents. In *P. sanguinolentus*, the mean monthly growth rates were 10.3 mm and 8.8 mm, attaining a carapace width of 124.1 mm and 112.5 mm on completion of one year, in males and females respectively. In *P. pelagicus*, the average monthly growth rates were 11.0 mm and 9.6 mm attaining a carapace width of 145.2 mm and 132.5 mm by the first year, in males and females respectively. It is indicated that the population of these crabs, exploited by different gears comprises mainly of the '0'-year class, the 1-year-old forming only about 10% or less. However, the gill nets which are used at certain centres, during peak seasons of occurrence of crabs, land large proportion of the 1-year old, possibly due to the larger mesh size. The 50% level of maturity is generally at 90-105 mm in *P. sanguinolentus* and *P. pelagicus*. In *Portunus sanguinolentus* on an average 25% to 55% of female crabs were caught in ovigerous condition. Sexes were more or less equally distributed with about 16% of females in immature stage and 45% in berry. In *P. pelagicus*, the size ranged from 71 mm to 165 mm with 29.5% females in berry and in *Charybdis feriatus*, the size ranged from 46 mm to 140 mm, with 37% females in berry. These crabs breed throughout the year with peak seasons and spawning may take place twice or more in a season. Peak breeding and recruitment seasons vary from region to region. In Karnataka, peak spawning season for *P. sanguinolentus* was January-February and December. The total number of eggs ranged from 229,000 (90 mm) to 920,000 (160 mm). In *P. pelagicus* peak spawning season was January to March and in *Charybdis feriatus* peak spawning season was March to May. The number of eggs on ovigerous females ranges from about 50,000 to over 1 million.

Stock assessment and management options: Status of the stocks along the Karnataka coast was assessed in 1997 and 2006. From Thompson and Bell yield prediction analysis it is seen that in *P. pelagicus* any additional effort from the present level will yield only less than 10% additional catch, indicating that increasing the effort for better catch of the resource will not be economical and it is suggested that restricting the catch to MSY level will be the suitable management option for the sustainability of the fishery of the species from Karnataka coast. In *P. sanguinolentus*, it is seen that yield increases with the increasing effort, but an increase of fishing effort by 10 to 20 % from the present level will yield 3 to 4% additional yield indicating that any increase in effort level would not be economical. In *C. feraitus* the exploitation ratio is 0.62 against the E_{max} of 0.59 (Beverton and Holt plot) in 2008 . So there is a need to reduce the fishing pressure to get maximum yield per recruitment.

With the practice of multi-day fishing which necessitates facilities for freezing or icing the priced catches, crabs get landed usually after sorting. Thus, species and sizes that are not used for human consumption are often discarded at sea. This makes it all the more difficult to estimate the quantity of catches discarded or the quantity of juvenile crabs being caught. In Gujarat, large quantities of crabs are landed in putrefied state and are used for production of fish meal. Studies on the resources of crabs in various maritime states have shown an overall improvement. The spurt in catches is attributed to expansion of fishing area into deeper waters by fisherman engaged in multi-day fishing and utilization of species such as *C. feriatus* and *C. lucifera* for human consumption.

Analysis of the catch data of crabs over the years showed that there is no drastic decline or sign of over-exploitation of the stock. The slight improvement in the landings may be due to the facts that fishermen now venture into deeper waters for multi-day fishing and that non-conventional species like *C. feriatus* and *C. lucifera* are gaining popularity among consumers. However, it is essential to ascertain rational utilization of the crab resources as demand for this commodity in both in the export and domestic markets of the country is on the increase.

Stomatopods

Mantis shrimps, generally known as squilla are one of the major crustacean resources caught from sea. It is caught mainly as by-catch and used for fish meal preparation. During 2003-07 the average annual landing was 29,160 tonnes. Average annual landing for 1991-2000 was 7,218 tonnes with highest landing in 1994 (98,058 tonnes). The species forms the major food item for most of the demersal fishes. Recent studies showed that stomatopod fishery of Chennai coast is constituted by various big-size species caught from varied depths (Table 6.6). Bigger species of stomatopods are having great export potential in markets in China where the species is sold as "squilla meat".

A total of 65 species belonging to 23 genera and 8 families are known to occur in the seas. The catch from south-west coast is exclusively constituted by *Oratosquilla nepa*, whereas the catch from east coast is composed of multi species (*O. nepa*, *O. woodmasoni*, *O. interupta* etc). The largest size is attained only in genera *Harpiosquilla* (310 mm) and *Lysiosquilla* (275 mm).

Future thrust areas

The crustacean resources, especially penaeid shrimps and lobsters are high-value resources and owing to their economic importance these stocks are intensively exploited in the coastal waters. Despite rapid growth, short life-span and continuous breeding, these resources have been steadily declining. Wide catch fluctuations, decline in catch rates and changes in species composition in the recent past are the indicators of their over-exploitation, which call for immediate implementation of management measures. However, management measures such as trawl ban during monsoon have reduced

Table 6.6. Stomatopod landing (tonnes) in different maritime states 1985-2007

Year	WB	OR	AP	TN	PO	KE	KA	GO	MH	GJ	Total
1985	5	173	399	287	0	7,817	9,428	6,554	2,759	3,769	31,191
1986	6	456	349	476	1	9,102	15,754	12,430	6,150	3,385	48,109
1987	53	1,089	406	676	97	11,223	45,159	13,931	21,747	4,233	98,614
1988	2	1,145	394	1,003	1	11,549	24,601	14,888	12,940	2,457	68,980
1989	0	502	1,961	336	8	13,312	24,832	7,838	18,404	2,083	69,276
1990	13	105	1,786	145	0	17,028	19,494	4,230	20,773	1,897	65,471
1991	107	743	3,124	137	3	8,205	19,629	7,088	17,832	3,940	60,808
1992	27	1,008	1,884	231	1	12,730	25,597	12,310	13,942	4,958	72,688
1993	92	1,210	2,716	229	0	19,145	18,258	23,419	19,104	2,080	86,253
1994	1	396	1,761	509	0	20,031	21,416	27,926	23,142	2,869	98,051
1995	9	836	2,098	729	0	11,573	18,571	4,343	24,713	3,458	66,330
1996	5	890	795	973	43	9.115	14,311	6,432	35,328	4,450	72,342
1997	1	1,195	1,064	652	0	24,082	20,587	8,309	30,326	6,395	92,611
1998	0	531	1,087	872	0	9,115	12,435	5,691	35,874	7,283	72,888
1999	0	763	1,541	496	0	13,020	13,136	1,430	16,607	2,917	49,910
2000	10	1,353	1,194	327	1	11,835	12,650	2,582	10,498	5,691	46,141
2001	0	638	681	465	0	6.789	12,706	2,517	8.784	2,364	34,944
2002	0	416	723	798	0	7,444	23,284	6,122	8,566	1,198	48,551
2003	0	358	900	1,415	0	4,720	12,650	6,882	9,009	1,407	37,341
2004	0	87	787	1,054	0	5,617	12,457	3,643	7,050	1.376	32,071
2005	0	86	620	1,087	0	1,433	12,787	742	2,212	2,220	21,187
2006	0	94	550	1,211	0	7,040	15,723	344	3,245	2,344	30,551
2007	0	62	642	1,099	0	1,586	17,493	159	2,058	1,549	24,648

WB, West Bengal; OR, Odisha; AP, Andhra Pradesh; TN, Tamil Nadu; PO, Puducherry; KE, Kerala; KA, Karnataka; GO, Goa; MH, Maharashtra; and GJ, Gujarat.

fishing pressure on some of the demersal finfish resources, the remedial measures on crustacean resources have not been fully realized.

Although most of the shrimps exhibit high biotic potential, yet their recruitment is largely influenced by abiotic factors. Most of the penaeid shrimps migrate to deeper areas for breeding and trawling beyond 40 m resulted in large-scale exploitation of the spawning stock. There is apprehension that recruitment over-fishing is mostly responsible for the declining catches. Therefore, it is necessary to understand their reproductive dynamics and the relationship of spawning biomass and recruits and the future research shall focus on studying these aspects. Integration of environmental factors such as rainfall or wind-driven surface currents (especially for lobsters) may improvise uncertainties associated with the models used for such studies.

Successive generations (of females) need to produce sufficient 'spawning units per recruits' over their life-span to rejuvenate the stock. For the targeted resources of shrimps and lobsters, which are presently under heavy fishing pressure, the management may require conservation of the spawning stock. Failure to meet this objective is frequently associated with reduction in spawning stock biomass to low levels. Reduction of spawning stock biomass to less than 20% of its unexploited level is often considerable undesirable for stock conservation. The capture of juveniles constitutes a threat to sustainable fish production. There is need to develop selective fishing gear that has minimal impact on ecosystems, which will reduce exploitation of immature/juvenile fishes and other unwanted catch including the threatened species. The strategic research also should focus on participation of stakeholders in coastal resource management and community development. The fisheries communities should be made responsible for the optimal utilization and conservation of the resource.

Sea-ranching and establishment of Marine Protected Areas were widely used for stock enhancement or maintenance of depleted stocks and for increasing coastal productivity. The Marine Protected Areas have several benefits and they may help in protecting important habitats from damage by destructive fishing practices. They may serve as benchmark for undisturbed natural ecosystems that can be used to measure the effects of human activities in other areas and thereby help to improve resource management. The Marine Protected Areas may provide areas where fish are able to spawn and grow resulting in increasing fish catches in surrounding fishing grounds. They also help in preventing certain vulnerable fish population from extinction, which is attributed to environmental fluctuation and climate change.

7. Molluscan Fisheries

Molluscs are a fascinating and varied group of animals and although their outside features may vary greatly in form and colour, their internal structure is constant. The invertebrate phylum Mollusca with more than 80,000 species is second only to Arthropoda in number of species. The molluscs occupy a variety of habitats ranging from mountain forests, freshwater to more than 10 km depth in the sea. They range in size from less than 1 mm to more than 15 m (for example the giant squid) and their population density may exceed 40,000/m^2 in some areas. In the tropical marine environment, molluscs occupy every trophic level, from primary producers to top carnivores. As primary producers, some molluscs depend upon symbiotic relationship with algae, as exemplified by the giant clams.

In India, the use of molluscs as food, ornaments, utility articles, and medicine has been widespread from ancient times. Also they are deeply associated with mythology, folklore and superstition, in social customs and tradition, trade, handicrafts, and as currency. Among the molluscs, the sacred chank (particularly the sinistral type) and pearls from pearl oysters are intimately linked with the Hindu religion and mythology. Even today they continue to hold this exalted position.The molluscs contribute to important fisheries, providing nutritious food, and are also foreign exchange earners to the country. The shell has many industrial uses and is the object in making eye-catching articles by deft craftsmen. Men, women and children participate in fishing molluscs, which provide employment and income in coastal rural areas.

Three classes of the phylum Mollusca, namely Gastropoda, Bivalvia and Cephalopoda, are of fisheries interest and their general characters are discussed here.

Gastropoda: Gastropoda is the largest molluscan class with about 35,000 extant species. The gastropods are torted asymmetrical molluscs and usually possess a coiled shell. The soft body normally consists of head, foot, visceral mass and the mantle. Among the marine gastropods, the members belonging to the subclass Prosobranchia, are of major fishery importance. The shell in this subclass is typically coiled with an opening at the ventral end known as aperture. The aperture is covered by operculum which closes the opening of the shell. The head normally protrudes anteriorly from the shell and bears mouth, eyes and tentacles. The foot is muscular, ventrally located with a flattened base and is used for creeping or burrowing. The visceral mass fills dorsally the spire of the shell and contains most of the organs. The mantle forms mantle cavity which lines and secrets the shell. Asymmetry of the internal anatomy of the gastropods is due to twisting through 180° called the 'torsion' which takes place during the first few hours of larval development.

Bivalvia: There are about 10,000 living bivalve species. The bivalve as the name implies, possesses two valves (shells) lying on the right and left sides of the body. Bilateral symmetry is a characteristic feature. The shell is mostly composed of calcium carbonate. Umbo is the first formed part of the valve and is above the hinge. The soft body of the bivalve is covered by the mantle comprising two lobes. The foot is muscular and is ventral. Byssus is a clump of horny thread spun in the foot and helps the sedentary bivalve to attach to hard substrates. In bivalves head is absent. Many bivalves possess a pair of gills, which are respiratory in function and produce water currents from which food is collected.

Cephalopoda: Cephalopods are purely marine in habitat, and there are about 600 living species. They are considered as the fastest marine invertebrates. Head is highly developed. The cuttlefishes come under the order Sepioidea and are characterised by the presence of a shell (chitinous or calcareous), 10 circum oral appendages and the tentacles are retractile into pockets. Suckers have chitinous rings. Posterior fin lobes are free and not connected at midline. The cuttlebone is internal and located dorsally underneath the skin. The squids come under the order Teuthoidea. The shell is internal and is known as gladius or pen. It is chitinous and feather-or rod-shaped. There are 8 sessile arms and 2 tentacular arms which are contractile but not retractile. Suckers are stalked. and with or without hooks. Fin lobes are fused posteriorly. Eyes are without lids and either (*i*) covered with a transparent membrane, with a minute pore (Myopsida) or (*ii*) completely open to the sea, without a pore (Oegopsida). Octopuses are members of the order Octopoda. There are 8 circumoral arms and tentacles are absent. Fins are sub-terminal (on sides of mantle), widely separated or absent. Shell is reduced, vestigial, "cartilaginous", or absent. Suckers are without chitinous rings and are set directly on the arms without stalks.

Magnitude of molluscan fisheries in India

Cephalopods are by far the most important group with an average annual production of about 112,000 tonnes and in 2008, the production has touched an all time high of 154,000 tonnes. They are landed as by-catch and as a targeted fishery mostly in mechanized trawlers operating up to 200 m depth, and beyond in some areas. Next in importance are the bivalves and fishing is pursued as a small-scale activity, mostly at subsistence level in various estuaries and inshore seas. The annual average clam production is about 57,000 tonnes, oysters about 18,800 tonnes, and marine mussels about 14,900 tonnes. There was no fishery for marine pearl oysters since 1962 in the Gulf of Mannar area, which earlier supported major fisheries.

Scallops occur in stray numbers and do not form a fishery, while the windowpane oyster was of considerable fishery value till a few years back. Among gastropods, the chank is most important with annual production of over 1,000 tonnes till a few years back. The fishing for top shell (*Trochus* sp.) has been banned as they have been declared as endangered. Abalones occur in stray numbers and are not fished. Mining for subsoil shell deposits for industrial purposes is a major activity in the Ashtamudi and Pulicat lakes.

Bivalve fishery

A variety of clams, oysters, mussels and the windowpane oysters are distributed

along the Indian coastline where they are fished by the local people (Table 7.1). Clams and cockles form 73.8%, followed by oysters (12.5%), mussels (7.5%) and windowpane oysters (6.2%). The major bivalve resources and their total landing are given in Table.7.2. The production levels in other states are meagre. Information on the bivalve production from the north-east and north-west, and north-west states are scanty.

Table.7.1. Commercially important bivalves of India

Resource	Common English name	Local name
Clams and cockles		
Villorita cyprinoides	*Black clam*	Karutha kakka (Ma)
Paphia malabarica, Paphia sp.	Short neck clam, textile clam	Manja kakka (Ma), Chippi kallu (Ka), Tisre (Ko)
Meretrix casta, Meretrix meretrix	Yellow clam	Matti (Ta)
Mercia opima	Baby clam	Njavala kakka (Ma), Vazhukku matti (Ta)
Mesodesma glabaratum		Kakkamatti (Ta)
Sunetta scripta	Marine clam	Kadal kakka (Ma)
Donax sp.	Surf clam	Mural,Vazhi matti (Ta)
Geloina bengalensis	Big black clam	Kandan kakka (Ma)
Anadara granosa	Cockle	Aarippan kakka (Ma)
Placenta placenta	Windowpane oyster	
Tridacna sp. *Hippopus hippopus*	Giant clam	Kakka (Ma)
Mussel		
Perna viridis	Green mussel	Kallumakkai, Kadukka(Ma)Alichippalu (Te)
Perna indica	Brown mussel	Kallumakkai, Chippi (Ma)
Pearl oyster		
Pinctada fucata	Indian pearl oyster	Muthu chippi, (Ma, Ta)
Pinctada margaritifera	Blacklip pearl oyster	Muthu chippi (Ma, Ta)
Edible oysters		
Crassostrea madrasensis	Indian backwater oyster	Kadal muringa (Ma); Ali,Kalungu (Te) Patti (Ta)
Saccostrea cucullata	Rock oyster	Kadal muringa (Ma); Ali,Kalungu, Patti (Ta)

Ka – *Kannada*, Ko – *Konkani*, Ma– *Malayalam*, Mr – *Marathi*, Ta- *Tamil*, Te- *Telugu*

Exploitation of bivalves: Bivalve fishing methods are simple, using non- mechanized gear ranging from manual picking to hand operated dredges. Clams are fished by men and women usually during low tide. In the shallow estuaries and sandy beaches fishers usually remove the sand by their feet or by wooden or metal poles and pick out the buried clams. Approximately 40 to 50 kg of clams are fished within 3 to 4 hr/day. A scoop net made of semi-circular iron frame and nylon net of 30 mm mesh size is also used for fishing clams. In deeper areas, fishermen go out in pairs, dive in turns and collect clams. In Kerala as the demand for clams increased the local fishermen started operating hand dredges which has increased the catch per unit effort. In Vembanad lake a new fishing method is followed wherein a mechanized boats tows several canoes to the fishing site to reduce the effort of the fishermen to reach the site.

After fishing the same boat helps the fishers in the canoe to reach back their respective

Table.7.2. Bivalve fishery in different maritime states

States	Commercially important bivalve resources	Average total landing (tonnes)	Prospects
Kerala	Vc, Pm, Mc, Mo, Cm, Sc, Pv, Pi	58,763	Clams and mussels are optimally exploited. Fishing effort for oysters can be increased. As management measures for Vc and Pm which are intensely fished, semi-culture is recommended.
Karnataka	Mc, Vc, Pm, Cm, Sc, Pv	12,750	Clams are optimally fished. Effort can be increased for oysters and mussels. Establishment of clam fishermen co-operative societies for marketing is suggested.
Goa	Mc, Vc, Pm, Cm, Sc, Pv	1,637	Effort can be increased for all resources.
Maharashtra	Pm, Mc, Gb, Cg, Cr, Sc	2,035	Effort can be increased for all resources.
Gujarat	Cg, Cr, Sc, Pp, Pf	4,202	Utilization of pearls from windowpane oysters. Repopulating of pearl oyster beds in Gulf of Kachchh will be beneficial.
Tamil Nadu and Puducherry	Mc, Mm, Pm, Cm, Sc, Pv, Pi, Pf	2,098	Resources are fished only for shell; meat can be used instead of being discarded. Establishment of clam fishermen cooperative societies for marketing is suggested. Repopulating of pearl oyster beds of Gulf of Mannar and Palk Bay will help to revive the pearl industry.
Andhra Pradesh	Ag, Gb, Mc, Mm, Pm, Cm, Pv, Pp	1,278	Resources are fished only for shell; meat can be used instead of being discarded. Establishment of Clam fishermen Co-operative societies for marketing is suggested.
Andaman and Nicobar Islands	Tc, Tm, Pmar, Pv, Pm	NA	Intense effort to be made to replenish and conserve the existing stock.
Lakshadweep	Tc, Tm	NA	Estimation of standing stock of these endangered resources: Effort to repopulate the coral reef with giant clams and pearl oysters.

Ag, Anadara granosa; Cg, Crassostrea gryphoides; Cm , C.madrasensis; Cr, C. rivularis; Mc, Meretrix casta; Mo, Mercia opima; Mm, Meretrix meretrix; Pf, Pinctada fucata; Pi, Perna indica; Pv, Perna viridis; Pm, Paphia malabarica; Pp, Placenta placenta; Pmar, Pinctada margaritifera; Sc, Saccostrea cucullata; Tc, Tridacna crocea; Tm, T .maxima; Vc, Villorita cyprinoids; and Gb, Geloina bengalensis

villages. In Kakinada Bay, special type of craft, *Shoe Dhone* is used in which the entire family lives during a fishing trip that extends for 3 to 4 consecutive days.

Oysters, which are cemented to the substratum, cannot be fished by the clam fishing methods. They are gathered by separating them from the rocky substratum or dead oysters to which they adhere using tools that have a flat end like chisel or knife.

Mussels are also fished in the same manner but those in the sub-tidal regions are fished by diving.

Along the west coast, Kerala accounts for a majority of the total landings of clams and cockles. The commercially important clams are *Villorita cyprinoides, Paphia malabarica, Meretrix casta, Mactra* sp, *Sunetta scripta*, and *Mercia opima*. Vembanad and Ashtamudi lakes in Kerala are the two main estuarine systems which have well organized clam fishery. The former for the black clam *Villorita cyprinoides*, and the latter for the short-neck clam *Paphia malabarica*. The clam production in Vemband lake, the largest estuarine system in Kerala has been estimated 33,988 tonnes during 2000 which is about 65% of the states clam landings. In Ashtamudi lake, *Paphia malabarica* is the main species, which shows wide inter-annual fluctuations. Mussels are the second dominant group, which are fished all along the coast. A large number of fishers are involved in *Perna viridis* (green mussel) fishery along Malabar Coast during post-and pre-monsoon. The fishers dive on sub-tidal mussel beds and collect mussels. The seed mussels available during post-monsoon are used in the growing mussel farming industry in the area. In the south of Kerala, mussel fishery is dominated by the brown mussel, *Perna indica*, which is also picked from inter, tidal and sub-tidal beds. Oyster fishery (*Crassostrea madrasensis*) is limited to certain estuaries like Dharmadam, Kayamkulam and Ashtamudi lake in Kerala. Hand picking is practised in these areas and the main season is pre-monsoon when the oysters have ripe gonads.

Clams are very popular in Karnataka where the fishery is dominated by the *Meretrix casta, Meretrix meretrix, Villorita cyprinoides* and *Paphia malabarica*. The state has extensive estuarine system and in estuaries like Aghanashini, Kalinadi, Coondapur, Mulky and Gurupur the clam resources are fished and utilized locally. In the recent years the demand for green mussel has increased and about 2,000 tonnes of *Perna viridis* was landed during 2000. Oysters are also popular and about 190 tonnes of oysters are fished annually.

Information on the bivalve fishery and exploitation along the north-western states are scanty. Based on the earlier reports and information gathered by enquiry it has been estimated that the average annual landing in Goa is about 1,637 tonnes. Clams like *Meretrix casta* and *Paphia* sp. are fished from the estuarine systems. Nauxim Bay is famous for the fishery of windowpane oyster where about 8,000 to 10,000 oysters are fished per day. In Maharashtra, bivalves are fished and utilized only in certain regions like Ratnagiri coast. About 1,200 tonnes of clams (*Paphia* sp., *Meretrix casta*), 780 tonnes of green mussel and 55 tonnes of oysters (*Crassostrea gryphoides, C. rivularis* and *Saccostrea cucullata*) are landed annually. Windowpane oysters and edible oysters are the main bivalve resource of Gujarat. Of the estimated 4,202 tonnes of bivalve landing, 4,200 tonnes is contributed by the windowpane oysters fished from the Gulf of Kachchh and the rest by edible oysters. *Crassostrea gryphoides, C. rivularis* and *Saccostrea cucullata* are fished from the creeks but a well-organized fishery is not in vogue.

Along the East coast, the estuarine ecosystems of Tamil Nadu and Puducherry have rich bivalve resource but their utilization for human consumption is very negligible. In Andhra Pradesh, *Meririx casta, Paphia malabarica, Anadara granosa* and *A. rhombea* are the major bivalves. Windowpane oysters, mussels and edible oysters are also fished. Information on bivalve fishery in the north-eastern states like Odisha and West Bengal are not available.

The Andaman and Nicobar Islands have several bivalve resources among which the black lip pearl oysters, *Pinctada margaritifera*, the Giant clams *Tridacna maxima, T. squamosa, T. crocea*, and *Hippopus hippopus* and the Mabe or winged oyster *Pteria penguin* are fished for the tourism based ornamental shell industry. In the Lakshadweep islands giant clams are fished by the locals. However, there is no information on the quantities fished and exploitation rate.

The freshwater mussels belonging to the genera *Lamellidens* and *Parreysia* occur throughout India in lakes, ponds and rivers and produce gem quality pearls. Little is known about the exploitation of pearl mussels in the country, however, cultured mussel pearl production has been standardized. It is estimated that about 2,000 to 3,000 tonnes of this species are fished and the nacreous shells used for making shell buttons.

Over-exploitation and destruction of seed resource: Bivalve fishery is supported by the 0-year and 1-year class. The fishing season is usually during the post-and pre-monsoon. In certain estuaries of Goa, the clam fishery is mainly during the monsoon when there is no other fishing activity. Indiscriminate exploitation of seed clams is seen in Kerala and Andhra Pradesh where the clams are utilized in the lime shell industry. In Kakinada Bay the intensity of blood clam fishery has increased and in 1991 small-sized clams formed 43.4% of the total landing. In the mussel fishery of Kerala, destruction of seed mussel has been observed as the fishers discard the seed mussel after they are fished from the natural bed.

Utilization: India has been exporting bivalves especially clam and mussel meat to other nations. The average foreign exchange earned by the nation during 1991-2003 through bivalve and gastropod exports is ₹ 130 millions from the export of 1,998 tonnes of various products like frozen, smoked and dried meat and seashells. Bivalves fished along the West Coast are utilized for human consumption. Some bivalve products like smoked and canned oysters have good market in Indian metro cities. In Kerala and Andhra Pradesh part of the clam landings are used as a major ingredient of shrimp feed. The extensive shrimp farms also use dried and boiled clam meat as shrimp feed. Apart from these, the shells of bivalves are used in the manufacture of cement, calcium carbide, sand-lime bricks and lime. The lime-shell is used as manure in coffee plantations, as mortar in building construction, in the treatment of effluents, as a pesticide by mixing with copper sulphate ($CuSO_4$) and in glass, rayon, polyfibre, paper and sugar industries. Bivalve shells with attractive sculpture are used by the ornamental shell craft industry. The shells of giant clams, winged oysters and black lip pearl oysters are used as curios in the Island territories.

Biology: Growth, reproduction and recruitment of bivalves are greatly influenced by the environment and the same species exhibit varied growth rates and spawning periods in different regions. Though the sexes are separate, in certain bivalves like oysters hermaphrodites have been observed. Most bivalves have a wide spawning

period with certain peaks. Spatfall, population growth, zonation and species dominance in bivalves is controlled by a combination of different hydrographic parameters like salinity, availability of settlement substrates and current pattern. Typical examples are the disappearance and relocation of *Paphia* beds along the west coast and the seed settlement of mussels. In central Kerala, the mussel seed settlement during 1997–98 was negligible. In the same beds in the following year there was dense seed settlement which was estimated as 7,954 tonnes extending over a stretch of 5.6 million m^2. The biological details of the commercially important bivalves are given in Table 7.3.

Table 7.3. Biology of the commercially important bivalves

Species	Length at first maturity (mm)	Spawning period	L_{max} (mm)	Region/ coast	Growth attained (mm)		
					I yr	II yr	III yr
Villorita cyprinoides	20-25	May- June; November	52	West	30	41	-
Paphia malabarica	20	September–February	55	West	43.1		
Meretrix casta	11-17	Throughout the year	55	West	42.6		
Meretrix meretrix	21-26	May–June; February–September	91	East	47.0	61.5	-
Mercia opima	11-20	December;	53.8	(East)	30.0	43.5	-
		May–August		West	22.0	31.0	43.0
Anadara granosa	20-24	Throughout the year	73.4	East	41.1	55.3	66.3
Perna viridis	15.5-28	December–January		(East)	91.5	117.0	129.0
		July–November		West	96.0	117.0	129.0
Perna indica		May–September		SE & SW	55.0	-	-
Crassostrea madrasensis	12-14(M)	November–February	128	West	60.0	85.0	95.0
	24-26(F)	November–February					

SE, South-East; SW, South-West; yr, year

Stock assessment: Only few studies have been made to assess the stock of bivalves. However, short term surveys have been conducted in the estuaries and coastal regions of maritime states to study the standing stock bivalve resource. Using the standing stock estimates by CMFRI the potential yield of bivalves has been estimated (Table 7.4). The present status showed that the clam and oyster resources are underutilized in Gujarat and Maharashtra and effort to utilize these resources should be enhanced. However, bivalves have varied reproductive potential hence these resource estimates have to be revalidated frequently. In other states like Kerala and Karnataka the resources are utilized and in some regions they require conservation.

Management strategies: Bivalves offer one of the important examples of marine resource management along the Indian coast. However, apart from the restriction on the pearl oyster fishery by the Government of Tamil Nadu, and the management measures on the short-neck clam fishery of Ashtamudi lake, Kerala, there are no regulations for effective utilization and conservation of these sedentary marine resources. One of the major bivalve resources, the short-neck clam (*Paphia malabarica*) is well protected by the following regulations formulated by the Government of Kerala based on recommendations made by CMFRI. The recommendations are: (a) Ban on fishing activity during breeding season (September to February); (b) use of gears with 30 mm mesh size to avoid exploitation of smaller clam; (c) restrict the grade of export of frozen clams meat to 1,400 nos/kg and above; and (d) initiate semi-culture or relaying of small clams. The minimum legal size (MLS) for exploitation of *Anadara granosa* from Kakinada Bay has been set at 20 mm anterio, posterior measurement. One of the major drawbacks in bivalve fishery management is that there is no proper data collection system on the fishery landings. A proper database on the resource availability and their utilization pattern is essential.

Ashtamudi lake: A managed clam fishery

The short-neck clam fishers (numbering about 500 full-time and part-time fishers) of Ashtamudi lake are perhaps one of the best examples of a well managed local fishery benefiting the fishers and maintaining sustainable harvests. The management practices are implemented by the cooperative societies with the active scientific support of Central Marine Fisheries Research Institute.

Table 7.4. Standing stock and potential yield estimates of bivalves

Resource/ States	Estimated standing stock	Potential yield-estimate
	Clams and cockles	
Maharashtra	4,000	5,000
Goa	1,200	2,000
Karnataka	8,027	6,823
Kerala	65,000	55,250
Tamil Nadu and Puducherry	5,770	4,905
Andhra Pradesh	58,000	49,300
Total	141,997	123,278
	Oysters	
Gujarat	1,500	1,050
Maharashtra	335	235
Karnataka	450	315
Kerala	4,200	2,940
Tamil Nadu	19,032	13,322
Andhra Pradesh	23,000	16,100
Total	48,517	33,962
	Mussels	
Maharashtra	1,800	1,260
Goa	1,120	784
Karnataka	9,800	6,860
Kerala	17,473	12,231
Tamil Nadu	350	245
Andhra Pradesh	1,000	700
Total	31,543	22,080
	Windowpane oysters	
Gujarat	5,000	3,500
Goa	120	84
Andhra Pradesh	12,420	8,694
Total	17,540	12,278
Grand Total	239,597	191,598

Cephalopod fishery

Cephalopods are a marine fishery resource of increasing importance and many species are exploited as by-catch by trawlers from throughout the Indian coast. Although they form only 4,5% of the total marine fish landings, cephalopod stocks are under heavy fishing pressure because of their high value as an exportable commodity. So much so, of late, they are even targeted by the trawl fleet in certain seasons of the year along parts of the west coast of India. The CMFRI has initiated studies on cephalopod stock from Indian waters during the seventies. The initial results of this programme on the taxonomy, biology, fishery and stock assessment of cephalopod stocks pertaining to the seventies were published as a bulletin. Subsequently a major exercise on the stock assessment of Indian cephalopod stocks with data of 1979-89 was made by the CMFRI. These studies indicated that squids were exploited at optimum level on both coasts and cuttlefishes were optimally exploited along east coast and under exploited along west coast.

Exploited cephalopods: Cephalopods exploited from Indian seas can be broadly divided into three, viz. squids (order Teuthoidea), cuttlefishes (order Sepiiodea) and octopuses (order Octopodidea). A list of neretic species commercially exploited is given in Table 7.5. The dominant species occurring in commercial catches are *Loligo duvauceli*, *Sepia pharaonis*, *S. aculeata* and *Octopus membranaceous*.

Table 7.5. Commercially exploited cephalopods from Indian seas

Species	Common name	Distribution
	Squids	
Loligo duvauceli	Indian squid	All along Indian coast
Loligo uyii	Little squid	Chennai, Visakhapatnam
Doryteuthis sp.	Needle squid	South-west and South-west coast
Loliolus investigatoris	Investigator squid	All along Indian coast
Sepioteuthis lessoniana	Palkbay squid	Palk bay and Gulf of Mannar
Symplectoteuthis oualaniensis	Oceanic squid	Oceanic Indian EEZ
Thysanoteuthis rhombus	Diamond squid	Oceanic Indian EEZ
	Cuttle fishes	
Sepia pharaonis	Pharaoh cuttlefish	All along Indian coast
Sepia aculeata	Needle cuttlefish	All along Indian coast
Sepia elliptica	Golden cuttlefish	Veraval and Kochi
Sepia prashadi	Hooded cuttlefish	South-west and South-east coast
Sepia brevimana	Shortclub cuttlefish	Chennai and Vishakhapatnam
Sepiella inermis	Spineless cuttlefish	All along Indian coast
	Octopuses	
Octopus membranaceous	Webfoot octopus	South-west and South-east coast and islands
Octopus dollfusi	Marbled octopus	South-west and South-east coast and islands
Octopus lobensis	Lobed octopus	South-west and South-east coast and islands
Octopus vulgaris	Common octopus	South-west and South-east coast and islands
Cistopus indicus	Old woman octopus	South-west and South-east coast and islands

Methods of exploitation: Although about 40% of the world's cephalopod catches are taken by squid jigging and 25% by trawling, in India, cephalopods are principally caught by bottom trawlers operating up to 200 m depth zones. While most of the catch is brought in as by catch from the shrimp and fish trawls employed by the trawlers, of late, there is a targeted fishery for cuttlefishes during the post-monsoon (September-December) using off bottom high opening trawls along the south,west and north,west coast. Prior to the seventies traditional gears like shore seines, boat seines, hooks and lines and spearing were the principal gear employed to capture cephalopods. These traditional gears continue to be used especially for cuttlefishes at Vizhinjam, where there is no trawl fishery. Experimental squid jigging has been tried with Japanese expertise along the west coast by Government of India vessels with considerable success. However, commercial squid jigging is not practised in India.

Cephalopod production: Cephalopod production, which remained at very low level up to the early seventies, showed a remarkable increase crossing the 100,000 tonne mark in 1994. From 1973 onwards the commencement of export of frozen cephalopod products to several countries saw the transition of the resource from a discard to a quality resource fetching high foreign exchange. Thereafter its production showed a steep increase. The west coast maritime states, Gujarat (GUJ), Maharashtra (MAH), Goa (GOA), Karnataka (KAR) and Kerala (KER) contribute to the bulk (86%) of the production. While the production from the east coast amounts to only 14%, of which, Tamil Nadu (TN) contributes the maximum followed by Andhra Pradesh (AP). The West Bengal (WB), Odisha (OR) and Puducherry (PON) contribute only a small percentage. Overall, KER ranks first contributing a third of the all India production followed by MAH, GUJ and KAR. The cephalopod production in different maritime states indirectly this indicates the relative abundance in the continental shelf and level of exploitation of cephalopods in the different maritime states. Maximum productivity (0.699 tonne/km^2) was observed in Kerala, followed by Tamil Nadu, Karnataka, Maharashtra and Goa.

At the national level, January–March, and October–December were the most productive period. Along the upper east and west coast, the above months were the most productive, while in KAR, KER, TN and AP, July–September was also equally productive.

Species-wise production: The neritic squid *Loligo duvauceli* followed by the pharaoh cuttlefish *Sepia pharaonis* and the needle cuttlefish *Sepia aculeata* together contribute to 84% of the total cephalopod production from India. Along the west coast, *L. duvauceli* contributes to more than 50% of the landings, followed closely by *S. pharaonis* and *S. aculeata* (47%). Among squids, *Doryteuthis* sp. and among cuttlefishes, *S. elliptica* form significant part of the catch from Kerala and Gujarat respectively. A number of octopus species, chiefly, *Octopus membranaceous* forms 1% of the catch mainly from Kerala.

The dominant species in landings from the east coast is *S. pharaonis*, followed by *L. duvauceli* and *S. aculeata*. The diversity of squid and cuttlefish species exploited in commercial quantities is more along east coast as compared to west coast. The *Doryteuthis* sp. and *S. lessoniana* are also caught in considerable quantities from TN and AP. *Octopus* species, which were formerly discarded, has gained importance in recent years. The major production is from Kerala. Their proportions in the landings from both the coasts are increasing considering the export value of the same.

Biology of exploited species: All investigations on cephalopod biology, centre around the commercially exploited species, viz. Palk Bay squid, *Sepioteuthis lessoniana*, *L. duvauceli*, *Sepia pharaonis*, *S. aculeata*, *Sepiella inermis* and *Octopus dollfusi*. The aspects of biology of cephalopods detailed here pertain mainly to *L. duvauceli*, *S. pharaonis* and *S. aculeata*.

Food and feeding: Adult cephalopods are voracious and active carnivores feeding mainly on fishes and crustaceans. Fish always occurs in the diet of *L. duvauceli* of all sizes. The preference to crustacean meal declines with increase in size and there is evidence of cannibalism above 80 mm dorsal mantle length (DML). The cephalopods are preyed upon by a variety of marine fishes (including tunas and billfishes) and cetaceans. Many workers have noticed the predominance of empty stomachs in samples and slackness in feeding during spawning period. This may be due to the partial ingestion; fragmentation and rapid digestion of prey.

Age and growth: The relationship between length and weight of Indian cephalopods has been reported to be allometric with the 'b' value of the regression near to 2 than 3. This relationship is also significantly different for males and females. Growth in cephalopods has been perceived to be linear, exponential, asymptotic and/or oscillating and the use of VBGF model was advocated with seasonal oscillation as a means of standardising growth estimates of different cephalopods allowing comparative studies to be made. Studies on the growth of Indian cephalopods have been made by using the asymptotic (VBGF) model and the seasonally oscillating version of VBGF. Clear sex-wise difference in growth rate has been reported from Indian waters. In the case of *L. duvauceli* and *S. pharaonis* females grow faster than males, while in *S. aculeata* males grow faster than females. A comparison of the results of various studies carried out in India is given in Table 7.6.

Size at first maturity: Pioneering work on the reproductive biology of the Palk bay squid *Sepioteuthis lessoniana*, three species of squids and six species of cuttlefishes have been made by CMFRI. In *L. duvauceli*, males attained sexual maturity earlier than females and in all species spawning is prolonged. The size at first maturity of male and female squids and cuttlefishes along west and east coast of India is shown in Table 7.7.

Maturity stage and spawning: The simple 4-point-maturity stages for biological studies of squids and cuttlefishes include: Immature, Maturing, Mature and Spent, which has since been used by all workers on Indian cephalopods. Similar to other tropical marine resources, cephalopods along the Indian coast are reported to spawn almost throughout the year. Information on this aspect is scanty, but the peak spawning period of some of the studied species is given in Table 7.8.

The squid *L. duvauceli* spawns throughout the year along both the coast, but along the west coast, peak spawning was observed during post monsoon, i.e. September-

Table 7.6. Estimates of growth parameters (L_∞ and K), natural mortality rates (M) and level of exploitation of cephalopod stocks exploited from the seas around India

Species	Sex	Area	Period of study	L_∞ (cm)	K yr^{-1}	M	Level of exploitation
Loligo duvauceli	Male	Chennai	1979-80	20.0	0.94	1.42	Optimum
	Female	Chennai	1979-80	20.0	0.94	1.42	Optimum
	Male	Kochi	1979-80	32.7	0.61	0.91	Optimum
	Female	Kochi	1979-80	20.5	1.19	1.78	Optimum
Loligo duvauceli	Combined	Veraval	1979-83	33.4	0.5	1.5-2.2	Under
Loligo duvauceli	Male	Kochi	1981-84	37.2	1.1	2.2	NA
	Female	Kochi	1981-84	23.8	1.7	2.2	NA
Loligo duvauceli	Male	E coast	1984-88	22.0	0.9	1.3-2.7	Optimum
	Female	E coast	1984-88	20.5	1.3	1.9-3.9	Optimum
	Male	W coast	1984-88	36.0	0.8	1.2-2.4	Optimum
	Female	W coast	1984-88	23.2	1.1	1.6-3.3	Optimum
Loligo duvauceli	Male	Mangalore	1987-91	41.5	0.9	1.8	Over
	Female	Mangalore	1987-91	24.5	1.1	2.1	Over
Loligo duvauceli	Combined	Karnataka	1983-95	37.1	1.4	2.1	Over
Sepia pharaonis	Male	Vizhinjam	1978-80	36.5	0.7	1.07	Under
	Female	Vizhinjam	1978-80	34.2	0.86	1.29	Under
Sepia. pharaonis	Male	E coast	1984-88	27.0	0.9	1.08-1.8	Optimum
	Female	E coast	1984-88	23.0	1.0	1.23-2.05	Optimum
	Male	W coast	1984-88	32.0	0.7	1.41-2.35	Under
	Female	W coast	1984-88	29.6	0.8	1.5-2.5	Under
Sepia aculeata	Male	Chennai	1979-80	20.5	1.13	1.69	Optimum
	Female	Chennai	1979-80	20.5	1.13	1.69	Optimum
Sepia aculeata	Male	E coast	1984-88	20.3	0.9	1.33-2.25	Optimum
	Female	E coast	1984-88	20.3	0.9	1.33-2.25	Optimum
	Male	W coast	1984-88	20.6	1.1	1.65-2.75	Under
	Female	W coast	1984-88	20.5	1.0	1.5-2.5	Under

E, East; W, West

Table 7.7. Size at first maturity (in mm DML) of various exploited cephalopods along Indian coast

Species	East coast		West coast	
	Male	Female	Male	Female
Loligo duvauceli	85	96	122	128
Sepioteuthis lessoniana	122	98	-	-
Doryteuthis spp.	-	-	97	84
Sepia pharaonis	121	138	154	157
Sepia aculeata	100	118	124	130
Sepia brevimana	56	63	-	-
Sepia elliptica	-	-	93	96
Sepiella inermis	53	61	81	83

DML, Dorsal mental length

November. This species forms large schools (consisting of fully mature animals, 80% males) during this season, and becomes vulnerable to the purse-seine fleet operating along Karnataka coast and also to cast netters along coastal knee-deep water of Alleppey. Based on this observation, it is assumed that the squids congregate for spawning (copulation) in near shore areas after which the females migrate to the shallow sub-tidal regions with hard substratum for laying the fertilized eggs and such eggs have been collected from the sub-tidal areas of Karwar for rearing. From the sex ratio (M 80: F 20) of such squid schools it would be easy to conclude that female dies after spawning (semelparity is common among cephalopods world-wide). However, based on the relatively low GSI levels and the occurrence of mature females over a wide range of size classes, it is also concluded that this species is a multiple spawner and not a semelparous species. More evidences need to be gathered to reach a final conclusion. Similar studies on other commercial cephalopods are lacking.

Table 7.8. Area-wise peak spawning season of Indian cephalopods

Species	Geographic area	Peak season
Loligo duvauceli	East coast	Throughout the year
	West coast	Throughout the year
	Mumbai	September
	Ratnagiri	October-November
	Mangalore	December-May
	Mangalore, Malpe	September-October
Doryteuthis sibogae	Vizhinjam	December-February
Sepioteuthis lessoniana	East coast	January- October
	Mandapam	January -June
Sepia pharaonis	East coast	October -April
	West coast	October- April
Sepia aculeata	East coast (Waltair)	January- April; July- December
	East coast (Mandapam)	February- April; July-August
	West.coast (Cochin)	April-July, December
	West coast (Mumbai)	February-March; September -November
Sepiella inermis	East coast (Mandapam)	October -December
	West coast	September- December

Fecundity: Estimates on the fecundity of Indian cephalopods are few. In the spineless cuttlefish *S. inermis* the total number of ripe eggs of individuals between 69 and 71 mm DML was from 470 to 850 (average 14.9 eggs/g body weight). In the squid *L. duvauceli*, on an average an individual produced 5,300 eggs and that there was good correlation between length, ovary weight and fecundity. Fecundity of the same species varied between 2,000 and 14,000 eggs (average 65 eggs/ g body weight). In general, fecundity is low in cephalopods because of the absence of a larval stage and the hatchlings are virtually miniature adults.

Stock assessment and management: The CMFRI has a major research project on the biology and stock assessment of cephalopod resources of India. Mostly F-based models have applied to study cephalopod stocks. The first study on Indian cephalopod stocks, used length cohort analysis to estimate stock sizes. Later studies also used

Table 7.9. Recommended minimum legal sizes and weights for the 3 major commercial cephalopods exploited in India

Species	Mantle length (minimum legal size)	Corresponding total live weight
Loligo duvauceli	80 mm	25 g
Sepia pharaonis	115 mm	150 g
Octopus membranaceous	45 mm	15 g

cohort analysis to estimate mortality and stock and the yield and biomass estimates were obtained with length based Thomson and Bell analysis. To estimate MSY for Mangalore populations of *L. duvauceli*, the yield per recruit model was used. Later, the squid yield along Karnataka coast was assessed using the TB model to derive MSY and MSE. They also studied the relationship between spawning stock and recruitment of squids to assess the productivity of the population in terms of recruitment. They found that Ricker's stock recruitment curve could adequately explain the variation in recruitment with respect to spawning stock biomass (SSB). Most of these studies indicated that cephalopods were either under exploited (e.g. *S. pharaonis* and *S. aculeata* along east coast) or optimally exploited (Table 7.9), while squid stock along Karnataka coast to be found to be marginally over exploited.

Since trawl is the principal gear used for exploitation, and since the cod,end mesh used by these trawls are much below the notified mesh sizes, a large number of juveniles or young ones are caught. Thus there is need for curtailing this exploitation. It is vivid that regulation of cod-end meshes by the state fisheries departments has not been effective. An alternate measure would be to regulate the trade in such a manner that young or juvenile cephalopods are not traded or exported. Prescription of a minimum legal size as a trade barrier is an accepted practice in such instances. The minimum legal size and corresponding weights for 3 species of commercial cephalopods was determined (Table 7.9) and recommended to the MPEDA.

At present, the proportion of juveniles commercially exploited for *L. duvauceli* is 5.3%; *S. pharaonis*, 8.7% and *O. membranaceous*, 5.9%. If the juveniles are permitted to grow to L_{mean} by implementing the MLS, the estimated economic gain is to the tune of ₹ 426 crore per annum. It was also shown that harvest weights can be improved by up to 34 times and would result in higher incomes to trawl fishers. Cephalopods are not a targeted fishery along the Indian coast (excepting seasonally along the south-west coast) and therefore, it is difficult to set management targets and many of the models applied would have little relevance. Yet, the most effective means of managing cephalopod fisheries is by regulating fishing effort, which will reduce the risk of recruitment overfishing. The present ban on trawl fishing during the monsoon as variously practised by different maritime states is in effect a means of regulation of fishing effort and should be continued.

Utilization and marketing

There is very little internal market demand for cephalopods and consequently almost all the catch is exported. While the export quantity peaked in 1995 the annual average is about 24%. However, the value of cephalopods in total marine exports has remained at 15% from 1992 onwards without much variation. In 2003 the value of cephalopods exported amounted to more than ₹ 800 crore. Category-wise, squid products are the maximum in all years followed by cuttlefish products. The products include dried, frozen whole, filleted, tentacles, rings, roe, wings, IQF and bones and ink. Octopus products exported are meagre, but from 1994 onwards there is rising trend in its exports. The main markets for export of Indian cephalopods are the Europe, Japan and China.

The emergence of cephalopods as an important marine fishery resource of the country with almost cent per cent export potential warrants careful monitoring and appropriate management particularly because we are exploiting above the revalidated potential yield of 101,000 tonnes. Several gaps exist in our knowledge of these valuable resources, especially on the life-histories of our species. For example, we still have not resolved the question of semel-parity of most of our species. At present we know that most of the species lay their eggs in the shallow inshore waters. These grounds are subjected to sedimentation due to man-made causes such as dumping of sludge. This might degrade the benthic conditions with a negative impact on cephalopod egg laying and consequently on the recruitment.

Oceanic squids

The purpleback flying squid *Sthenoteuthis oualaniensis* is distributed in the tropical and sub-tropical areas of the Pacific and Indian Oceans. The Arabian Sea is considered as one of the richest regions for these oceanic squids in the Indian Ocean. These squids are pelagic animals living in the open ocean, usually absent over the continental shelves (<200 m), and first appear over continental slopes at depths above 250 to 300 m. The species has been called as the Master of the Arabian Sea due to its high abundance, large size, short life-span, fast growth and near monopoly of the higher trophic niche. The estimated squid stock in the Arabian Sea varies in the range 0.9 to 1.6 million tonnes. In recent years, the species has been found to occur in hook and line and gillnet catches in Kochi and Veraval and its population characteristics has been worked out as $L\infty = 49.1$ cm; $K = 0.83$ yr^{-1} and $t_0 = -0.06$ yr. A major programme is currently underway to exploit this resource using squid jigging.

Gastropod fishery

The exploitation of gastropods in India is age-old for both as food and as curios. The famous money cowries used as currency and the religious sentiments attached to the sacred chank are well known. The gastropod biodiversity in Indian waters is very large (Table 7.10) and no systematic effort has been made to document this qualitatively and quantitatively, apart from few works. Considering the intense exploitation of these shelled animals in certain areas of the country as a raw material for the shell-craft industry, 21 of these ornamental molluscs are declared as endangered and are protected under the Indian Wildlife Protection Act, 1972.

Table 7.10. List of commercially exploited gastropods from Indian waters

Species	Common name	Utility		Availability
		Edible	Ornamental	
Xancus pyrum	Sacred chank		O	South-West coast, Andaman Nicobar and Gulf of Mannar
Turritella attenuata	Screw shells		O	West coast
Polystira sp.	Screw shells		O	West coast
Crassispira sp.	Screw shells		O	West coast
Architectonia perspectiva	Staircase shells		O	West coast
Epitonium scalaris	Ladder shells		O	West coast
Xenophora sp.	Carrier shells		O	West coast
Tibia curta	Wing shells		O	West coast and East coast
Natica albula	Moon snail		O	West coast and East coast
Natica lineata	Moon snail		O	West coast and East coast
Phalium glaucum	Ton shells		O	West coast and East coast
Ficus ficus	Fig shells		O	West coast and East coast
Rapana bulbosa	Purples		O	West coast
Murex pecten	Venus comb		O	East coast
Murex trapa	Rock shells		O	West coast
Murex virgineus	Rock shells		O	West coast
Murex badius	Rock shells		O	West coast and East coast
Murex sp.	Rock shells		O	West coast and East coast
Babylonia spirata	Whelk	E	O	West coast
Babylonia zeylanica	Whelk	E	O	West coast
Hemifuses pugilinus	Spindle shells		O	West coast
Fusinus toreuma	Spindle shells		O	West coast
Oliva gibbossa	Olive shells		O	West coast and East coast
Oliva sp.	Olive shells		O	West coast and East coast
Harpa conoidalis	Harp shells		O	West coast and East coast
Conus glans	Cone shells		O	West coast and East coast
Conus sp.	Cone shells		O	West coast and East coast
Umbonium vestum	Button shells		O	East coast
Cellana radiata	Limpet shell	E	O	East coast
Turbo intrcostalis	Turban shell	E	O	East coast
Turbo sp.	Turban shell		O	Lakshadweep
Strombus sp.	Conch	E	O	East coast and akshadweep
Thias sp.	Dog whelk	E	O	East coast
Chicoreus ramosus	Ramose murex	E	O	East coast
Plueroploca trapezium	Elephant shell	E	O	East coast
Lambis lambis	Common spider conch		O	East coast
Melo indica	Begger's bowl		O	East coast
Dentalium sp.	Tusk shell		O	West coast and East coast
Nassa sp.	Button shells		O	East coast
Nerita sp.	Nerite shells		O	East coast
Trochus niloticus	Top shell	E	O	Andaman Nicobar
Turbo marmoratus	Turban shell	E	O	Andaman Nicobar
Cyprea moneta	Money cowry		O	East coast and Lakshadweep
Cyprea arabica	Cowry		O	East coast and Lakshadweep
Cyprea tigris	Cowry		O	East coast and Lakshadweep
Lambis truncata	Spider shell		O	Lakshadweep
Charonia tritonis	Trumpet triton		O	Lakshadweep

Chank fishery

Chanks (*Xancus pyrum*) are fished mainly for the shell and an organized fishery of considerable magnitude exists along the south-east coast of India. They are also collected at a few other places along the Indian coast. Major chank resources occur in the Gulf of Mannar, particularly along the Ramanathapuram – Tirunelveli coast. Other areas are Tanjavur, South Arcot and Chingelpet in Tamil Nadu, Trivandrum coast in Kerala, the Gulf of Kachchh in Gujarat and the Andamans. Unlike pearl oysters, the chanks are regularly fished with few exceptions.

Chank fisheries of Tamil Nadu coast: The Tamil Nadu Government exercises control over the chank fisheries. The minimum legal size for the capture of chanks is 64 mm MSD (maximum shell diameter). The undersize chanks are to be released in the chank bed. The coast is divided into 6 fishing areas: namely (a) Tirunelveli, (b) Ramanathapuram, (c) Sivaganga, (d) Tanjavur, (e) South Arcot and Chingelpet, and (f) Kanyakumari. Among these the first named two placed are the most productive and the chank beds (known as 'Sangunilam' in Tamil) are mostly located in 10-20 m depth zone. Skin diving is the most important method for collecting the chanks. Each plank built boat takes 10-15 divers to the fishing grounds. Expert diver can remain underwater for about a minute and can make about 40 dives in a day. A diver collects 15-20 chanks/day. There are about 1,000 divers engaged in chank fishing. In the northern areas, chanks are incidentally caught by light trawls locally known as 'vellaivalai' and 'thurivalai' operated from catamarans. The annual average production of chanks in numbers is approximately 500,000 (value ₹ 0.8 million) in the Tirunelveli fishery. Here the TN Fisheries Department organizes the fishery during November, May season. Usually 100 to130 chank diving days are organized in a season depending upon clarity of water. The annual average landing in the Sivaganga – Ramanathapuram fishery is 300,000 chanks (lease rental ₹ 0.225 million) and the fishing season is variable, depending upon the location of the fishing grounds in the Palk Bay or the Gulf of Mannar. The annual production from the remaining fishing areas is about 45,000 chanks.

In recent times chanks are increasingly caught in the bottom trawls operated from mechanised boats and also in gears such as gill nets. During July 1971 – June 1972, trawlers that operated in 14 to 36 m depth off Porto Novo landed a total of 1,01,117 chanks. In May 1972 itself trawlers operating in 31 to 36 m depth landed 53,635 chanks indicating greater abundance in deeper waters. The proportion of under-size chanks (<64 mm MSD) was alarmingly high. During May 1976 to December 1977 at Porto Novo, 56,539 chanks were landed by bottom trawls and set gill nets, the former accounting for the bulk of the production. The total length varied from 51,270 mm. The average annual catch by skin diving at Tuticorin for a 12-year during 1971-72 to 1982-83 was 568,921 chanks and by fishing nets (mostly trawls) 27,254 chanks. Among the chanks landed incidentally by the fishing nets, the under-sized and wormed chanks formed 83.9% against 19.5% in the chanks collected by skin divers. This is attributed to the non-selective nature of the fishing gear. During 1984-85 and 1985-86 seasons there was substantial increase in the chank catches by fishing boats at 56,638 and 52,775 chanks, respectively, against a decline in the catches collected by skin diving.

Along the Rameswaram coast a modified shrimp trawl known as '*chanku madi*' is used to fish chanks. This net has 300-350 sinkers and 40 mm cod end mesh against 110 to 115 sinkers and 25 mm cod end mesh of the shrimp trawl. The *chanku madi* ploughs through the bottom sediments upto 15 cm deep and all the soil biota in this layer is hauled. In five hours trawling, 153 kg of chanks (61.2%), 56 kg echinoderms and 41 kg rays were fished. The chanks measured 91,220 mm shell length and the monthly production was 54 tonnes (150,000 chanks). The authors stated that *chanku madi* is carried in the shrimp trawlers and operated clandestinely, whenever the fish/ shrimp catch is poor. In 1994-95 the Tamil Nadu Government removed the entire control over chank fisheries excepting issuing licences to divers and boats engaged in chank fishing. Currently an 11-point scale of MSD is used by fishers and traders to grade chanks and price them. The price of one top grade (>110 mm MSD; OO class) chank at the landing centre is ₹ 600-650 while in the 1980s its cost was just ₹ 3.50.

Chank fisheries of Kerala coast: The Kerala Government leases the right to collect chanks to cooperative societies. Chanks are fished since early times along 65 km Trivandrum coast by skin diving. The season is from January to April and they are fished from 10 to 20 m depth zone by divers wearing locally made masks. Catamarans are used for transport and each diver collects about 10 chanks per day. Chanks are also caught incidentally in bottom set gill nets and shrimp trawls. At Sakthikulangara, shrimp trawlers fishing at 40-50 fathom (72-90 m) depth land considerable quantity of chanks (length 100-220 mm). Chank fishing is also done with 250,500 m long line, holding 500-1000 hooks. As the hooks are dragged on the seabed the foot of the chank gets hooked firmly. Long-line fishing began at Vizhinjam in 1976. During the four fishing seasons from 1976-77 to 1979-80, long-line units accounted for 70 to 86% of chank catch. During 1964-65 to 1979-80 the average annual production was 22,000 chanks.

Chank fisheries of Gujarat coast: The Gujarat Fisheries Department controls chank fishing. Chanks are fished along the Gujarat coast in the Gulf of Kachchh. The fishing area lies in 200 km coast line between Sachhana and Okha. The chanks are fished in the intertidal area of patchy coral reefs and due to high tidal amplitude vast stretches of intertidal areas are exposed at low tides. The fishing season is from September to May with peak during December-January. However, around Sikka the fishing season is from March to June. Plank-built boats are used to reach islands. During the spring tides, the fishermen wade through the water, handpick the chanks and empty the catch in a basket known as 'Gumbha'. Between 1952-53 and 1983-84 the number of chanks collected varied from 3,696 (value ₹ 3,813) in 1977-78 to 14,360 chanks (value ₹ 143,718) in 1983-84. Average annual production was 9,581 chanks. In 1984-85 a high production of 20,899 chanks was recorded. There was decline in the chank catches from 1987-88 onwards. In 1996-97 only 798 chanks were caught. The fishermen are paid ₹ 1-50 for wormed chank and up to ₹ 6/, for <10 cm MSD chank. Further ₹ 10/, is given as bonus to those who bring 100 chanks during a single tide.

The fishermen take out the chank meat for their consumption. The Gujarat Fisheries Development Corporation undertakes marketing of the chanks.

Total chank production in India: The average annual chank production in India is around 1,256,000 chanks comprising 877,000 from Tirunelveli coast, 300,000 from Ramanathapuram coast, 40,000 from Thanjavur – South Arcot – Chingelpet coast, 22,000 from Kerala, 12,000 from the Gulf of Kachchh and 5,000 from the Andamans. In terms of weight, chank production would be 1,250 tonne /year.

Population dynamics: The average annual stock in the Gulf of Mannar is estimated at 2 million adult chanks of which 44.83% are exploited. However, the initial stock size varied from year to year. Hence there are different levels of optimum yields for different initial stock sizes. The average annual stock of chanks in the intertidal region of the Gulf of Kachchh is 25,000 of which only 30.6% is exploited; additional catch is possible only for the 60 to 80 mm MSD chanks as >81 mm chanks are already well exploited. There is scope to increase the production by introducing SCUBA diving in 20 to 30 m deep grounds in the Gulf of Mannar and by exploiting the chanks in the Gulf of Kachchh beyond the inter-tidal zone.

Whelk fishery

The whelks come under the order Neogastropoda and family Buccinidae. They are mostly carnivorous and scavengers. The meat is edible and the shell is used in the shell craft industries. In India, two species namely, *Babylonia spirata*, and *B. zeylanica* are landed as by-catch, mostly in the bottom trawls. The former species is more abundant and most of the production is exported. Except for some fishery data in the by-catch of shrimp trawls, no information seems to be available on *B. zeylanica*.

Till early 1990s, *Babylonia* spp. was incidentally caught, mainly in shrimp trawls, and was not considered as of much fishery value. In July 1993, their meat was exported to Japan for the first time. Since then the by-catch landed by shrimp trawlers, particularly off Kollam, is being sorted and the whelks collected. Total whelk meat export amounted to an average 247 tonnes valued at ₹. 52.8 million during 1999-2003. The meat of *B. spirata* fetches US $ 6.9/kg and the operculum US $ 17/kg. Heavy landings of *Babylonia* spp. occur off Kollam. During January-May 1996 as the whelk price shot up to ₹ 35 to 70/kg from an earlier price of ₹ 20 to 30/kg coupled with relatively poor shrimp landings, the shrimp trawl owners modified the net by adding 20-28 kg of lead rings to the trawl nets and increased the cod end filament thickness to 1.5 mm. As a result, the trawl net operated much closer to the bottom and the thick cod end filament helped to withstand the weight of shells. This was reflected in higher by-catch and the whelk catch was estimated at 390 tonne in May 1996, compared to an average monthly catch of <50 tonnes during the proceeding four months. The *B. spirata* formed 60% of whelk catch and the length ranged from 19 to 51 mm (average length 33.7 mm and average weight 12.7 g). The *B. zeylanica* accounted for 40% of the production and the length ranged from 21 to 67 mm (average length 48.1 mm and average weight 17.87 g). The value of the whelks fished in May 1996 was estimated at ₹ 1.75 crore. It was observed that 390 tonnes of whelk would yield 3.9

Table 7.11 Population parameters of whelk fishery at Kollam, Kerala

Parameters	*Babylonia spirata*	*Babylonia zeylanica*
L_∞ (mm)	68.7	76.0
K (y^{-1})	1.08	1.15
Z (y^{-1})	6.05	5.02
M (y^{-1})	1.61	1.65
F (y^{-1})	4.4	3.6
E	0.73	0.71
E_{max}	0.73	0.77
$E_{0.1}$	0.66	0.72
Spawning stock biomass (tonnes)	92.9	267.7
Standing stock biomass (tonnes)	216.2	404.1
Recruitment numbers	84,565	92,782

tonnes of operculum valued at ₹ 15.5 lakh. The population characteristics of *B. spirata* and *B. zeylanica* have been studied, and the estimates (Table 7.11) indicated that both *B. spirata* and *B. zeylanica* are overfished at Kollam following the $E_{0.1}$ management strategy.

Since 1995, the fishermen began to exploit *Babylonia* spp. off Puducherry in 5 to 25 m depth with slightly modified ring net, normally used for crab fishing. The average daily catch for ring net/catamaran unit varied from 14 kg in March 1996 to 42 kg in February 1996. At Annappanpettai landing centre along the Porto Novo coast, fishing for *B. spirata* was carried by special traps with dried octopus or eel as bait and operated from catamarans in 5 to 20 m depth. Fishing is throughout the year except during October-December. There are 7 mechanised and 6 non-mechanized catamaran trap units and the former unit carries 60-70 traps and the latter 25-40 traps. During March-August 1993, the production of *B. spirata* was estimated at 211 tonnes. Boiled meat from 211 tonne of the whelk was estimated at 54 tonnes (₹ 40/kg) and operculum 11 tonne (₹ 400/kg). At Tuticorin, both the whelk species occur in 100,150 m depth at a distance of 50-60 km from the coast. During January-February the whelk catch was 1.5 tonnes/trawler/month and in July it was 1.7 tonnes/trawler/month. In other months the whelk catches were poor. Along southern Karnataka, whelk (*B. spirata*) fishing is practised using traps normally used for crabs and ladyfish. Annual yields are around 175 tonnes and maximum abundance is seen in January-February and November. The major market for Indian whelk (as chilled whelk, shell-on) is Hong Kong (90%) followed by Thailand, UAE and Maldives.

Fishery for ornamental gastropods

There are several economically important species of gastropods which are regularly collected for meat / and or shell. They come under many families, extensively used in shell craft industry and are popularly called as ornamental gastropods. Many of them live in coral reef habitat in regions such as the Gulf of Kachchh, Gulf of Mannar, Palk Bay, Andaman and Nicobar Islands and the Lakshadweep group of Islands.

Occurrence of 29 species of gastropods has been recorded in the by-catch of shrimp trawls, operated off Kollam. In addition to *Babylonia* spp. and chank, important ornamental gastropods landed are *Tibia curta* (wing shell), *Bursa spinosa* (purse shell), *Turritella attenuata* (screw shell), *Rapana bulbosa* (purple shell) and *Conus glans* (cone shell). They accounted for 80% of total gastropod landings.

The Ramanathapuram coast in Tamil Nadu is famous for the production of several ornamental gastropods and 12 small-scale shell-craft industries exist at Rameswaram and Keelakarai. The species of the following genera are collected and used by the industry: *Oliva, Cypraea, Natica, Cerithidea, Cymatium, Lambis, Xancus, Pyrena, Umbonium, Littorina, Tibia, Strombus, Conus, Murex, Babylonia, Fusinus, Cymbium, Faciolaria, Cassis, Bursa, Phalium, Tonna* and *Thais*. Among these, 175,000 *Lambis* spp. are fished annually and each shell fetches ₹ 1 to 3 for the fishermen. The methods of collection include hand-picking, skin diving, hand dredging and as by-catch from different fishing gears. On an average 400,000 shells, which also include those brought from the Andamans are used by the shell-craft industry. The shells are placed in bleaching powder solution for 24 hr in cement tanks, followed by immersion in caustic soda solution for 1 hr. They are polished by keeping them in 5% Hydrochloric acid for 10 sec to 4 min, depending on size, thickness and colour. The ornamental products made out of these shells include table lamps, lamp shades, necklaces, ear-drops, beads, hair pins, sculptures of Gods and Goddesses, agarbathi stands, bangles, flower vases, and shell screens for doors and window curtains. There are about 70 shell craft selling shops at Rameswaram and the annual turnover is about ₹ 10 lakh. From the Kakinada Bay, the estimated the average annual production of *Cerithidia* sp. is 990 tonnes, *Telescopium* sp. 221 tonnes, *Umbonium* sp. 292 tonnes, *Thais* sp. 79 tonnes and *Hemifusus* sp. 35 tonnes. Some of these gastropods are also used in lime preparation.

In the Andaman and Nicobar Islands, in addition to the use of topshell, green snail and chank, species of *Cypraea, Strombus, Lambis, Conus* and *Thais* are regularly used in shell craft industry. The ornamental gastropods of the Lakshadweep include the cowries *Cypraea caputserpentis*, *C. moneta* and *C. tigris*, and are exploited at a sustenance level by hand-picking during low tides. Other methods adopted are by diving and by collecting from the coconut leaves, placed in the lagoon water for a few days on which *C. moneta* congregate. The estimated production in numbers of *C. moneta* was 5 to 7 lakh / year priced at ₹ 25 to 30/kg and *C. caputserpentis* 2 to 3 lakh/year valued at ₹ 30 to 35/100 cowries. Other ornamental gastropods collected include *Cypraea rufa, C. arabica, Conus leopardus, C. litteratus, Cassis cornuata*, and the spider conchs, *Lambis truncata* and *L. chiragra*.

Estimated production of ornamental gastropods from the country at 600 tonnes/year. Since then substantial increase in production is discernible. During 1991-2003, on an average 271 tonnes/year of sea shells (average value ₹ 72.0 million) were exported from the country (MPEDA). In a recent notification dated 21 July 2001 the Ministry of Environment and Forests, Government of India has included 44 gastropod species in Schedule I of the Wild Life Protection Act, 1972. The species include 11 under the genus *Cypraea*, 6 each under the genera *Conus* and *Lambis*, 3 under *Murex*, 2 each under *Harpulina, Strombus* and *Mitra* and one species each under 12 different genera.

A vast majority of them are ornamental gastropods and are protected by the Act.

Future of molluscan exploitation

The following are areas of concern with regard to exploitation of molluscs in India:

- Exploitation of cephalopods above the potential yield estimate and localized over-exploitation of stocks
- Oceanic cephalopod potential to the tune of 20 to 50,000 tonnes which are yet to be exploited
- Grossly under-reported catches of bivalves and gastropods
- No major studies in the country on bivalve and gastropod biology and no information on the magnitude and economics of the shell-craft industry
- Conservation and stock rebuilding strategies with respect to endangered molluscs are not in place

It is important to determine the science, management and institutional requirements needed to obtain the tremendous potential value from molluscan resources to the country and to make a path for sustaining molluscan fisheries and rebuilding protected species stocks to realize their long-term potential.

8. Island Fisheries

India is endowed with two unique oceanic island ecosystems, the Lakshadweep island ecosystem and the Andaman-Nicobar island ecosystem, both distinctly different in their topography, physical characteristics, climate, ecology, fauna, flora, as well as culture and traditions of the inhabitants. Both are pristine biodiversity-rich habitats offering unique opportunities for conservation as well as responsible utilization of the natural resources. Most of these islands are inhabited and various anthropogenic activities and interests have contributed to both development and deterioration. Thus, a knowledge-based responsible and inclusive agenda for future use is needed for ensuring ecological sustainability and economic viability. Recent interests in the developmental activities of these island systems are to be viewed in the context of long-term environmental costs and social benefits and therefore careful consideration of risks and vulnerabilities attracts priority.

Status of fisheries in the Lakshadweep islands

The Union Territory of Lakshadweep consists of a chain of 11 inhabited and several uninhabited islands, scattered in the Arabian Sea between latitude 08° 00' and 12° 30' N and longitude 71° 00' and 74° 00' E, at about 200 to 400 km away from the Kerala coast. The archipelago consists of 12 atolls, 3 reefs and 5 sub-merged banks. There are 36 islands, covering an area of 32 km^2. The inhabited islands are Androth, Amini, Kalpeni, Agatti, Bitra, Chetlat, Kadamat, Kaileni, Kavaratti, Kitan, Minicoy and Bengaram. Among the uninhabited islands, Suheli is a coconut growing and fishing centre. Pitti island is a small reef with sand bank covering an area of 1.2 ha where thousands of birds nest and is now designated as a bird sanctuary. All islands except Androth have a lagoon. Bitra has a magnificent lagoon. These being oceanic islands, the continental shelf area around them are limited to 4,336 km^2. However, the lagoons altogether have an area of 4,200 km^2 offering immense biotic diversity and potential. Also, the territorial waters around the island provide about 400,000 km^2 offering extensive fisheries potential.

Lakshadweep has a long history of being a traditionally maritime community of sailors, traders and fishers for centuries. The mainstay of the community is coconuts and marine fish caught mostly through traditional fishing methods as well as income form native men who are employed as crew in maritime trading vessels.

Fisheries resources

The major fishery resources of the island include the oceanic resources such as tuna, billfishes, pelagic sharks, marlins, sailfish and other groups of food fishes such as flying fish, barracuda, seerfish, rainbow runner, garfishes, halfbeaks, snappers, perches, clupeids, carangids, breams, trigger fishes, rays, octopus, etc. The live baits and ornamental fishes of the islands are exclusive living resources of the islands. While the live baits are essential components in the traditional pole and line fishery for the capture of tuna, the ornamentals have immense potential for export trade. The common species of tuna in the Lakshadweep waters are: skipjack, *Katsuwonus pelamis*, yellowfin, *Thunnus albacares*, frigate tuna, *Auxis thazard*, and little tunny, *Euthynnus affinis*. The Central Marine Fisheries Research Institute (CMFRI) has reported 601 species of fishes from the Lakshadweep waters. The commercial tuna fishery of the islands presently depends mainly on the skipjack. The potential annual yield of tunas is estimated to be about 50,000 tonnes and all other fishes another 50,000 tonnes against the average current yield of 7,500 tonnes (2000 to 2005 data), which is only 15% of the harvestable potential. In 2006, the CMFRI recommended several measures for the fishery development of the Lakshadweep: revalidation of the potential yield estimates; upgrading of the fishing fleet; introduction of new tuna longliner-cum-gillnet for *sashmi* grade tuna; modernization of fishing gear; value-addition and production of high-end products such as *sashmi* grade tuna; smoked and frozen tuna loins and high quality *masmin*; conversion of tuna waste into pet food and organic manure; improvement in marketing; training demonstration; human resource development in craft and gear technology and processing for stakeholders of the islands. A project, intervening at five stages, namely resource assessment, production, processing, economics and consumption in value chain of oceanic tuna fisheries of the Lakshadweep (under the National Agriculture Innovation Project), is currently under operation.

Fishing methods

The fishing has remained in the traditional mode for centuries and this was a hindrance for development of the industry. One of the limiting factors in the development of the pole and line fishing is the availability of live baits. Live bait fishes are used for chumming and attracting the tuna shoals. The live baits are essential for operation of the pole and line fishery. These fishes caught from the reefs and lagoons are kept in live condition in special region of the boats for use at the capture. There are 21 species of live baits available in the Lakshadweep waters, of which over a dozen species are normally used for fishing. The most common are: *Spratelloides delicatulus*, *S. japonicus*, *Apogon sangiensis*, *A. savayensis* and *Chromis ternatensis*. The major fish landing centres are in the islands of Agatti, Suheli, Minicoy, Bitra and Androth. With the introduction and gradual increase in the number of the mechanized fishing vessels, the marine yield has been steadily increasing to about 10,000 tonnes/year. The highest landings are in Agatti, which on an average contributed to 31%, followed by Minicoy (17%), Suheli (14%), Kavarati (8%), Androth (8%), Bitra (6%), Kiltan (6%), Chethlath (5%), Amini (2%), Kadamath (2%) and Kalpeni (1 %). However, the potential for tuna alone is over 50,000 tonnes, the current yields are too small in contrast to those from Maldives (148,000 tonnes) and Sri Lanka (27,000 tonnes). The major species landed from the islands are *K. pelamis* (86%), *T. albacares* (12%) and *Euthynnus affinis* (2%).

The total fish yield from the Lakshadweep islands have grown rapidly from 9,887 tonnes in 1995 to 11,400 tonnes up to 2007. The tuna component in the catches have generally remained steady around 8,000 tonnes during this period except in 1998 when it reached an all time high of 12,308 tonnes. Since 1996 onwards, the total fish yield has remained above 10,000 tonnes except in 2002 (9,149 tonnes). The all time highest fish yield was 14,615 tonnes in 1998. The data for 2007 indicated that the tuna catches were about 8,874 tonnes with the yield reaching 11,400 tonnes. The catches of sharks have been declining from the island ecosystem. The highest yield was in 1998 with 980 tonnes. Since 2001, the yield of sharks has declined considerably to less than 100 tonnes. In 2004 the yield was only 77 tonnes. The contribution of miscellaneous fishes also dwindled in recent years. The highest catch was in 1999 with a record of 4,188 tonnes, whereas in 2004 it was only 790 tonnes.

Over 97% of the catch is from the traditional pole and line fishing followed by the troll lines. The oceanic tuna longline fishing was introduced in the early 1980s. The Maritime Zone of India (regulation of Fishing by Foreign Vessels) Act of 1981 permitted charter of foreign vessels for fishing in the Indian EEZ. Under this scheme, tuna long liners operated in the Indian waters from 1985 and 1995. Tuna vessels also operated under two other schemes introduced in 1991: (*i*) leasing of foreign vessels by Indian entrepreneurs for operation in the Indian EEZ, and (*ii*) joint ventures between Indian and foreign companies in fishing, processing and marketing. The charter scheme was gradually phased out between 1992 and 1995 in favour of joint ventures by Indian owned vessels. The joint ventures were not successful and the Tuna conference in 1999 recommended conversion of 30% of the existing fleet of Indian trawlers of 23 to 27 m overall length for undertaking monofilament tuna long lining.

For the past 15 years, about 300 boats were operating the pole and line for tuna in the islands. These boats of 25 to 35 feet (7.5 m to 10.5 m) OAL conduct single day fishing trips, sometimes operating two trips per day during the peak season. Larger boats with higher capacity cannot be introduced because of the shallow nature of the lagoons. The islands of the Lakshadweep has an overall fishing fleet of 1,401 country crafts and 1,249 motorized crafts and 10 mechanized vessels (2007 data). Pre- 2007 data indicated that the island Kavaratti had the highest number of country crafts (260), whereas the island Agatti had the maximum number (130) of motorized boats.

The Catch per unit effort (CPUE) and mean sizes have remained more or less steady over the past many years. About 23 % of the fish landings of the islands are from Agatti, followed by Kavaratti (14%) and Minicoy (13%). Tuna landings in Androth have increased since 1994 after the introduction of drift gillnetting and fishing in distant grounds such as Elikalpeni Bank. The Fish Aggregating Devices (FADs) were introduced on experimental scale in the lagoons and open seas in 2002. The data buoys for Arabian Sea Monsoon Experiments installed by the National Institute of Ocean Technology, which are 16 to 26 nautical miles from Minicoy and Kavaratti aggregate young tuna, which the fishermen find convenient to locate using GPS and attractive to operate fishing gear because of assured catch. The catches from the FAD sites had higher percentage of juvenile tuna (18 to 20%) than non-FAD sites and therefore indiscriminate use of FADs can be adversely impacting the tuna stocks.

Development of the tuna fisheries of the Lakshadweep will largely depend on the ability of the local fishers to adopt modern fishing techniques and the preparedness of the industry to invest in modern handling and transportation methods and processing facilities for high value tuna products. There is need for a shift of focus from the Skipjack tuna to Yellowfin tuna in the Lakshadweep island ecosystem. Currently the fishermen catch the Skipjack by pole and line fishing. The traditional Pablo boats can be converted to operate long lines and provided with a fish hold with ice to chill the catch until landing. There is need for ensuring steady supply of ice to fishers as well as a mechanism to buy the chilled fish on landing at any time of day or night. Larger vessels of 62 ft or 18.34 m overall length (OAL) with global positioning system (GPS) and chilled sea water (CSW) should venture into oceanic fishing and the sashimi grade tuna to be brought into the mainland for export. The Marine Products Export Development Agency (MPEDA) has been providing subsidies to convert trawlers into long line fishing boats.

The CMFRI has worked on an NAIP Project which has, among others, objectives aimed at evolving effective fishing methods for Lakshadweep Seas to increase and sustain production of oceanic tunas and related resources by assessing the status and health of stocks and ecosystems. The project also aims at developing technologies for hygienic and improved handling, processing, packaging and development of high-value products as well as transferring the fishing and processing techniques to stake holders.

Post-harvest

About 50% of tuna caught in the islands around Minicoy are consumed fresh or converted to *masmin,* while the rest are used for canning. Almost all the tuna caught in the rest of the islands are consumed fresh or converted to the traditional *masmin.* The traditional processed product *masmin* is the favourite item made out of more than 50% of the catch while the rest are consumed fresh and small quantities canned into white tuna meat in brine/oil. The Lakshadweep Development Corporation Limited (LDCL) is promoting export of frozen tuna, canned tuna and tuna pickles.

Tuna is one of the best marine products which has global market. The world tuna market has two preferred items: the high prices *sashimi* which is consumed fresh and uncooked and the low-priced canned tuna. The *sashimi* market relies on Bluefin, Bigeye and Yellowfin while the canned tuna market depends on Skipjack, Albacore and Bonito. The high-priced *sashimi* market is very strong, catering to the soaring Japanese demand and the recently upcoming market demands of the Europe and the USA. On the other hand, the low-priced canned tuna market which mainly depends on the Skipjack is rather over-supplied and is facing declining demand and prices. A new trend involving trade of fresh and frozen tuna is emerging, especially for loins, the trading of which has doubled from 1986 to 2005. Tuna waste is another emerging market. A number of products such as tuna viscera powder as a flavour for feeds, tuna bone products as a dietary calcium source, and tuna oil products and tuna eye as a source for long chain polyunsaturated fatty acids–Docosahexaenoic acid (DHA) and Eicosapentaenoic acid (EPA). Tuna waste from the Lakshadweep islands is a potential raw material for the fast-growing pet food industry. Skipjack tuna viscera protein hydrolysate is used as a protein supplement in manufacture of sauces and bread. There is considerable scope for converting tuna waste to productive use.

Ornamental fishes

Out of the 600 odd marine fish species reported from the Lakshadweep waters, over 300 species belonging to 35 families are recognized as ornamental fishes with attractive colour and shape. The CMFRI survey showed that 252 species belonging to 35 families are present in the islands, of which 165 species belonging to 20 families are common ornamentals which have great demand. The bionomics of these commercial species and their harvestable numbers also have been worked out in this study. There is a good scope for evolving hatchery breeding protocols for some of the species which are in great demand and developing an export trade. Some efforts have been made by the LDCL as well as MPEDA towards commercial production of marine ornamentals through hatchery protocols, but has not met with any success. The CMFRI has developed commercially viable techniques for mass breeding and larval rearing of many marine ornamentals. However, no commercial enterprise has come forward to establish an export-oriented hatchery for development of this potential area.

Mariculture

The islands provide shallow lagoons and clean waters which are ideal for developing mariculture of certain high value species such as seaweeds of commerce, pearl oysters, cage culture of groupers, pomfrets, tuna, breams, rabbitfish (*Siganus* sp.), cobia (*Rachycentron canadum*) etc. These would provide the needed employment opportunities for the local youth and provide avenues for investment and entrepreneurship. The high scope for mariculture of seaweeds, sea cucumbers, cage culture of finfish like seabass, cobia and tuna in the Lakshadweep island ecosystem could be promoted to highly lucrative business models by involving the local youth.

Sport fisheries

Presently the concept of sport fisheries or recreational fishing is yet to get any acceptance in the Lakshadweep islands. Since there is an influx of international tourists to the islands and their numbers are fast increasing, scope exists for its development in the islands. Concerted efforts on this line are needed not only from the recreational point of view, but also as an avenue for employment for local youth from this activity as local guides, people movers and fishing gear providers. There is need for changing the outlook of the local population towards tourists as well as training the youth to take up tourism-related activities as a source of employment.

Future prospects for fisheries development

The Lakshadweep islanders, being a traditional orthodox society with a different social, cultural and attitudinal background, development initiatives and interventions need to be planned by taking into consideration the views, aspirations and visions of the communities. The CMFRI and CIFT have jointly prepared an Integrated Perspective Plan for the Fisheries Development of Lakshadweep (LAKFISH). This comprehensive document addresses the development agenda holistically and outlines a master plan for a well-planned and knowledge-based development approach. Infrastructure development for fishing, berthing, landing, storage, processing, value-addition and marketing of fish and fishery products are outlined in this document. Also addressed are issues in mariculture, product diversification, market expansion, eco-tourism, human resource development, investments, economic benefits, administrative reforms and policy interventions.

By 2017, the export trade will develop to ₹ 3,751 million and the domestic trade to ₹ 611 million, totaling to ₹ 4,362 million by harnessing 75% of the potential yield. About 15,000 tonnes of processed fish are expected to be exported from the islands, if the master-plan is implemented in three phases as proposed. The master-plan also outlines the possible employment and investment opportunities in the fisheries sector of the islands. The master-plan prepared by the CMFRI for the development of the fisheries sector in the Lakshadweep island provides several key recommendations and interventions which, if implemented, could make significant development in the fisheries sector.

Status of fisheries in the Andaman and Nicobar islands

The Andaman and Nicobar group of islands enjoy the status of an archipelago. These islands are situated in the Bay of Bengal lying between 6° 45' N and 13° 41' N latitude and 92° 12'E and 93° 57'E longitude. There are more than 550 islands, islets and rocky outcrops in the archipelago. These islands are typically oceanic in nature and encompass an EEZ of 0.6 million km^2. This area is about 28% of the Indian EEZ. These islands have an aggregate coastline of 1,962 km. The continental shelf around these islands is very narrow and on the western side relatively wider, extending up to 10 nautical miles in some places. All together the continental shelf is 35,000 km^2. These islands have diverse ecosystems like evergreen forests, mangroves, sandy beaches, tidal flats, coral reefs, etc. The mangroves occupy around 115 km^2, while the coral reefs are spread across an area of more than 2,000 km^2.

Earlier studies showed that the Andaman seas are oligotropic in nature with relatively low (273 mg C/m^2/day) primary and low (288.8 mg C/m^2/day) secondary productivity. However, primary production of Nicobar region is significantly higher than that of the rest of Andaman seas. The limitations in the extend of continental shelf are compensated by presence of numerous bays, creeks and inlets on the landward side and vast areas of productive oceanic waters of the Bay of Bengal and the Andaman seas on the east coasts.

The Andaman and Nicobar islands have been a group of historically isolated and segregated islands. It was only during the rule of the British that these islands were utilized for many purposes including defence, natural resource, deportation and confinement of prisoners as well as freedom fighters. There has been no traditional fishing population in Andaman and Nicobar (A&N) islands. Migration of fishermen from the mainland especially from the maritime states of Andhra Pradesh, Tamil Nadu and West Bengal commenced after independence. These settlers and their descendants form the present fisherfolk in these islands. In few islands, fishing is carried out by aborigines with bow and arrows and by the Nicobari tribes with spears. Therefore, the development of fisheries in these islands has been tardy. The crafts and gears used by the fishermen are of the traditional type and of limited capacity. The fisheries is thus mostly confined to limited areas. Endurance for high sea fishing, exploratory and multi-day fishing, fishing for coastal tunas, oceanic tunas and other straddling stocks are not possible with the limited capacity of the craft and gear. Further, lack of modem and adequate infrastructure for landing, storage, processing and transportation of fish and fishery products, remoteness of the islands from the main land, limitations in marketing and trade, both for local as well as consumption on the mainland, poor information and communication facilities, lack of adequate data on the stock size, availability and accessibility coupled with lack of a proper fisheries development action plan have contributed to the inadequate and unorganized development of fisheries in the A & N islands. A roadmap for the Development of Fisheries in Andaman and Nicobar Islands (ANDFISH 2005)was prepared for comprehensive fisheries development of the islands.

Major fisheries of Andaman and Nicobar Islands

There are varying estimates of the potential yields from the Andaman island eco-systems. The Fishery Survey of India estimates 56,000 tonnes of pelagic resources, mainly tuna, 32,000 tonnes of demersal resources, mainly perches and 56,000 tonnes of oceanic resources, mainly oceanic tuna. The revalidated potential yield of the Government of India estimates a potential yield of 148,000 tonnes of pelagic, demersal and oceanic resources.

The capture fisheries of Andaman and Nicobar islands is restricted to near shore waters. The A & N islands have 2,973 active and full-time fishermen. The average yield is around 31,000 tonnes, and the major exploited resources are carangids (4,570 tonnes), lesser sardines (2,990 tonnes), mackerel (1,520 tonnes), seerfish (1,680 tonnes), anchovies (830 tonnes), coastal tunas (810 tonnes), other clupeids (340 tonnes), pelagic sharks (70 tonnes) and other varieties (13,160 tonnes). Of the above resources, carangids and miscellaneous groups (others) are over-exploited while anchovies are exploited at sustainable level. The rest are all under-exploited. Out of the potential yield of 139,000 tonnes of pelagic marine fish, the present exploitation is around 25,900 tonnes contributing to 19% of the resources. Thus, it is clear that there is great scope for increasing the yield for sardines, mackerel, clupeids, seerfish, anchovies and coastal tunas. This is especially important as the stock of coastal tunas in the Andaman and Nicobar islands waters is around 100,000 tonnes, while the capture is limited to only 810 tonnes.

In demersal fisheries the major species caught are: perches (1,820 tonnes), mullets (1,320 tonnes), silver-bellies (750 tonnes), crabs (550 tonnes), pomfrets (320 tonnes), catfishes (130 tonnes), prawns (120 tonnes), sciaenids (60 tonnes) and polynemids (20 tonnes). The potential yield of demersal fishes is around 22,500 tonnes, of which the present level of exploitation is only 23%.

Development of marine fisheries

Our information on the marine fishery resources in terms of resource size, potential yield and actual yields is rather scanty. The estimates on marine fishery potential in the EEZ of Andaman and Nicobar islands range from 4,000 tonnes for demersal and 8,000 tonnes for pelagic in 1973 to 690,000 tonnes in 1990. Since there are over a dozen estimates of potential yield based on different methods (catch rate, organic production, production per unit area, swept area method, tertiary method, etc.), comparison between estimates would be difficult. The working group on revalidation of fishery potential has estimated the Andaman and Nicobar islands fishery resources to be 243,500 tonnes (22,500 tonnes for demersal, 139,000 tonnes for pelagic and 82,000 tonnes for oceanic region). The estimate was subsequently reassessed as 148,000 metric tonnes by the Fishery Survey of India (FSI). In addition to the above, other resources such as deep sea, crustaceans, edible and other commercial molluscs, sea cucumbers, soft corals, seaweeds, etc. have not been assessed for their potential. Further, no estimates are available for reef fishes, groupers, snappers, rabbit fish, lobsters, shrimps, bivalves, sharks, sea cucumbers and seaweeds.

The data on fishing efforts is not avaliable, hence deficiency estimates on catch rates and abundance are not available. Based on data available before tsunami the Andaman and Nicobar islands have 523 motorized boats and 1,334 non-mechanized country crafts. Similarly, the fishing gears in the islands consist of 3,419 gill nets, 11,361 hook and line, 2,101 cast nets and 98 miscellaneous. ANDFISH (2005) gives a catch index (catch/EEZ area × 100) of 5.00 for A & N islands, as against 284.44 for Malaysia, 144.48 for Indonesia, 133.66 for India and 17.39 for Maldives. Thus, it is obvious that the A & N waters are being under-fished and there is a great scope for further development.

Since the future development of the marine fisheries of A & N Islands will largely depend on the level of exploitation of the potential tuna resources of about 100,000 tonnes, there is a great need for addressing the issues related to the capture of these fishes. Tunas along with pelagic sharks, barracudas and seerfish will have to be targeted by drift gill netters and small longliners through the deployment of new vessels in a phased manner. The climate for investment by entrepreneurs by the private sector also should improve by creating a conducive investment climate for the private sector. There is also a great scope for preparation and export of *sashimi*-grade tuna by private investment. Aquaculture development is another area which requires serious consideration. The pristine sheltered habitats of the Andaman and Nicobar Island system provide an excellent habitat for open sea mariculture of many species of finfishes, shellfishes and seaweeds. There is also a need for developing harvest and post-harvest fishery estates to promote organized and faster development. Development of sport fishing also has good scope for investment and growth in the islands in view of the

large tourist flow. Conservation mariculture by sea ranching of threatened species of molluscs, sea urchins, hatchery production and transplantation of giant clams, propagation of live rock and corals also is important in the island ecosystem.

The strategy for future development should therefore depend on the availability of unexploited or under-exploited resources such as coastal tunas, pelagic sharks, seerfishes and demersal fishes; scope for introduction of diversified fishing, multi-day fishing, longline for tuna; development of adequate infrastructural facilities for berthing and landing, cold storage and holding facilities, cold chain and transport facilities, post-harvest processing, product development and value-addition; development of export trade for live and process fish; development of an ornamental fish industry; development of trade linkages to countries of the far east Asian region. In view of the remoteness of the islands from the mainland, infrastructural development, adequate power, water, transport and communication facilities would be required to be developed as part of the fisheries development agenda.

The upgradation of fishing crafts is the most urgent intervention needed for the islands. It is envisaged to increase the catch to 20% of the potential yield by the end of the XI Five- Year Plan. It is estimated that existing 107 crafts of LOA 10 m and gears such as gill nets/lines could be upgraded through an investment of ₹ 9.4 million immediately. Upgradation of 215 FRP coated motorized gill-netters and liners would need about ₹ 24.3 million. The introduction of more efficient motorized gill-netters of LOA 10-12 m to harvest the coastal resources is aimed as an alternate option to traditional coastal fishers. It is proposed to allow introduction of 250 such vessels to harvest about 5,000 tonnes/year. The second initiative would be to allow introduction of 200 each of 12.5 LOA gill-netters and long-liners of either wood or FRP which could target 100,000 tonnes coastal tuna and 10,000 tonnes of pelagic sharks and seerfish. The third initiative proposed is to exploit the oceanic tuna with a potential of around 82,000 tonnes. By the end of the XI Five-Year Plan, it is projected to exploit about 16,000 tonnes through introduction of 53 vessels of LOA 24 to 27 m with 50 tonnes storage capacity and –60°C freezing facility. The economic feasibility of collector vessels was examined and because of several reasons found not appropriate.

Some other important considerations in the ANDFISH include deployment of FADs, development of air/sea connectivity, handling and storage facilities, processing and value-addition, market development, waste disposal, HRD requirements, management of marine resources, access to credit and financial support mechanisms and issues in policy and governance.

Brackishwater aquaculture

Brackishwater aquaculture is another area for development in the Andamans. The post-tsunami scenario has provided vast brackishwater areas in the islands which are suitable for brackishwater culture. The A&N islands have around 110,000 ha brackishwater/salt-affected areas besides 33,000 ha of mangroves. Before the tsunami, about 680 ha area was identified as suitable for development of brackishwater aquaculture. After tsunami, about 4,000 ha has become brackish due to intrusion of salt water and out of this, about 1,000 ha have been identified suitable for brackish water aquaculture. Thus, about 1,680 ha area is currently available for aquaculture in ponds, cages, pens, etc. Species, viz. *Penaeus monodon, Fenneropenaeus merguiensis, F. indicus, Lates calcarifer, Tilapia* sp., *Scylla serrata, S. tranquebarica, Epinephelus* sp., *Mugil cephalus, Liza* sp., *Chanos chanos*, etc., were identified as potential species for brackishwater culture.

Open sea cage mariculture

Open sea cage mariculture is another potential area for development in the Andaman and Nicobar islands. Presently, some fattening activities are going on in the islands and there is a reasonable well-established trade of live edible fish to the far-east markets. This trade is a potential hazard to the stock of groupers as large-size individuals are caught and exported live, leading to potential recruitment failures in a population where unbalanced sex ratio and protogynous hermaphroditism is the rule. The young are predominantly females up to 10 kg body weight after which they transform to males. Thus, capture of potential males will adversely affect the recruitment and the wild stock in course of time. There is need for urgent curbs in the capture and trade of groupers from the Andaman waters.

Good scope exists for establishment of open sea cages in the bays and lagoons of the islands. Although this is a new area where expertise is yet to be gained in India, the potential cannot be overlooked and given the right initiatives and investment climate, great strides could be achieved resulting in a huge trade of live edible fish to the far-east markets. Since 2006 the initiatives in developing indigenous skill in cage fabrication at the Central Marine Fisheries Research Institute, and operational protocols for open sea cage culture of finfishes are commendable and currently there are many cages in the coastal waters of the country. The calm waters of the Andaman seas provide ideal locations for open sea cages and there is great scope for developing this into a profitable venture by using local species such as groupers, other perches, cobia, milk fish and even tuna.

The present status of the island fisheries both in the Lakshadweep and Andaman and Nicobar islands is far below any degree of significance. There is urgent need and scope for immediate, well-planned and phased interventions. Since both are union territories, the administration has great responsibility in ensuring appropriate and timely interventions so as to ensure a planned development. There is a need for change in the strategies, mindset, willingness to follow the knowledge-based intervention proposals and changed tempo of implementation of the proposed action plans. Dynamism and proactive interventions are needed for any scenario change. The local administration and the Departments of Fisheries have a vital role to play in the scenario change. Such concerted and well-planned result-oriented action plans are the forerunners for realizing the long-term goals of the two island systems which have great potential but are currently underutilized by India while they are open to exploitation by other countries. The proposed interventions could result in the positive benefits anticipated for the sector as well as the island communities whose life style, aspirations and future depend on a fuller utilization of the marine fisheries resources.

9. Riverine Fisheries

Inland waters provide a wide range of services to human population, being a basic element in development of agriculture, transport, industry and power generation. It also provides fundamental ecological services, such as those required to support a healthy ecosystem and demand-derived services, such as fish production for fisheries. Human influences on rivers, lakes and estuaries usually result in changes to the form and function of inland aquatic systems with an associated decline in the ecosystem services that they offer.

The rate at which the form and function of inland waters are being modified is increasing as population expands and their economic development grows. The recent reviews indicate that over half of the river systems are negatively impacted by dams. If other forms of ecosystem modifications are included such percentage of modified ecosystems would be much higher.

River fisheries, and in general inland fisheries, in the tropical regions of the world provide a range of benefits including a means of livelihood and a source of food for millions of people. However, national policies relating to crucial issues, such as economic development, poverty alleviation, food security, conservation and sustainability, often fail to recognize these important attributes. Taking cognizance of these issues the FAO members have a responsibility to maintain aquatic ecosystems in a state consistent with the sustainability of fish stocks and the fisheries they support. The right to fish carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources. The growing awareness of the general degradation in the form and function of rivers caused by water abstractions and pollution is focusing attention on the need to improve the health of such ecosystems. In this context the conservation and sustainable fishery from our rivers in India assumes importance.

River basins

There are large number of rivers in the country which run into a total length of 45,000 km. These rivers fall under 113 river basins having a total catchment area of 3.12 million km^2. There is a large network of perennial rivers, all of which are characterized by very large seasonal variations in their discharge due to seasonal rainfall and prolonged dry periods. The Indian mainland is drained by 15 major (drainage basin >20,000 km^2), 45 medium (2,000 to 20,000 km^2) and over 102 minor (<2,000 km^2) rivers, besides numerous ephemeral streams in the western arid region. These river systems are traditionally grouped, according to their origin, into Himalayan and Peninsular rivers, or according to directions of flow into east-flowing and west-flowing rivers (Table 9.1).

Indus system includes the river Indus and its tributaries (Jhelum, Chenab, Ravi,

Table 9.1. Profile of major river systems of India

River system	Name of main rivers	Approximate length (km)	States
		Extra Peninsular Rivers	
Himalayan Ganges	Ganga	2,525	Uttarakhand, Uttar Pradesh, Jharkhand, Bihar, West Bengal
	Ramganga	569	Uttar Pradesh
	Gomti	940	Uttar Pradesh
	Ghagra	1,080	Uttar Pradesh, Bihar
	Gandak	300	Bihar
	Kosi	492	Bihar
	Subernarekha	395	Bihar, Odisha, West Bengal
	Yamuna	1,376	Uttarakhand, Haryana, Delhi, Uttar Pradesh
	Chambal	1,080	Madhya Pradesh, Uttar Pradesh, Rajasthan
	Tons	264	Uttarakhand
	Sone	784	Uttar Pradesh
	Ken	360	Madhya Pradesh, Uttar Pradesh
Brahmaputra	Brahmaputra, Dibang, Siang, Lohit, Manas, Buri Dihang, Dhansiri, Koppili	4,000	Arunachal Pradesh, Asom, Nagaland, Sikkim, Manipur
Indus	Jhelum	400	Jammu and Kashmir
	Chenab	330	Jammu and Kashmir, Himachal Pradesh
	Beas	460	Himachal Pradesh, Punjab
	Sutlej	1,450	Himachal Pradesh, Punjab
	Ravi	725	Jammu and Kashmir, Himachal Pradesh Punjab
		Peninsular Rivers	
East Coast	Mahanadi	851	Odisha, Madhya Pradesh
	Brahmani	799	Odisha, Bihar
	Godavari	1,465	Maharashtra, Andhra Pradesh
	Krishna	1,401	Andhra Pradesh, Karnataka, Maharashtra
	Cauvery	800	Karnataka, Tamil Nadu
	Pennar	597	Karnataka, Andhra Pradesh
	Bhima	861	Karnataka
West Coast	Narmada	1,322	Maharashtra, Gujarat, Madhya Pradesh
	Tapti	720	Gujarat, Maharashtra
	Mahi	583	Gujarat
	Sabarmati	371	Gujarat, Rajasthan

Beas, and Sutlej). They all originate in north and generally flow in west or south-west direction into Arabian Sea through Pakistan.

Ganga-Brahmaputra-Mehgna system includes main river Ganga and its tributaries (Yamuna, Sone, Gandak, Kosi and others) and the main rivers eventually flow into Bay of Bengal, through Bangladesh, Ganga-Brahmaputra-Meghna system jointly covers some 35% of the entire country and is characterized by extensive flood plains and deltas.

Mahi, Sabarmati and Luni rivers flowing through the arid regions of Rajasthan and Gujarat carry relatively little flow. Some of them flow to Arabian Sea through Gujarat while others are lost through internal drainage.

Mahanadi, Brahmani, Baitarni, Subernarekha, Damodar, Krishna, Godavari, and Cauveri are all east flowing peninsular rivers. They all flow into the Bay of Bengal along the eastern coast and cover a range of climates.

Narmada and Tapti rivers originate in central peninsular and flow in a western direction into Arabian Sea, south of Gujarat.

In coastal parts of Maharashtra, Karnataka, and in Kerala there are several short rivers in the Western Ghats and carry significant amount of water due to high rainfall in the region. These rivers drain only 3% of the India's land area but carry about 11% of the country's water resources.

Most Indian rivers, at present, are highly regulated numerous multipurpose reservoirs for irrigation, water supply, hydropower have been constructed, along with many barrages for water diversion. Many long reaches of river passing through urban areas go almost completely dry for greater part of the year, except during monsoon, as the flow is diverted to irrigation and other needs, flood plains are lost and even river beds are cultivated during dry periods. During the past few decades, rivers have also received increasingly large discharges of industrial effluents, agro-chemicals, and domestic wastes. All this has affected the riverine ecology and its biodiversity. It is a matter of serious concern that out of the 30 rivers basins marked as global level priorities for the maintenance and protection of aquatic biodiversity, ten are from India (Cauvery, Ganga, Brahmaputra, Godavari, Indus, Krishna, Mahanadi, Narmada, Pennar, and Tapi). Observations from other study with regard to flow fragmentation and regulation in these nine basins, showed that eight (except Ganga-Brahmaputra) basins strongly affected. Though some efforts have been made towards cleaning of these rivers and enforcement of treatment of industrial effluents, there have been no systematic efforts to maintain the ecological integrity of these river systems and associated waters.

Main rivers systems

Ganga river system

The Ganga river system, which has a total length of about 8,047 km, is the most important river system in India and one of the largest in the world. It drains the southern slope of Central Himalayas and covers the states of Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, West Bengal and parts of Haryana, Rajasthan and Madhya Pradesh. The main river, Ganga has its source in two headwaters (Gangotri and Alaknanda), at a height of about 6,000 m above sea level (asl), in Garhwal Himalayas (30°55'N and 79°07'E) in Uttarakhand. The river first flows in a westerly direction for about 30 km before turning southwards. Gorging a distance of about 220 km and after cutting its ways through the Shiwaliks, it enters the plains at Haridwar. Then it flows south-east and meanders over a distance of about 2,290 km in the Indo-Gangetic plains in Uttar Pradesh, Bihar, Jharkhand and West Bengal before ultimately joining the Bay of Bengal. Many major and minor tributaries (rivers Ramganga, Yamuna, Tons, Varuna, Gomati, Basu, Karamnasa, Thora, Ghaghra, Sone, Gandak, Punpun, Burhi Gandak, Man, Jumania, Kosi, Gumani) join river Ganga during its course through the plains. The main channel of river Ganga, after Farakka barrage (West Bengal), flows in south-easterly direction as river Padma, through Bangladesh, where it is joined by Brahmaputra (Jamuna) and Meghna rivers, finally leading to Bay of Bengal.

In India, below the barrage, through a 41 km long feeder canal, river Ganga meets its tributary, river Bhagirathi, after flowing for about 150 km in West Bengal it enters the long estuarine zone, where it is better known as river Hooghly, which after flowing through Kolkata and Diamond Harbour reaches its destination (Bay of Bengal). About 300 km from the sea face, the Bhagirathi-Hooghly river system begins to spread into many small distributaries forming the great Gangetic delta. The lower Gangetic delta circumscribes extensive marshy area, called the Sunderbans. The Hooghly estuarine system extends for about 300 km from north to south and about 150 km from east to west. The entire estuarine system is estimated to be about 8,029 km^2 and the total area of Sunderbans estuarine water in India is about 2,340 km^2.

Brahmaputra river system

The mighty Brahmaputra, a freshwater moving ocean of the north-east India, rises from the snout of Chemayungdung mountains near Tachhong (Tomchok), Khambab Chhorten, about 100 km south-east of lake Mansorovar in Tibet, at an altitude of 5,150 m. It runs for about 1,250 km through Tibet, as river Tsangpo, almost parallel to the main Himalayan range, before taking a sharp turn southwards to enter India near Tuting in Siang district of Arunachal Pradesh. Running for about 160 km in Arunachal Pradesh, as river Dihang/Siang, it enters Asom on the north-west of Sadiya where it meets two equally important trans-Himalayan tributaries, Dibang (Sikong) and Lohit. After joining with these tributaries the river assumes the name Brahmaputra. Fortified by 41 main tributaries (25 on the northern bank and 16 on the southern bank), the river flows through the heart of Asom for about 740 km before entering Bangladesh, where it is called river Jamuna. After flowing for its last 480 km in Bangladesh, the river joins river Padma (Ganga) at Goalando, which reaches Bay of Bengal through Meghna estuary. The total length of this river is about 2,900 km of which about 900 km falls in India. The combined length of the river, with its 41 main tributaries, in India is about 4,000 km with a catchment area of about 580,000 km^2 (195,000 km^2 in India) and average water discharge of 510,450 m^3.

Indus river system

The Indus is one of the great rivers of the world. From its source up to the sea it is 2,000 km in length while principal tributaries the Kabul and the Swat drain Afghanisthan region on its right bank and the Jhelum, Chenab, Ravi, Sutlej and Beas as its left bank tributaries have a total stream length of 5,600 km. In India the river Indus flows at an elevation of 3,200 masl for a short distance in the town of Leh in Ladakh (J & K) and flows into Pakistan. The other rivers of this system, viz. Jhelum and Chenab, flow partly through Jammu and Kashmir, while Ravi, Sutlej and Beas

flow through Himachal Pradesh and Punjab, before entering Pakistan.

River Jhelum: This river has its origin from a spring (Verinag) in Kashmir and flows northward receiving large number of tributaries. It flows through the city of Srinagar into the Wular lake, its delta and finally drains into Pakistan.

River Chenab: This river originates in high altitudes in Himachal Pradesh, enters the Jammu and Kashmir at 1,820 masl and flows for about 290 km in different towns and finally enters Pakistan.

River Ravi: This river originates from BaraBang-Dhauladhar range of the Himalayas as two channels, namely Budhil and Tantgari, at an elevation of 4,423 and 4,418 masl. After receiving number of tributaries, skirting Chamba town of Himachal Pradesh and being dammed at many places (Chamera I, II, III and Ranjitsagar/Thein), the river enters Punjab at Shahpur Kandi (foothills of Shivalik), where its resources are extensively diverted for irrigation purposes as a result very little water remains in river basin. River regains water resources due to induction of many tributaries from adjoining Shivalik hills and flows through Gurdaspur and Amritsar districts of Punjab forming international border between India and Pakistan. Out of total river length of 725 km, it is 320 km within India, of which 158 km lie within Himachal Pradesh and 162 km within Punjab.

River Beas: This river takes its origin in the southern slope of Rohtang pass from two sources Beas Kund (4,060 masl) and Beas Rishi (4,350 masl). It has a catchment area of 12,130 km^2 and drains 25,900 km^2 of Himachal Pradesh and Punjab. In its downstream flow the Beas receives number of tributaries. At Pandoh the river has been dammed to divert its water into river Sutlej via the *Beas-Sutlej link canal* and again dammed at village Pong in Kangra District. The river enters plains at Talwara town of Punjab where it is again manoeuvred extensively for irrigation purposes. The river has total 470 km length and is the only tributary of Indus confined to India. It culminates with river Sutlej near village Lohian at *Hari-ke-Pattan* (confluence of 3 districts of Punjab, Amritsar, Kapurthala and Firozpur).

River Sutlej: Sutlej, the longest tributary of Indus system, has its source in the Trans-Himalayas at an elevation of 4,630 masl at south-west of Tibetian lakes, Ralkarthal and Mansarovar. The river enters into India at Shipki pass (Himachal Pradesh) passes through deep gorges traversing greater and lesser Himalayas. Has total length of 1,450 km out of which 740 km lie within India. The river enters into plains at Ropar in Punjab. In its upper reaches in Himachal Pradesh, it has been dammed at Bakhra where there is a hydro-electric project as well, the lower reaches at Ropar are also maneouvered extensively for irrigation purposes.

East coast river system

The East coast river system in Peninsular India is a composite system of rivers. Its main constituents are rivers Mahanadi, Godavari, Krishna and Cauvery. The total combined length is about 6,437 km. This system drains the entire Peninsular India (from east of Western Ghats in the west to Bay of Bengal in the east) and southern parts of Central India (including Chhota Nagpur hill ranges).

River Mahanadi: River Mahanadi rises from Sihawa hills (near village Pharsia) in south-west of Raipur district in Chhattisgarh. With a total length of about 857 km, in Chhattisgarh, Madhya Pradesh and Odisha, it drains an area of about 141,600 km^2. After a brief run westwards it turns north and then eastward at Khargoni to reach Mahadeopalli, 140 km away, where Hirakund dam is located on this river. After Hirakud reservoir, it runs east for about 415 km in the state of Odisha before joining Bay of Bengal at Paradip.

River Godavari: River Godavari, the largest of Peninsular rivers and the third largest river in India (next to rivers Ganga and Brahmaputra), is about 1,465 km long from its origin near Triambakeswar in Deolali hills near Nasik (Maharashtra) in Northern-Western Ghats to its tidal limits below Rajahmundry (Andhra Pradesh). It flows across the Deccan plateau from western to eastern Ghats through Maharashtra (about 693 km) and Andhra Pradesh (about 772 km). Below Dhawaleswaram (Andhra Pradesh), river Godavari splits into a northern distributary (Gautami Godavari) and a southern one (Vasishta Godavari). The Gautami joins Bay of Bengal 19 km below Yanam. Vasishta further divides into Vainateyam and the main Vasishta before opening into Bay of Bengal near Narsapur and Vadalarevu respectively. Between these distributaries lies the extensive fertile region of Godavari delta. The main major tributaries of river Godavari are rivers Manjira, Waingunga and Indravati with rivers Purna, Maner and Sabari, and a host of rivulets and seasonally active streams as minor tributaries. The catchment area of river Godavari is about 312,812 km^2 in Maharashtra (48.6%), Andhra Pradesh (23.8%), Madhya Pradesh (20.7%), Odisha (5.5%) and Karnataka (1.4%).

Two reservoirs (Gangapur and Nathsagar) are situated on mainstream of river Godavari in Maharashtra. A 321 km long irrigation barrage is also situated on this river at Vishnupuri (near Nanded) in this state. In Andhra Pradesh a large reservoir (Sriramsagar) has been formed at Pochampad in Nizamabad district on this river. Two large anicuts on this river, constructed a century ago, exist at Dhawaleswaram (for irrigation and navigation) and Dummagudem (navigation) in Andhra Pradesh. The Dhawaleswaram anicut has been replaced by a barrage in 1985.

River Krishna: The Krishna river system has a total length of about 1,280 km from its origin in Mahabaleshwar hills in the Western Ghats, south of Pune (Maharashtra), to its delta on the east coast. Traversing the states of Maharashtra, Karnataka and Andhra Pradesh, it has a catchment area of about 233,229 km^2. Krishna and Godavari water sheds are contiguous over major terrain of Deccan plateau. The main tributaries of river Krishna are Bhima and Tungbhadra rivers. River Bhima is almost a dry river during summer while river Tungbhadra is perennial with greater volume of flow than main Krishna itself.

Many reservoirs have been built within the Krishna drainage (Lakkavali, Tungbhadra, Koyna, Vanivilassagar, Himayatsagar, Osmansagar, Hussainsagar etc.). A number of anicuts or weirs on rivers Tungbhadra and Bhima have also been established for irrigational needs.

River Cauvery: River Cauvery is the longest perennial river south of river Krishna.

It originates from the Brahmagiri hills on the Western Ghats in Karnataka and flows in a south-easterly direction for about 850 km before emptying into Bay of Bengal in Thanjavur district of Tamil Nadu. In the Thanjavur delta, the river divides into a northern branch, river Coleroon, and a southern branch, river Cauvery proper. The main tributaries of river Cauvery are rivers Bhavani, Noyil and Amaravati.

This is one of the most tamed rivers of the country. A number of reservoirs (Mettur, Bhavanisagar, Krishnarajsagar, etc.) and anicuts have been constructed on the main river as well as its tributaries/distributaries, both in Karnataka and Tamil Nadu, and as a result very little water goes through this river into the sea.

West coast river system

The west coast river system drains the narrow belt of Peninsular India west of Western Ghats. In north it includes the basins of rivers Narmada and Tapti and the drainage of Gujarat. Rivers Narmada and Tapti are the main rivers of this system. All other rivers, arising from Western Ghats are short, though perennial. The total length of rivers of this system is about 3,380 km.

River Narmada: The largest west flowing river of the country, Narmada, originates from Maikala highlands near Amarkantak in Shahdol district of Madhya Pradesh. Its drainage area is the northern extremity of Deccan plateau. Of its total length of about 1,312 km, it traverses for about 1,077 km in Madhya Pradesh, forms boundaries between the Maharashtra and Madhya Pradesh, and Maharashtra and Gujarat (for about 35 and 39 km respectively), flows through Gujarat for about 161 km before joining the Gulf of Cambay (Arabian Sea) near Broach (Gujarat). River Narmada is fed by 41 major tributaries during its course, 22 from the south bank (21 in Madhya Pradesh and 1 in Gujarat) and the rest from north bank (18 in Madhya Pradesh and 1 in Gujarat). Total catchment area of river Narmada is about 94,235 km^2.

Due to altitudinal gradient prevailing in entire course of river Narmada and its tributaries, high potential of their impounding exists. A comprehensive programme to tap this resource for development has been chalked out. The plan entails commissioning of 30 major projects (21 irrigational, 5 hydel and 4 multipurpose), 188 medium irrigation projects and 2,637 minor schemes. Ten of the major projects are sited on the main river course and the rest (20) on the tributaries. Four reservoirs (Tawa and Sukta on left bank tributaries, Barna on the right bank tributary and Bargi on the main river) have already come up. A number of projects (proposed reservoir area from 505 to 91,340 ha) are in different stages of completion. The proposed Narmada Sagar (Indira Sagar) and already completed Tawa are the biggest reservoirs on the main river and left bank tributary, respectively. Sardar Sarovar is the ultimate dam/reservoir on the main river in Gujarat, about 150 km before the sea mouth.

River Tapti: River Tapti, also called Tapi, is the other westerly flowing river of the Peninsular India. Rising from the Vindhya mountain of the Satpura range, it flows westward through Madhya Pradesh, Maharashtra and Gujarat before joining the Arabian Sea at Dumas near Surat (Gujarat). The total catchment area of this river is about 48,000 km^2.

With a view to utilize huge quantities of rainwater to develop the regions of the lower Tapti valley and also to control the floods in Surat district, a weir has been constructed on this river at Kakrapar in Mandvi *taluka* of Surat district. Ukai, a big multipurpose dam, has been constructed above the Kakrapar weir, just on border of Maharashtra and Gujarat. An anicut has also been constructed on this river in the district of Jalgaon (Maharashtra) near Adilabad.

Ecological status of some important rivers

Ganga: The water quality parameters of Ganga in different zones have been presented in Table 9.2. Entire stretch of river was rich in oxygen (6.9-8.3 mg/litre) and poor in nutrients (nitrate: 0.017-0.050 and phosphate: 0.003-0.040 mgl/litre). Due to strong buffering capacity of water there was practically no fluctuation in *p*H (8.1-8.2). Water temperature varied from 20.4 to 26.8°C and transparency was comparatively high in the upper zone (58.9 cm). On the basis of conductance, alkalinity, dissolved solids, hardness and chlorides, the Ganga appears to be divided into three significant zones (upper zone: Deoprayag to Farrukhabad; middle zone: Kannauj to Varanasi; lower zone: Patna to Farakka). The upper zone showed minimum value of above parameters (206 µmhos, 78.7, 104, 74 and 14.9 mg/litre respectively), while middle zone showed maximum values (456 µmhos, 150.2, 227, 148 and 30.8 mg/litre respectively). As compared to sixties, water quality of the Ganga has registered decline in quality at certain stretches.

Among the biotic communities the plankton concentration was maximum in middle zone and minimum in the upper zone. In all the three zones phytoplankton was the dominant component being 96.0, 85.0 and 82.6% in upper, middle and lower zones, respectively. Among different groups diatoms were almost 100% in the upper zone, 56% in the middle, and 50% in the lower zone. Considerable population of Chlorophyceace has been observed in the middle zone (44%) and Myxophyceace in lower zone (22%). Periphytic deposition was maximum at Kahalgaon in the lower zone and minimum at Deoprayag. The quantitative abundance of macrobenthic communities has been minimum in the upper zone and maximum in the middle zone. The qualitative picture showed dominance of insects in the upper zone, molluscs and insects in the middle, and molluscs (85%) in the lower zone.

Indus tributaries: Water qualities of Indus tributaries are given in Table 9.2.

Sutlej: The water quality parameters of river between Roopnagar to Harike and below Beas confluence up to Ferozpur has been presented in Table 9.2. Water temperature ranged from 20.0 to 23.44°C. Transparency showed wide range, being low between Ludhiana to Harike (15.2 -34.7 cm) but comparatively higher below the confluence along Firozpur (108 cm). Dissolved oxygen was quite rich (6.5-8.7 mg/litre) till the influx of elluent loaded channel-white Bein at Sultanpur town, henceafter it becomes critical, 2.8-4.4 mg/litre till its culmination with Beas at Harike. Water showed alkaline character with *p*H ranging from 7.3 to 7.8. Conductance, alkalinity, dissolved solids, hardness and chloride all varied significantly depending upon the influx of various channels and were comparatively higher before Beas confluence and

showed decline after the confluence. The nutrient status of the river was moderate (phosphate: 0.08-0.40 mg/litre).

Among the biotic communities the plankton concentration was comparatively higher at lower zone (Ferozpur). Phytoplankton remained the dominant component. The various groups were evenly distributed diatoms (24.0 to 42.33%), Chlorophyceace (23-43%) and Myxophyceace (10.67-23.04%). Among the zooplankton, rotifers, copepods and cladocerons were the main component. Diatoms (31-50%), green algae (23-24%) and Myxophyceace (23-35%) were the dominant group among periphyton. River was quite rich in benthic population. Chironomids (15.3-100%) and gastropods (0-83.54%) were the main benthic organisms.

Beas: The average water temperature of middle Beas within Punjab between Talwara to Harike was 23.3°C and transparency 30-39 cm. Dissolved oxygen was fairly rich (6.7-8.22 mg/litre) and *p*H was alkaline (6.8-8.2 mg/litre). Conductance, alkalinity, and dissolved solids were comparatively low in Beas (208 µmhos, 71.5, 103 and mgl/litre) than the main river Sutlej before confluence. This river also showed poor nutrient status (Table 9.2).

Plankton density was poor, 80-270 unit/litre comprising Bacillariophyceae (38-90%), Myxophyceae (10-57%), Cholophyceae (9.3-26.3%) and rotifers (nil-14.7%). The periphytic community concentration showed great variation being high at shallow clean areas – Talwara (634 unit/cm^2) and low at stressed zones (128 unit/cm^2), benthic population on an average was 524 unit/m^2.

Ravi: It is still considered one of the clean rivers,water being clear up to bottom in the upper zone. There is not much variation in temperature (20.5°-25.3° C), dissolved oxygen (7.2-7.7 mg/litre) and *p*H (7.3-7.4) along the river within Punjab. But considerable difference was observed in respect of conductance, alkalinity, dissolved solids and total hardness, all being comparatively low between Shahpur (entry point to Punjab) to Madhopur (170.9 µmhos, 82.3, 86 and 56.3 mg/litre) than between Kathlour to Dharamkot pattan, exit point from Indian Punjab, (235 µmhos, 110.4, 112.7 and 75.5 mg/litre respectively). Chloride and silicate were within the range of 11.9-15.05 and 4.2-6.3 mg/litre, respectively, in the entire stretch. Nutrient status of the river was poor (Table 9.2).

Among the biotic communities plankton population was generally poor in the river. Phytoplankton was the dominant component mainly represented by diatoms (62-100%) and green algae (0-34%). Myxophyceace was almost absent except at Kathlour (6%). Periphyton deposition was also poor, represented by diatoms (68-86%), blue green algae (11-20%) and green algae (7-16%). The river sustained rich benthic population. Insect nymphs were dominant in upper stretch, between Shahpur to Modhupur, whereas molluscs were dominant in lower stretch between Kathlour to Dharamkot pattan. Macrophytes were present mainly in shallow stretches.

Brahmaputra: The water quality parameters of river between Sadia (the confluence of Siang, Dibang and Lohit rivers) to Dhubri (before entering Bangladesh) are depicted in Table 9.3. In the entire stretch water temperature did not show much variation (18.2-20.4°C) while the clarity of water was more in the upper zone. Water was fairly

Table 9.2. Water quality parameters of the Himalayan rivers

Rivers	Zones	Water temp. (°c)	Transparency (cm)	DO (mg/litre)	pH	Total alkalinity (mg/litre)	Conductance (µmhos)	TDS (mg/ litre)	Total hardness (mg/litre)	Chloride (mg/ litre)	Silicate (mg/ litre)	Nitrate (mg/ litre)	Phosphate (mg/ litre)
Ganges	Upper zone (Deoprayag-Farukhabad)	20.4	58.9	8.3	8.1	78.7	206	104	74	14.9	2.0	0.017	0.003
	Middle zone (Kannauj-Varanasi)	26.8	37.2	6.9	8.2	150.2	456	227	148	30.8	3.8	0.050	0.035
	Lower zone (Patna-Farakka)	26.5	28.6	7.2	8.1	107.5	259	123	103	18.8	1.7	0.037	0.040
Indus													
Ravi	(Shahpur-Madhopur)	20.5	55.4	7.7	7.4	82.3	170.9	86.0	56.3	12.0	4.8	-	0.272
	(Kathlour-DharamKot pattan)	25.3	38.65	7.2	7.3	110.4	235.0	118.0	75.5	15.05	6.2	-	0.239
Sutlej	(Roopnagar-Harike)	20-23.4.	15.2 -34.7	8.7 -2.8	7.3	76- 218	261-560	131-280	-	3.6- 32.7	1.6-4.7	-	0.08-0.40
	(Below Beas confluence)	23.4	108.7	9.6	7.8	87.0	204	103	-	8.3	1.4	-	0.150
Beas	(Talwera-confluence)	23.3	30-39.5	6.7-8.2	6.8-8.2	71.5	208	103	89	20.7	2.0	-	0.260
Brahmaputra	Upper zone (Sadia-Jorhat)	18.2	55.9	7.4	7.6	65.5	147	74	72	22.9	5.5	0.027	0.010
	Middle zone (Biswanath ghat-Guwahati)	18.8	38.9	7.9	7.6	63.6	147	74	72	21.0	5.1	0.030	0.006
	Lower zone (Goalpara-Dhubri)	20.4	41.6	7.9	7.8	68.5	155	78	73	26.9	5.8	0.020	0.010

rich in dissolved oxygen (7.4-7.9 mg/litre) and as a result of strong buffering capacity pH showed very little variation (7.6-7.8). Conductance, alkalinity, dissolved solids, hardness and chloride were within the range of 147-155 µmhos, 63.6-68.5; 74-78; 72-73 and 21.0-26.9 mg/litre, respectively, with slightly higher values in the lower zone. The nutrient status both in respect of nitrate and phosphate were poor in the river.

Among the biotic communities maximum concentration of plankton was observed in the upper zone, the bulk of which being phytoplankton. Zooplankton formed only negligible proportion. Diatoms contributed 60% of the population followed by Chlorophyceae and Myxophyceae. Benthic population also showed maximum value in the upper zone and minimum in the middle zone. Gastropods dominated in the lower zone while both gastropods and bivalves were present in the upper zone.

Mahanadi: Important water quality parameters of the river in three zones have been presented in Table 9.3. The average water temperature in the river varied between 26.2 to 30.8°C while clarity of water was comparatively higher in the lower zone (101.7 cm). Dissolved oxygen was fairly high (7.4-8.0 mg/litre) and pH did not show much fluctuation due to high buffering capacity. Conductance, alkalinity, dissolved solids, hardness and chloride were within the range of 164-195 µmhos, 70-89, 82-92, 68-86 and 26.5-37.0 mg/litre in the upper and middle zone but except alkalinity, the values of all the other parameters showed sharp increase in lower zone. The nutrient status both in respect of nitrate and phosphate were poor.

Among biotic communities plankton population was poor and did not show any marked variation in the entire stretch. Phytoplankton (42.5-99.7%) remained the dominant component throughout the stretch with few exceptions. Myxophyceae, Bacillariophyceae and Chlorophyceae were the dominant groups in order of magnitude. Among zooplanktons copepods and rotifers dominated the upper zone, cladocerons and rotifers the middle and copepods the lower. Macrobenthos decreased from upper to lower zone. Gastropods (40-61%) and bivalves (6-21%) were dominant in the entire stretch. Zonal variation in other benthic groups was noticed with prevalence of dipterans in the upper, nematodes in the middle and annelid worms in the lower stretch. The upper zone exhibited comparatively rich epiphytes due to its hard substrate with rocks and boulders. Bacillariophyceae were dominant (40.9-57.1%) among periphytic groups. Clear water, fast current, stony and sandy bed did not allow the macro vegetation to grow in the entire river.

Godavari: Water temperature was more or less similar in all the zones (28.2-29.3°C) but clarity of water was comparatively higher in middle stretch (72.8 cm). Water was always alkaline in reaction with pH ranging from 7.6 to 8.0 and also rich in dissolved oxygen (6.9-8.9 mg/litre). Conductance, alkalinity, dissolved solids and hardness all were comparatively higher in the middle stretch (482 µmhos, 160, 242 and 125 mg/litre respectively) and low in lower stretch (Table 9.3). Chloride was within the range of 25.6-34.8 mg/litre. Both phosphate (0.007-0.009 mg/litre) and nitrate (0.026-0.036 mg/litre) were poor in the entire stretch.

Phtyoplankton remained the dominant component in the river except some estuarine ireas. The dominant group was bacillariophyceae followed by chlorophyceae, nyxophyceae and dynophyceae. Zooplankton was mainly represented by rotifers, :ladocerans and copepods. The benthic fauna was maximum in the middle zone and vas poor in the upper zone. Benthos was mainly represented by molluscs followed by nsect and nymphs of mayfly and dragonflys. Macrophytes were also recorded but :onfined to stagnant deep pools.

Krishna: Among the physical parameters, temperature was within the range of !7.8-30.5°C and transparency from 57 to 108 cm being comparatively higher in the ower zone. Dissolved oxygen was fairly rich in the river (6.4-8.0 mg/litre) with alkaline ›H (8.1-8.2). Total alkalinity and hardness were in the range of 149 to 160, and 159 to 89 mg/litre in the entire stretch but conductance, dissolved solids and chloride showed harp increase from middle zone reaching maximum in the lower zone (1,039 μmhos, 20 and 254 mg/litre). The nutrient status of the river both in respect of nitrate and hosphate was found to be poor (Table 9.3).

Among the biotic communities phytoplankton accounted 88.4 to 98.8% of the total opulation. Myxophyceae mainly represented by *Microcystis* remained the dominant roup (46.7%) followed by Chlorophyceae (22.9-31.8%). Crustaceans and rotifers onstitute the major portion of zooplankton. Among benthic communities molluscs 39.8-93.5%) were the dominant component. Other forms were insect, chironomids nd worms. Among the periphytic population, Bacillariophyceae dominated over others 58.1-95.6%). Some species of macrophytes were also recorded from the river.

Cauvery: Water temperature fluctuated between 24.6° and 28.1°C and water was lear up to bottom on many occasions. Dissolved oxygen was within the range of 6.6 › 7.0 mg/litre in the entire river. Water was near neutral to alkaline in reaction with H fluctuating from 6.9 to 7.9, although slightly acidic *p*H (6.2) has been recorded in ie upper stretch. Conductance, alkalinity, dissolved solids, hardness and chloride rere comparatively low in the upper zone (295 μmhos, 98, 191, 89 and 20.8 mg/litre ›spectively). Alkalinity and chloride were maximum in the middle zone (217 and 8.4 mg/litre) while other three parameters showed maximum values in the lower one (1215 μmhos, 655 and 412 mg/litre respectively). The nutrient status of the river as invariably low both in respect of nitrate and phosphate (Table 9.3).

Molluscs with a dominance of gastropods were the only benthic group showing ontinuous distribution along the river. Bacillariophyceae was the dominant component mong periphytic communities. Floating and submerged macrophytes were available the river.

Narmada: Water quality parameters of river at Amarkantak (origin) and Dindori Gadarwara have been presented in Table 9.3. Water temperature was in the range of 4.0 to 25.7°C and transparency was higher in Amarkantak (76.0). Water was almost eutral at the origin point (6.8), while in other stretches it was in the alkaline range ›H-8.0). Dissolved oxygen was fairly rich in all the stretches (6.4-7.4 mg/litre). The ver showed considerable variation in respect of conductance, alkalinity, dissolved olids and hardness, all being comparatively low (98 μmhos, 42, 52 and 52 mg/litre) Amarkantak, while their values were higher in the other stretches (225 μmhos, 123,

Table 9.3. Water quality parameters of peninsular rivers

Rivers	Zones	Water temp. (°C)	Transparency (cm)	DO (mg/litre)	*p*H	Total alkalinity (mg/litre)	Conductance (μmhos)	TDS (mg/litre)	Total hardness (mg/litre)	Chloride (Cl) (mg/litre)	Silicate (Si) (mg/litre)	Nitrate (NO_3) (mg/litre)	Phosphate (PO_4) (mg/litre)
Mahanadi	Upper zone (Sihawa-Tamdel)	27.1	62.1	7.4	8.2	89	195	92	86	37.0	6.2	0.030	0.004
	Middle zone (Durgapalli-Narsinghpur)	26.2	89.7	8.0	7.8	70	164	82	68	26.5	7.1	0.043	0.004
	Lower zone (Sasnag-Paradip)	30.8	101.7	7.2	8.1	80	220	109	294	65.6	13.4	0.040	0.007
Godavari	Upper zone	28.2	49.7	7.3	7.6	105	378	189	110	34.8	15.3	0.036	0.009
	Middle zone	29.3	72.8	6.9	8.0	160	482	242	125	32.1	12.6	0.026	0.008
	Lower zone	28.8	64.0	8.9	8.0	106	301	151	95	25.6	10.1	0.033	0.007
Krishna	Upper zone (Wenna-Kallol)	27.8	73.0	8.0	8.1	149	406	292	159	52.5	9.1	0.140	0.098
	Middle zone (J.khandi-Bhadra)	28.9	57.0	7.3	8.2	160	689	359	185	109.7	7.46	0.370	0.038
	Lower zone (Bispalli-Penumudi)	30.5	108.0	6.4	8.1	155	1,039	520	189	254.0	8.0	0.097	0.067
Cauvery	Upper zone	24.6	clear	7.0	6.9	98	295	191	89	20.8	3.7	0.020	0.023
	Middle zone (Shivsamudram-Hogenakkal)	26.7	clear	6.9	7.8	217	795	397	158	58.4	7.2	0.132	0.078
	Lower zone (Hozenkkal-confluence)	28.1	103.4	6.6	7.9	188	1,215	655	412	-	4.57	0.098	0.094
Narmada	Amarkantak (origin)	24.0	76.0	6.4	6.8	42	98	52	52	-	6.0	0.180	0.070
	Dindori-Gadarwara	25.7	53.1	7.4	8.0	123	225	120	121	-	10.8	0.160	0.008

120 and 121 mg/litre respectively). The nutrient status of the river both in respect of nitrate and phosphate was poor in the entire stretch (Table 9.3).

Among the biotic communities plankton density was poor, dominated by phytoplankton (69.2-98.6%). Bacillariophyceae was the most important group among phytoplankton (23.1-90.6%) followed by Chlorophyceae (0-40.6%); while zooplanktons was mainly represented by crustaceans and rotifers. Macrobenthos was comparatively higher in the down stretch. Annelida and insects were dominant in the upper zone while gastropods and pelecypoda in the lower zone.

Fish and fisheries

Riverine fisheries scene is a complex mix of artisanal, subsistence and traditional fisheries with a highly dispersed and isolated nature of fishing and landing areas, diverse fishing gears and tackle, migratory fishers, fish merchants buying off catches from fishing boats at the fishing spots itself, the multi-species composition of the catches and their landing in unsorted conditions and above all an unorganized marketing system. This frustrates all attempts to collect exact data on total fish yield of the resource. A firm data base of riverine fisheries being, thus, elusive, for understanding the fish catch trend, one has to depend on whatever information has been collected by the Central Inland Fisheries Research Institute (CIFRI), Barrackpore from selected stretches of various rivers of the country during different years. The river-wise information furnished here regarding fish catch of the freshwater stretch (i.e. excluding the estuarine fishery) is, thus, mainly based on catch statistics collected by the CIFRI.

Ganga river system

Fish diversity: The Ganga harbours 265 species of fish out of which 181 fish species are recorded for the whole freshwater sector. Other species counts have included estuarine species or have been confined to one country of the basin. The Alaknanda has the lowest number of species for any sector of the river. However, a total of 41 are still appreciable for a single cold, upland river and gives an indication as to how relatively rich the cold upland communities are. The community is characterized by a few specialized cyprinid types, especially *Schizothorax* spp., *Tor* spp., and small *Garra* spp. together with some of the mountain loaches, *Noemacheilus* spp. and highly specialized sisorid torrent cat fishes, *Glyptothorax* spp. The fish community of the upper Ganga is very similar to that of Alaknanda, although a few lowland species like *Mastacembelus* and *Channa* begin to appear. Cyprinids, particularly major carps and catfishes dominate the lowland sites from Allahabad to Bhagalpur. The number recorded for the Ganga in a stretch of about 30 km in and around Patna is 106. In this segment migratory species like major carps in the main channel can be distinguished from the small floodplain resident species with accessory respiratory organs and prolific reproduction. Patna downstream some species from the estuary start to appear such as the scieanid, *Scieana coiter*, the mullets, *Rhinomugil corsula* and *Sicamugil cascasia*. Particularly significant is the anadromous *Tenualosa ilisha* or 'hilsa'. Important species are listed in Table 9.4.

Table 9.4. Important fish species recorded in the river Ganga from the upper stretch (Tehri to Kannauj), middle stretch (Kanpur to Patna), lower stretch (Sultanpur to Katwah), estuarine stretch (Nabadwip to Diamond harbour/ Roychowk)

Species	Upper stretch	Middle stretch	Lower stretch	Estuarine stretch
Sperata seenghala	+	+	+	-
Bagarius bagarius	+	+	+	+
Catla catla	+	+	+	+
Channa punctata	-	-	+	+
C. marulia	-	-	+	+
C. striata	-	-	+	+
Cirrhinus mrigala	+	+	+	+
C. reba	-	+	+	.
Clarias batrachus	-	+	+	+
Clupisoma garua	+	+	+	+
Eutropiichthys vacha	+	+	+	+
Gudusia chapra	+	+	+	+
Heteropneustes fossilis	-	+	+	+
Labeo rohita	+	+	+	+
L. bata	+	+	+	+
L. calbasu	+	+	+	+
Lates calcarifer	-	-	-	+
Liza parsia	-	-	-	+
Macrognathus aral	-	+	+	+
M. pancalus	-	+	+	+
Mastocembelus armatus	+	+	+	+
Mystus cavasius	+	+	+	+
M. bleekeri	-	-	+	+
M. gulio	-	-	-	+
M. vittatus	-	+	+	+
Nandus nandus	-	-	+	+
Chitala chitala	+	+	+	+
Notopterus notopterus	+	+	+	+
Ompok bimaculatus	+	+	+	-
O. pabda	-	+	+	-
Pangasius pangasius	-	-	+	+
Polynemus paradiscus	-	-	-	+
Puntius sarana	+	+	+	+
P. sophore	+	+	+	-
Rhinomugil corsula	-	-	+	+
Rita rita	+	+	+	+
Scatophagus argus	-	-	-	+
Schizothorax richardsonii	+	-	-	-
Setipinna phasa	-	+	+	+
Silaginopsis panijus	-	-	-	+
Silonia silondia	-	-	+	-
Sperata aor	+	+	+	-
Tenualosa ilisha	-	+	+	+
Tor tor	+	-	-	-
T. putitora	+	-	-	-
Wallago attu	+	+	+	+

+, Available; -, not available.

Out of the total species recorded 34 are of commercial interest including the prized Gangetic carps, large catfishes, feather-backs and murrels. It has been observed the rhithron region of river Ganga (origin to Haridwar) is practically a non-fishing zone with no commercial fishing activity in the area. The species mostly available in this stretch are: *Schizothorax richardsonii*, *Tor tor*, *T. putitora*, *Labeo pangusia*, *Garra gotyla*, *Crossocheilus latius* and *Mastacembelus armatus*. Commercial fishing activity is mainly observed in the potamon region of the river (from Anupsahar, Uttar Pradesh downstream) where it is rich and diverse. The main-stay of fisheries in this region are species belonging to family Cyprinidae (176 spp.) and Siluridae. The hill stream and cold-water species found in the upper rhithron region are almost completely absent in the potamon region.

The time-scale estimates of total fish catch, made by the CIFRI from various centres of this river are summarized in Table 9.5. As per the Report, CIFRI (2008) the production has now improved to 389 kg / km but this has been possible due to greater contribution of exotics, viz. *Cyprinus carpio* and *Oreochromis niloticus*, in the catches. This trend is further damaging to the system as far as quality fishery, is concerned. It is evident from the same that, with passage of time, there is a marked decline in the fish catches and shift among species at Allahabad and other centres as well.

Table 9.5. Average catch from Ganga river system at Allahabad in different decades

Decades	Catch (kg/km)
1950s	1,344
1960s	1,168
1970s	529
1980s	665
1990s	333
2000s	362

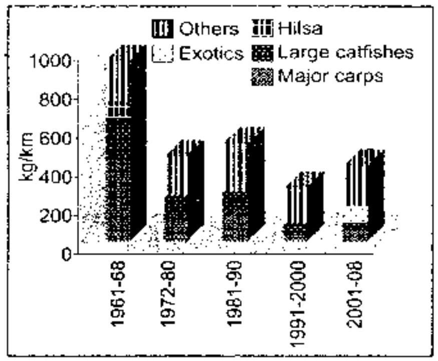

Fig. 9.1. Fish catch at Allahabad during 1960s to 2000s, indicating shift in species composition and appearance of exotic fishes.

Besides quantitative decline, the fish catch has also declined qualitatively. The average catch composition of riverine fish catch at Allahabad during different periods showed that the percentage contribution of Indian major carps (*Catla catla*, *Labeo rohita* and *Cirrhinus mrigala*) has gradually declined from 45% in 1961-68 to 11% in the recent past, with percentage contribution of miscellaneous species (commercially not so important) increasing from 23% to 64% during the same period. Time-scale shift in species is given in Fig.9.1.

Brahmaputra river system

Brahmaputra River System reported to inhabit 221 species belonging to 103 genera and 36 families. This system has a rich fish fauna of torrential streams in its upper reaches. But due to steep gradient and strong current, both at surface and underneath, commercial fishing in river Brahmaputra above Tezpur, with the existing type of indigenous craft and gear, is very difficult and sparse. Commercial-scale exploitation is, thus, mainly confined to Tezpur-Dhubri stretch (about 300 km) of this river (before it enters Bangladesh). Fisheries of commercial significance comprise 35 species.

A detailed survey of ecology and production dynamics of river Brahmaputra and its tributaries, undertaken during 1996-98 by the CIFRI showed considerable inter-stretch variation in fishery, both in quality and quantity. The fishery of main river Siang and its other two components, Dibang and Lohit, throughout their stretch in Arunachal Pradesh is dominated by mahaseer (*Tor putitora* and *Neolissocheilus hexagonolepis*), snow trout (*Schizothorax richardsonii*) and other coldwater species (*Labeo dero* and *L. dyocheilus*). At the confluence point of these three rivers, near Sadiya, mahaseer still forms the main fishery with little reduced percentage in the catch. Catfishes which are completely absent in the three rivers above are recorded in this region. Below Sadiya, in the stretch up to Dibrugarh, the mahaseer species almost disappears, and they are replaced by carps, catfishes and feather-backs. The miscellaneous fish contribution gets much increased. A few specimens of mahaseer and coldwater fishes are recorded between Dibrugarh and Tezpur but their contribution to the total catch is almost negligible. The picture of fishery of other species remain almost similar between Dibrugarh and Dhubri with minor variation in catch of different groups. Hilsa which is completely absent in upper stretches makes its appearance in and around Guwahati and continues up to Dhubri, though its present availability is much reduced than in the past. Apart from qualitative variations between the stretches, the fish yield also showed considerable quantitative variation, being minimum at Goalpara and maximum at Guwahati.

At three landing centres in Tezpur-Dhubri stretch, both quantitative and qualitative decline in fishery of river Brahmaputra over the years is recorded with average estimated annual catch of Tezpur-Dhubri stretch going down from 215 tonnes to 150 tonnes during the course of about two decades. Fishery of carps, catfishes and hilsa showed a marked decline (30 to 81%) with substantial increase (61 to 141%) in fishery of feather-backs and miscellaneous groups of fishes. The average catch per day in this stretch showed an overall decline of 30%.

Indus river system

An account of fishery within Indus system as a whole is not available so far. But the fish diversity status within individual tributaries within India especially wherever it is being exploited commercially has been observed by the CIFRI in different stretches at different times. Commercial fisheries of river Jhelum, flowing through the Kashmir valley in India were observed from July 1980 to June 1982. It comprised six species of *Schizothorax* (*S. esocinus*, *S. planifrons*, *S. micropagan*, *S. punctatus*, *S. curvifrons*, *S. longipinnis*) and *Oreinus plagiostomus*. The other species of occasional occurrence in commercial catches were *Labeo dero*, *L. dyocheilus*, *Crossocheilus latius* and *Puntius conchonius* among Cyprinids, *Glyptothorax kashmirensis* and *G. reticulatum* among Sisoridae and *Botia birdi*, *Nemacheilus kashmirensis*, *N. rupicola* and *N. marmoratus* among Cobitidae. The exotic fish, *Cyprinus carpio* (var. *specularis* and var. *communis*) were reported to contribute substantially to the commercial catches of river Jhelum. Systematic data regarding total catch, however, are not available in respect of this river.

Systematic account of fisheries of Punjab component of Indus system (Sutlej, Beas and Ravi) was undertaken from 2000 to 2007. The commercial exploitation of this component of the system takes place from Kiratpur to Firozpur within Sutlej and catch is disposed off mainly at 5 centres (Roopnagar, Ludhiana, Sultanpur, Harike and Firozpur). Beas is exploited from Talwara (entry point) to Harike (end point) and produce is disposed off at 6 centres (Talwara, Pathankot, Mukerian, Amritsar, Sultanpur and Harike) Ravi is exploited along specific stretches in Gurdaspur and Amritsar districts only because of it forming international border and catch is disposed of mainly at two centers namely, Pathankot and Amritsar.

The average fish catch from Sutlej (2000-02) was 366.9 tonnes/year, was low in the polluted stretch between Roopnagar and Harike compared to lower 50 km stretch between Harike and Firozpur. Catch composition too varied greatly. Roopnagar zone representing the foothills of Shivalik Himalayas had dominance of minor carps (68%), followed by IMC (12.87%), large size catfishes (5.78%) including *B.bagarius*, assorted group (6.13%), common carp (4.52%) and mahseer, *T.putitora* (1.26%). The middle stretch had sufficient presence of IMC (29.19%), assorted group (35.26%), large size catfishes (13.73%) mostly represented by *W. attu* and *S. seenghala* and minor carps (13.17%), but common carp has minimum presence (8.4%).Firozpur stretch had equal representation from all groups. IMC (28.82%), miscellaneous (25.68%),Common carp (22.75%), minor carps (13.77%) and cat fishes (8.98%).

The average fish catch from river Beas within Punjab was 255 tonnes/year (2002-05). Fishery mainly comprised of IMC (28.28%), minor carps (22.44%), common carps (22.02%), assorted group (17.71%) and large-size catfishes (8.54%). Mahseer (0.73%), snow trout (0.08%) and thai magur (0.21%) were also encountered, former two along upper stretch (Talwara to Mukerian) and latter at Harike.

The average fish catch from Ravi was minimum, being 47.65 tonnes/year (2005-07), represented mainly by minor carps (59.12%), assorted group (23.40%) and common carp (9.14%). Mahseer (2.54%) snow trout (1.13%), IMC(2.70%) and large-size catfishes (1.76%) were also present, former two in upper stretch between Shahpur and Kathlour and latter two in lower Amritsar zone. Amongst the two, IMC were encountered only during monsoon. Fish composition within this component of Indus in the plains is formed by 56 and 54 species in Sutlej and Beas, respectively, belonging to 18 families, Cyprinidae being the most common represented by 23 species followed by Bagridae (6 spp.). Ravi fishery is formed by 31 species belonging to 10 families, Cyprinidae again being dominant represented by 13 species followed by Bagridae (4 spp.). The upper stretch of all tributaries within plains hold eurythermal minor carps like *L. dero* and *L. dyocheilus* and to some extent cold water carps like *T. putitora* and *S. richardsonii*, because all these rivers run along the foot-hills of Shivalik Himalaya, having temperature range between 15° and 22°C. Middle stretch of Indus having pure lotic type of environment contains sufficient IMC (24.64-42.61%); large-size catfishes (6.90-15.45%) and minimum presence of common carp (nil-7.91%). Lower stretch of Indus in and around Harike to Ferozpur section (tail point) has in addition to IMC and catfishes, maximum presence of common carp ranging between 13.51 and 23.98% at Harike, and 22.75% at Ferozpur, indicating these prefer lentic type of environment caused by river being confined within 2 barrages, Harike and Hussainiwala. Existence of Thai magur, *C. gariepinus* although localized (Harike) and intermittent, nonetheless was observed to have invaded the system from 2002 onwards and is major of concern.

East Coast River System

From river Mahanadi, 253 species of fish belonging to 73 families have been recorded. Quantitative data of fish landing from different stretches of river Mahanadi are only available through an exploratory survey of the entire river, conducted by the CIFRI in 1995-96. In the upper stretch (origin to Hirakund dam) fish landings were observed at nine fish markets (Dhamtari, Rajim, Mahasamund, Aurang, Seorinarayan, Chandrapur, Raigarh, Surajgarh and Mahadeopalli) during the above survey. The average annual catch at these nine centres was estimated to be 142.47 tonnes comprising major carps (14.2%), minor carps (29.7), catfishes (39.9%) and miscellaneous (16.2%). In the nine fish markets (Burla, Sambalpur, Binka, Sonepur, Baunsuni, Bandh, Charichak, Angul and Narsingpur) of middle stretch (below Hirakund reservoir to Narsingpur), the estimated annual fish landing was observed to be almost similar (152.37 tonnes) with a catch composition of carps (34.8%), catfishes (34.6%), prawns (10.5%) and miscellaneous (20.2%). In freshwater stretch below Narsingpur (Sasang to Balikuda), the fish catch was seen to be poorer (86.2 tonnes).

Detail information on the fishery of 189 km of the penultimate stretch of river Godavari, between Dowlaiswaram and Dummagudem anicuts, were collected by the CIFRI during 1963-69 wherein 83 species of fish, belonging to 19 families, were recorded. The main species contributing to the fisheries were: *Labeo fimbriatus, L. calbasu, Cirrhinus mrigala, Catla catla, Sperata seenghala, S. aor, Silonia childrenii, Wallago attu, Pangasius pangasius, Bagarius bagarius, Hilsa ilisha* and the prawn, *Macrobrachium malcomsonii*. The total fish yield from this stretch showed a declining trend from 330.1 tonnes in 1963 to 218 tonnes in 1969. Species which showed sharp decline were *L. fimbriatus* (from 35 to 11.7 tonnes), *M. seenghala* (from 21.9 to 6.4 tonnes), *P. pangasius* (from 5.2 to 0.5 tonnes), *S. childrenii* (from 4.1 to 1.6 tonnes) and *B. bagarius* (from 7.8 tonnes to negligible quantity).

During exploratory survey of river Godavari, conducted by the CIFRI during 1997-99, quantitative data on its fishery were not collected. However, this survey reported occurrence of three species (*Rhinomugil corsula, Osteobrama vigorsi* and *Oreochromis mossambicus*) in this river, for the first time, and also the absence of *Tor musullah, Labeo kontius, L. gonius, Cirrhinus horai* and *Bagarius bagarius* in the catches. Further decline in fish catch as a whole and of *M. malcomsonii* and *L. fimbriatus* in particular was observed during this survey.

Quantitative data on fishery of river Krishna are not available. Qualitatively, during 2001-03 the fishery in upper stretch (Maharashtra and Karnataka) has been reported by the CIFRI to be of *Catla catla, Cyprinus carpio, Cirrhinus mrigala, Puntius sarana, P. jerdoni, Labeo calbasu, L. fimbriatus, Mystus* spp., *Rita* spp., *Ompok* spp., *Wallago attu* and *Mastacembelus armatus*, etc. In the lower stretch (Andhra Pradesh) *C. catla,* *L. rohita, L. calbasu, L. boga, L. gonius, C. mrigala, C. reba, Sperata aor, Bagarius bagarius, Pangasius pangasius, Silonia childreni, Eutroplus suratensis. Puntius kolus, P. sarana, P. ticto, Rita pavimentata, Wallago attu, Channa* spp., *Notopterus notopterus, Glossogobius giuris, M. armatus, Xenentodon cancila*, and the prawns, *Macrobrachium rosenbergii, M. malcomsonii* and *Penaeus monodon* were available.

Eighty species of fish belonging to 23 families were reported from river Cauvery. Main fishery of river Cauvery, during 1999-2001 was observed to be a mix of Cauvery carps (*Puntius carnaticus, P. dubius, Labeo kontius, L. ariza*), the transplanted Gangetic major carps (*Catla catla, Labeo rohita*, and *Cirrhinus mrigala*), *Labeo fimbriatus, Sperata seenghala, S. aor, Cirrhinus cirrhosa, Channa punctatus, Tor khudree* and exotic fishes like *Oreochromis mossambicus, Hypophthalmichthys molitrix, Ctenopharyngodon idella* and *Cyprinus carpio*. The *O. mossambicus* was observed to be well established throughout in this river.

West Coast River System

Based on the survey of 150 km western part of the river, from Punasa to Barwani, 84 fish species were reported from river Narmada. Available catch statistics for the period 1959-64, from a 48 km stretch of river Narmada, based on two landing centres (Hoshangabad and Shahganj) showed annual fish landing of the stretch ranged between 32.3 and 57.2 tonnes, with an average of 41.5 tonnes, during the period. Further, a comparison of data of the estimated fish landings from this river at Maheshwar, Mandleshwar, Hoshangabad and Shahganj during 1965-70, and landing data from Punasa, Omkareswar, Mandleshwar, Maheshwar and Barwani during 1989-90 did not reflect any marked difference in qualitative composition of fishery of different stretches. No significant decline in carp fishery was also observed, which varied from 58.4 to 65.5%, mainly constituted by *Tor tor* (25.3 to 30.1%) and *Labeo fimbriatus* (18.5 to 24.4%). Catfishes ranged from 21.8 to 35.9%. However, study on the qualitative and quantitative fish catch during 1996-99, from 280 km stretch of river Narmada (Sandia, Shahganj, Hoshangabad, Dongarwara, Budri, Gondagaon, Harda, Handia, and Harsud), showed that the carp fishery has declined, being 43.7% of the total catch, with 15.9 and 10.2% contribution of *Tor tor* and *Labeo fimbriatus* respectively.

There is not much information available about fish catches from river Tapti. The only information available is based on a fishery survey conducted during 1959-60 in a 728 km long stretch of the river from Burhanpur (Madhya Pradesh) to Kathor (Gujarat). Based on this survey, 52 fish species were reported from this river. Fishing season in this river was seen to commence from September-October and continue till onset of monsoon. Fishes mainly caught from this river were *Tor tor, Labeo fimbriatus, L. calbasu, L. bata, L. boggut, Sperata seenghala, S. aor* and *Wallago attu*. In the lower reaches of river Tapti, in Gujarat, hilsa constitutes a comparatively lucrative fishery during the monsoon season, particularly in the vicinity of Surat and downstream.

Fish spawn availability in the river Ganga: The Ganga river system covers the states of Uttarakhand, Haryana, Delhi, Uttar Pradesh, Madhya Pradesh, Bihar and West Bengal. Fish seed in this river system was collected in the form of eggs, spawn (hatchlings up to 8 mm in length), fry (seed, above 8 mm and up to 40 mm in length) and fingerlings. (Fish seed, above 40 mm and up to 100 mm in length).

The collection of spawn on commercial scale was prevalent in Bihar, West Bengal and Uttar Pradesh. A survey of the spawn collection centres in these states showed a large concentration of such centres on the main Ganga, yielding quality spawn. About 75 important spawn collection centres are registered with the Government of Uttar Pradesh on the Ganga, Yamuna, Betwa, Gomti, Ramganga, Rapti,Ghagra and a few other smaller streams.

In the Ganga system, major carp spawn was available from May to September. The first appearance of spawn in India occurs in the Kosi due to flood caused by melt snow in mid-May or early June. The other rivers, viz. Ganga, Gomti, Yamuna experience spawning only after having been flooded by heavy rains. Kursela centre situated just below the confluence of the Kosi with Ganga, has an additional advantage in that it first receives spawn from Kosi, followed by that of the Ganga. Spawn prospecting investigations, originally initiated by the CIFRI and intensified in 1964, helped in establishing many productive centres in Ganga river system. Investigations by the CIFRI on spawn prospecting were helpful in establishing excellent source of quality fish seed at Sapori (Tank) on the Banas, Anwara (Agra), Dhumenpur (Etawah), Kishanpur (Fatehpur), Mahewa Jamunapur (Allahabad) on the Yamuna; Salempur (Lucknow) on the Gomti. In lower stretch of Ganga and its tributaries in Bihar and West Bengal, spawn was collected by private fishermen on a very large scale and there existed private trade. However, with the large-scale aquaculture development in the country the maximum carp seed needed for culture purposes is produced in hatcheries both in public and private sector. This has resulted in significant drop in natural collection of seed from the river system. But the data generated by the CIFRI also indicated that overall major carp spawn availability at the previously potential sites in the river has drastically reduced due to destruction of breeding sites in the river and other anthropogenic factors as well, thus impacting the natural recruitment of these species.

Gears

The dragnets, gill nets and hooks are commonly used by fishers to catch fish. Dragnets of two types small (less than 300 m in length) and large (>300 m in length) are in use. The fishers use hook and lines in the upper stretch mainly and partly in the middle stretch, whereas traps are in use in some districts of Bihar stretch of the river system. Small scoop nets are used in the entire stretch but large ones are used only in lower stretches. Limited numbers of dip nets were observed in use by fishers at Allahabad and Mirzapur districts in Uttar Pradesh.

About two-thirds of gill nets in use were of smaller mesh size. The percentage use of lower mesh size gears was marginally more in Uttar Pradesh. Though no previous information is available about the percentage usage of different mesh-sized gill nets by fishers but on interaction with fishers from different centres it can be inferred that in past the use of small meshed gears was minimal. Mesh size of gill nets varied from 18 to 26 cm and in some dragnet fishing more than 2 cm mesh was operated.

In some districts of Bihar, and Varanasi, Ghazipur and Balia districts of Uttar Pradesh use of large dragnets of mosquito net clothing with minimal mesh size is common. These gears are highly destructive both to fish stocks and ecosystem as well.

In the recent past the use of dragnets, traps, hooks and lines has declined sharply as compared to sixties. At present the availability and use of gill nets had increased manifold in all stretches.

Energy transfer and fish production potential

The rate of net energy transformation by producers and fish production potential of both the Himalayan and Peninsular rivers has been worked out by the CIFRI shown in Figs 9.2 and 9.3. The rate of energy transformation in the Ganga was 1,015 cal/m^2/day

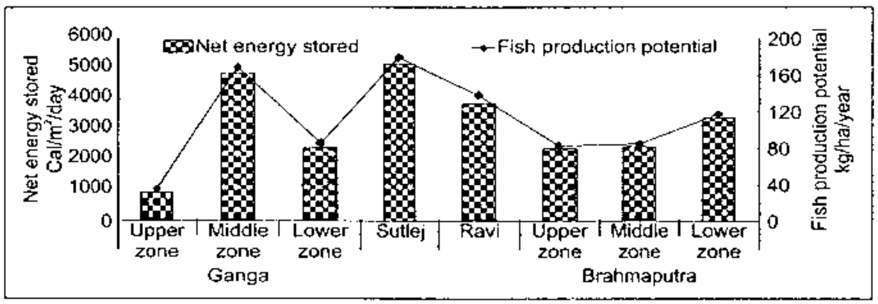

Fig.9.2. Rate of energy transformation and fish production potential of Himalayan rivers

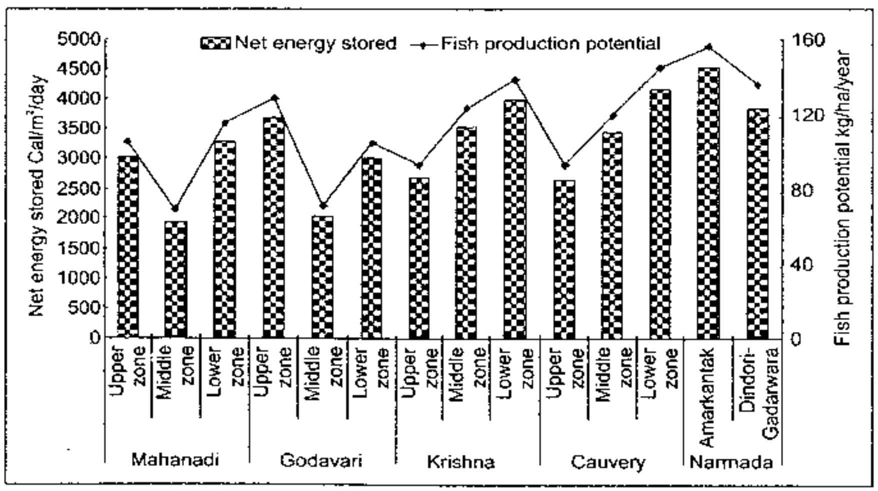

Fig.9.3. Rate of energy transformation and fish production potential of peninsular rivers

in the upper zone, 4,877 cal/m^2/day in middle, and 2,489 cal/m^2/day in the lower zone with a fish production potential estimated at 35.2, 168.9 and 86.2 kg/ha/year respectively. Thus, with respect to potential also the Ganga was divided into three clear cut zones. In Brahmaputra, the rate of energy transformation by producers was on the average 2,452 cal/m^2/day in the upper zone, 2,452 cal/m^2/day in middle, and 3,393 cal/m^2/day in the lower zone. The estimated fish production potential in the three zones was 82.9, 84.9 and 117.5 /ha/year respectively, being comparatively higher in the lower zone. These are just potential estimates based on energy fixed by producers but not the actual yield anticipated.

In Mahanadi the rate of energy fixed was 3,027, 1,977 and 3,312 cal/m^2/day in the three zones with the estimated fish production potential at 104.7, 68.3 and 114.6 kg/ha, respectively, potential was comparatively lower in the middle zone. The fish production potential in Godavari was estimated at 128.5 kg/ha in the upper zone, 70.7 kg/ha in the middle zone and 104.4 kg/ha in the lower zone with energy transformation rate 3,715, 2,045 and 3,017 cal/m^2/day, respectively. In Krishna, the rate of energy fixed by producers was 2,675, 3,535 and 3,987 cal/m^2/day in the three zones respectively. The fish production potential was estimated at 92.5 kg/ha in the upper zone, 122.4 kg/ha in middle zone and 138.0 kg/ha in the lower zone showing considerable increase from upper to lower zone. In Cauvery also both rate of energy transformation and fish production potential showed a gradual increase from 2,681 cal/m^2/day and 92.8 kg/ha in the upper zone to 4,164 cal/m^2/day and 144.2 kg/ha in the lower zone. In Narmada both rate of energy transformation and fish production potential were comparatively higher at Amarkantak (4,507 cal/m^2/day and 156.0 kg/ha). In the stretch between Dindori-Gadarwara values were 3,907 cal/m^2/d and 135.3 kg/ha being comparatively lower than Amarkantak.

These potential estimates worked out indicated that our rivers across the country due to their inherent biogenic properties, nutrients, availability of food and ecosystem functions have varied potential to produce fish. But to harness some percentage of this potential into fish biomass does depend on implementation of appropriate fishery and river management practices. But such information does provide a manager some benchmark to plan fishery development/conservation strategy.

Fish – As Energy harvest - time scale changes in the Ganga

The per unit estimates of fish yield from catch records and assessing it in terms of energy, has been worked out on the basis of primary production estimates at different stations, of the Ganga, using C^{14} technique by scientists of the CIFRI (Table 9.6).

Significant variation exists both in terms of stations and time periods in the transformation of available energy into potential per unit fish biomass in this case the conversion ranges from 0.032 to 0.082 %. This would imply that inspite of available energy source at each station there are other parameters of ecosystem functions that are impacting the fish production as well. Further, the pattern of per unit fish harvest among different food niches in terms of energy is set in Table 9.7, which indicated that across the stations there is a decline in fish energy harvest through the years. This

Table 9.6. Time-scale energy estimates at different stations of the river Ganga

Stations	Yearly average	Primary production (cal/m²/day)	Potential biomass estimates as per energy (kg ha/year)	Total annual per unit energy estimates (k cal/ha/year)
Kanpur	1960	4,678	162	194,000
	1987-88	1,008	34.9	41,880
	2000-2006	4,897	169.6	203,520
Allahabad	1960	4,545	157.3	188,822
	1987-88	3,085	106.8	128,160
	2000-2006	4,368	151.2	181440
Varanasi	1960	4,248	147	176,500
	1987-88	1,987	68.8	82,538
	2000-2006	3,842	133	159,627
Patna	1960	3,770	130.5	156,600
	1987-88	3,639	126	151,200
	2000-2006	3,533	122.3	146,760
Bhagalpur	1960	3,462	119.8	143,820
	1987-88	3,278	113.5	136,200
	2000-2006	3,024	104.7	125,640
Rajmahal	1960	3,078	106.5	127,800
	1987-88	2,897	100.3	120,360
	2000-2006	2,730	94.5	113,424
Farakka	1960	Na	Na	Na
	1987-88	Na	Na	Na
	2000-2006	2,849	98.6	118,320

Na, No estimates. *Source:* Modified after Jhingran and Pathak (1988); and Pathak (1999).

Table 9.7. Estimated fish as energy harvest (k cal/ha) sustaining on different food chain at selected stations in the river Ganga

River stretch	Period	Fishes on primary food chain	Fishes on secondary food chain	Fishes on tertiary food chain	Miscellaneous group of species	Fishes on detritus chain	Total fish harvest as energy
Allahabad	1961-68	10,212	3,996	12,084	12,720	17,124	56,136
	2000-06	612	780	2,436	13,404	996	22,080
Buxar	1963-71	91,176	1,872	8,988	29,676	1,848	133,560
	1981-86	4,464	1,212	15,960	36,996	5,688	64,320
Patna	1961-66	17,844	3,420	17,946	39,060	8,676	86,940
	1986-93	1,836	2,376	9,336	22,548	1,548	37,644
Bhagalpur	1961-70	4,008	3,780	14,412	27,240	2,796	52,236
	1981-88	1,104	1,308	12,348	24,240	792	39,792

decline is also reflected in fish species sustaining on different food chain as well. However, through the years an increasing trend in energy harvest of miscellaneous fish species is a noticeable feature. This data set on estimated energy harvest as fish from different stations of the Ganga River supports that ecosystem functions have registered a significant shift impacting the fish production as well.

Pollution and toxicity

Ganga river system: More than 29 cities, 70 towns and thousands of villages are situated along the banks of the Ganga. A part of the generated sewage from these cities/towns etc, estimated at 1,300 mld is discharged directly into the river. Another 260 million liters of industrial wastes are added to this by hundreds of factories situated along the river banks. City sewage constitutes 80% by volume of the total waste dumped into the Ganga. The majority of the pollution of Ganga is organic waste, sewage, solid waste and human and animal remains. The industrial pollutants also contaminate the Ganga. The major polluting industries are the leather industries, especially near Kanpur, which use large amounts of chromium (Cr) and other toxic chemical waste, pharmaceutical companies, electronics plants, textile and paper industries, tanneries, fertilizer manufacturers and oil refineries all discharge effluent into the river. This hazardous waste includes hydrochloric acid (HCl), heavy metals, bleaches, dyes and pesticide residues from riparian agriculture.

Industrial activities: The Gangetic plain is the hub of all types of industrial activities. Pollution load in the river Ganga and its tributaries is contributed by various types of industries (pulp and paper, textiles, tanneries, sugar factories, distilleries, oil refineries, fertilizers, chemicals, steel, paints and varnish, rubber, jute, etc.), besides domestic sewage from cities and agricultural run-off from villages, located on its bank. There are also coal washeries and thermal power plants, discharging there untreated solid and liquid wastes into the river. The discharge from various industries into Ganga River System in early 1980s has been estimated as BOD load of 1.166 million kg/day. The domestic sewage discharge was estimated as 1,528.1 million m^3, generating a BOD load of 2,504 million kg/day. The agriculture sector drains wastes into the Ganga basin to the tune of 134.84 million m^3. Fertilizers used in agriculture activities in the basin were estimated to release annually nitrogen (N_2) content to the tune of about 887,333 tonnes, phosphate (PO_4) 137,445 tonnes and potassium (K) 91,247 tonnes. Similarly, pesticides comprising mainly DDT and BHC-Y were estimated to be consumed to the tune of 2,573 tonnes for pest control measures.

Brahmaputra river system: Pollution load in this system has not much of impact on the environment of the river proper because of heavy quantum of its discharge and fast current. But it does effect the environment of its floodplain wetlands, the deterioration of which indirectly effects the fishery of the main river also. Thirteen major industries (oil refineries, pulp and paper, fertilizers etc.) are located in Brahmaputra valley. With all the major towns of the state located on the riverbanks, the discharge of municipal wastes along with run off from the tea gardens and agricultural plots also add to the magnitude of this problem. It has been reported that river Brahmaputra receives about 1,140 lakh litres/day of wastewater from the industries located in the valley.

Indus river system: Amongst the three tributaries of Indus, Sutlej is subjected to maximum pollutional load due to various types of industries (fertilizers, chemicals, pulp and paper, textiles, tanneries, sugar factories, distilleries, leather tannieries, dying and electroplating) besides ash and washoff from thermal power plants. The system as a whole is heavily subjected to municipal effluents as region is thickly populated having industrialized towns along its banks– Nangal, Ropar, Ludhiana etc. The system also receives washoff of fertilizers and pesticides as the same are used extensively in this belt, on an average 172 kg/ha compared to national average of 72 kg/ha. The pollutional load gets compounded due to abstraction of water resources as the system is extensively used for irrigation.

Environmental impact

River modifications and siltation: River course modifications have been a major developmental activity, during post-independent India. There are four major man-made projects for exploitation of water of river Ganga for irrigation/hydel generation, viz. Chilla canal near Rishikesh for power generation and Upper Ganga, Middle Ganga and Lower Ganga canals at Balawali, Bijnor and Narora, respectively, for irrigation and many more are coming in the upper region like Tehri Dam on river Bhagirathi. Farakka barrage, commissioned in 1972 at the border of Malda and Murshidabad districts (West Bengal), is for the purpose of diverting river water to Kolkata port which, with passage of time due to siltation of connecting river (Bhagirathi), was not receiving Ganga water from upstream.

The Ganga basin receives 48.96 million ha-m of annual run-off from a catchment area of 96.6 million ha. The river with a drainage basin of 1.1 million km^2 carries an annual sediment load of 1.46 million tonnes, only next to Yellow River of China. The river derives its water chiefly from south-west monsoon and from glacial melt in summer. The main channel carries its maximum volume of water during July-September at flow rates between 40,000 and 50,000 m^3/sec, which dwindles to about 3,000 m^3/sec in winter and summer. The mean flow in the main tributaries is less than 400 m^3/sec.

Fish passes and migration facilities: Limited fish pass facilities are available in the dams constructed on Indian rivers. Sarada Barrage and Farakka Barrage on Ganga Basin, Dakpathar and Hathnikund barrage on Yamuna, Run of the River Low Dams in Jammu and Kashmir, and on Mahanadi. These facilities were provided to provide passage to the *Anadromus* species, *Hilsa ilisha, Potamdromus* species, *Tor putitora, Tor tor, Scizothorax richardsoni, S. progastus, Barbodes hexagonolepis, Labeo rohita, C. catla, C. mrigala, L. calbasu, Amphidromus* spp., and *Macrobrachium rosenbergi*.

Utility of these passes is yet to be ascertained at many places. However, fishery assessment carried over by the CIFRI in Ganga observe that in spite of two fish locks which have been provided between Bay Nos 24 and 26 within Farakka Barrage, the commercially important hilsa (*Tenualosa ilisha*) has highly suffered from Farakka barrage since its construction (1975), blocking almost 1,000 km of its migratory path. Today, the upstream catches do not show a coherent tendency, with almost nil catches reported at Allahabad. No detailed analysis as to the functioning of the fish locks is available.

A survey conducted during 2000 by the Directorate of Fisheries on the functioning of the fish passes in the barrages (two) on Mahanadi revealed that the major portion of the catch is constituted by the species *L. bata, C. reba, L. rohita, C. mrigala, G. giuris, W. attu*, and the migratory fish *Tenualosa ilisha* caught during the flooded rainy season at Mundali (7 km upstream of Mahanadi barrage), Ramdashpur and even further upstream shows possible upstream migration through the fish passes.

Now it has become mandatory for the concerned authorities to consult fisheries people in designing fish passes so that specific design for specific fishery can be provided.In this connection, the CIFRI conducted extensive investigation in the upstream and downstream of the upcoming dams on river Bichum and Tenga in Arunanchal Pradesh to design appropriate fish passes profile (Pool type) for incorporation in the Bichum dam. The fish pass designed by the CIFRI for incorporation in Bichum dam on river Bichum has been accepted by the dam authorities. It will be worthwhile to evaluate its function after the project becomes operational.

Time-scale changes in ecology and fisheries: With passage of time, there is a gradual to sharp decline in riverine fisheries of most of the rivers of the country. Appearance of exotics in the fish catch, especially in the upper reaches of the rivers, and the gradual increase in their percentage contribution, during the last few years, is another matter of concern which may adversely affect the indigenous fish yield of indigenous species to great extent in years to come. Quantitative and qualitative time-series data, only available for the Ganga (Fig. 9.4) and Brahmaputra river systems clearly indicate depletion in fishery both quantitatively and qualitatively.

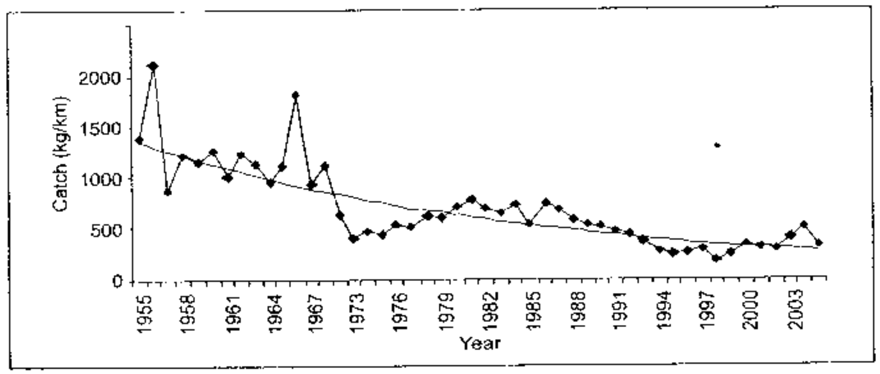

Fig 9.4 Fish catch from the Allahabad stretch of Ganga from 1955 to 2004.

The detailed account of soil and water quality of the river Ganga, observed during an exploratory survey of this river during 1995-96 by the CIFRI, based on holistic sampling at 43 centres from its origin to sea showed that the river bed between Tehri and Patna suffers severely from textural deformities and the sand drifting through a number of tributaries (rivers Ramganga, Yamuna, Gomti, Ghagra, Son and Gandak) in this region, the drifting sand heavily blankets the river bed resulting in decline in nutrient availability to food chain from the sediments.

A time-scale comparison of water quality parameters especially dissolved oxygen and *p*H from different stretches of the river Ganga during sixties and late nineties indicated on the whole a healthy trend except at certain hot spots.

A decline in total per unit density of plankton in middle and lower freshwater stretches of the river Ganga was observed during 2001-02 in comparison to what was reported to occur during early sixties. The qualitative composition of the plankton witnessed little change. The pollution indicator species, viz. *Anabaena, Lyngbya, Merismopedia* and *Spirulina*, were recorded less in number in lotic waters of Ganga, which reflects on water quality improvement.

The rate of abstraction of water from almost all the rivers of the Ganga River System is very intensive. The total length of canal network in Ganga basin is over 15,000 km. Resultant to continued increased abstraction of water, the volume of water available in this river system is on a continuous decline. Based on daily water level data of Central Water Commission it has been estimated that the mean water level of river Ganga at Allahabad during July to September (the period of maximum water availability) has declined by about 4 m between 1975 and 1995.

Detailed study on ecology and production dynamics of river Brahmaputra and its tributaries was done by the CIFRI during 1996-98 and also during 2002-2003. Comparing the ecological conditions, it could be concluded that the water quality parameters, like *p*H, dissolved oxygen, total alkalinity, specific conductance, dissolved solids, calcium, hardness and nutrients of river Brahmaputra have not shown any significant variation over the years. However, a declining trend could be observed in respect of water transparency, which was as high as 150 cm during 1974-77, which has been reduced to 30-40 cm. The reduction in transparency is a clear indication of increasing silt load in this river system. Tributaries play a key role in maintaining the annual water quality cycle of river Brahmaputra and increase in turbidity over the years is obvious as huge quantity of silt is discharged by these tributaries year after year. Observations showed that average annual silt discharge by north bank tributaries into river Brahmaputra is of the order of 666.7 m^3/km^2 and that from south bank tributaries range between 66.7 and 95.7 m^3/km^2. Due to this accumulation of huge amount of silt the Brahmaputra bed is rising alarmingly.

While basic ecological parameters seem to be reasonably within permissible limits but a gradual/sharp decline in fish production, both quantitatively and qualitatively, is evident in the freshwater zone of the river above Farakka barrage. Environmental aberrations in the form of high rate of sedimentation, increased water abstraction and river course modifications, coupled with non-judicious/irrational fishing of the broodstock and juveniles, appear to be the likely causes for this contrasting situation in this river system.

High rate of sedimentation, caused due to deforestation in the catchment areas, has resulted in desertification of river bed in major part of the freshwater zone (origin to Patna), blanketing of the soil water interface and, thus, loss in productivity of the system. In view of this, it can be said that the present available productivity of the river water in this stretch is the result of nutrients being drained into the system from allochthonous sources. Sedimentation coupled with increased water abstraction has naturally drastically decreased the available water volume in the river, which has resulted in habitat loss for the biotic communities inhabiting the system. Besides decreased feeding

area, the breeding areas of the quality fishes have also been adversely affected due to non-inundation of potential breeding grounds in the vicinity of the river.

Only with increased water discharge and resultant quantum jump in water volume in the river Hooghly, after commissioning of Farakka barrage, a sharp and continued rise in estuarine fishery, with average annual fish catch from 9,481.5 tonnes during 1966-67 to 1974-75 (pre-barrage period) to 62,000 tonnes during 1999-2000 (post-barrage period) has been observed. This amply confirms the view that the loss of water volume, in the freshwater stretch of the river Ganga, is the main cause of decline of its fisheries.

The biological properties of riverine fish communities make them extremely sensitive to any change in flood regime (which in turn is dependent on available water volume in the river) because of their dependence on seasonal floods to inundate the grounds needed for feeding and reproduction. Loss of original feeding and breeding grounds (due to considerable decrease in water volume in the rivers), accompanied with non-judicious/irrational fishing of the broodstock and juveniles, being more and more intensified by the fishers have adversely effected the process of recruitment and, thus, fish production.

River course modifications have affected the migratory species (specially hilsa and freshwater prawns). Sharp decline in fishery of hilsa above Farakka barrage, immediately after its commissioning, is a glaring example of river course modification affecting the fishery of migratory species. The mahseer fishery of various river systems in the country, like Narmada, Brahmaputra and other upland Himalayan rivers, has also suffered due to increased incidence of river valley modifications and irrational anthropogenic activities.

Deforestation and soil erosion in the catchment, habitat destruction of floodplain wetlands, coupled with large-scale killing of fishes using explosive materials and mass destruction of juveniles, were identified to be the main causes of decline in fisheries of river Brahmaputra.

Climate change and fisheries: Perceptible changes on a global and regional scale are evident in earth's climate. In India observed changes include an increase of air temperature, regional monsoon variation, frequent droughts and a regional increase in severe storm incidence in coastal states of India along with indication of Himalayan glacier recession. The impact is being felt in the inland aquatic resources and their fisheries. Analysis of time series data of 30 years from published literature and from current investigations on the River Ganga and water-bodies in its plains indicate increased minimum water temperatures, 1.5°C in colder stretches of the Ganga and 0.2 to 1.6°C in the aquaculture farms of the West Bengal in the Gangetic plains. Rainfall has also increased in the post-monsoon months of September–December. The impact is manifested in the breeding failure of the Indian major carps and a consequent decline in fish spawn availability in the river Ganga and is being given in chapter, "Climate Change–Impact and Mitigation."

Fish production showed distinct change in the last two decades in the middle stretch of river Ganga where the contribution of IMC has decreased from 41.4% to 8.3% and that of miscellaneous and catfish species increased. Climate change in India will put an additional stress on ecological and socio-economic systems that are already facing pressure. Thus the specific climate variables of importance to inland fisheries, viz. enhanced water temperature, extreme events like flood and drought, storms and water stress require specific adaptation actions.

Alien/exotic species: Introduced species occasionally replace native species in natural habitats through competition or predation, but most replacement occurs in altered environments that provide the introduced species an ecological advantage. One-way that introduced species eliminate native species is through the introduction of diseases. Thai Mangur *(Clarias gariepinus)* and Chinese grass carp *(Ctenopharyngodon idella)* are some of the introduced species in the Ganges river system. Details of impact on the native fish fauna are not well understood. In 1998, *Physa (Haitia) mexicana*, a North American snail was reported for the first time in the Indian subcontinent in the Ganga. The species flourished profusely by 2001. However, nothing is known if the species spread any disease. Similarly, well known South African aquatic plant, *Eichhornia crassipes*, has badly affected the lentic water-bodies in the Gangetic plains.

Besides fishes, turtles, gavialis, crocodile, birds, otter and freshwater dolphins are also exploited to different extents. Exploitation of crocodile, otter and dolphins depends on their abundance in the river. Rampant killing of the soft shell turtles, *Aspideretes gangeticus*, has reduced the population to scarce. In the last two years hundreds of freshwater turtles were confiscated by enforcement agencies in Bihar. The species is a natural scavenger of the river and as a part of the Ganga Action Plan about 40,000 turtles were released in the Ganges near Varanasi, but it couldn't be proved worthy due to their rampant killing.

Economic status of fishers and fish stock management

Socio-economic and livelihoods

The social framework and characteristics of fisheries and fishers operating in the Ganga river provide an insight into the status of ultimate beneficiaries, the fishers. A study to this effect was conducted by the CIFRI during 2006 covering approximately 960 km stretch from Hardoi to Bhagalpur in Uttar Pradesh and Bihar. In the survey, data from 162 villages covering 2,029 families were collected. The study revealed following observations.

Demography: The family size for the fisher community changed over the years due to conversion of joint families in the yester years to nuclear families. The overall family size for the river Ganga in the studied stretch was estimated at 4.52. The age distribution of the fisher community showed comparatively higher proportion of minors (55%) than adults (45%). The sex ratio across the age groups varied from 656 to 1,053 females per 1,000 males in the age groups 15-29 and <5 years respectively. The sex ratio was above one only in <5-year age group and it was less than one for all the other age groups. The lower ratio was primarily due to gender bias, poor health care and

social attention for the females. Higher number of females per male for below 5-year age group showed reversal trend and positively changing attitudes towards females. It may be considered as a positive change in social features of fisher community.

Literacy: Literacy rates were low with a significant difference between male (52%) and female (19%) indicating females were far behind the males. The percentage of literate males in Uttar Pradesh was more than Bihar, while it was *vice-versa* for females, although, the difference in literacy rate was small. The study revealed very poor literacy level of fisher community. Most of them were literate up to primary level and to the maximum of higher secondary. The literacy level also followed the similar trend across the sex groups of both the states. The overall scenario may be attributed to poverty, involvement of female children in domestic and household economic activities from childhood, ignorance of parents about girl's education.

Living standard: Most of the fishing community lived in hut and *kachha* tiled houses. The situation in Bihar was comparatively better than Uttar Pradesh with higher per cent having *pucca* houses. Floor type in both the states was earthen followed by cemented and with bricks. The estimates for number of persons per room indicated that mostly 3-6 persons had to adjust in a room. Such crowded housing conditions affected their health and quality of life. Most of the fishers were land less and some of them had own or shared land and few utilized unclaimed land for domestic and productive purpose. Proportion of fishing group households having own land was less than 25% for both states and the holding size was also small. Greater proportion of Bihar households had shared community land as compared to Uttar Pradesh, while it was *vice-versa* for unclaimed land utilized by fisher community.

The standard of living refers to the quality and quantity of goods and services available to the people and the way these goods and services are distributed within a population. This composite index was calculated by scoring for house type, toilet facility, source of lighting, main fuel for cooking, source of drinking water, ownership of land, livestocks, durable goods, etc. It was observed that the standard of living of fishers is very poor for over 75% of their community.

Employment: The estimates of Worker Population Ratios (WPRs) computed as number of persons employed per 1,000 persons indicated higher values for males (673) than females (431) for the river Ganga. The average ratio for male ranged between 666 for Uttar Pradesh and 696 for Bihar in comparison to females at 455 and 351 respectively. This may be due to participation of females in allied activities and agricultural harvesting in Uttar Pradesh. The principal activity among fisher males was fishing in rivers (48-57%) followed by general and fishing labour. In case of females allied activity (65%) was the principal activity in Uttar Pradesh, while in Bihar business (62%) was reported as the principal activity followed by fish retailing. Migration was common phenomenon among the fishers. Female migration was generally for short duration and related to unskilled activities. Male migration was common for all the activities including higher percentage for unskilled labour.

Expenditure pattern: The ranges for per caput monthly expenditure on food and non-food revealed that on an average, fishers spent 66% on food and 34% on non-food items. The major food item of the expenditure was cereals (37%) followed by vegetables (7%). Among non-food items highest expenses were on medical (9%) followed by intoxicants (8%).

Stock and system management policy

The property regimes: The rivers are the state property and various river stretches within or between the states belong to departments of fisheries, revenue, forestry, village panchayats, etc. These departments adopted varied policies for fishing in these stretches. The rivers being fluvial and fish being migratory renewable resource, it is difficult to apportion the fish biomass in territorial limits. From fisheries viewpoint most of the rivers are in open access, with some exceptions where these are leased to cooperatives or private parties. A comparative account of fishery activities under these management regimes has been made by the CIFRI, selecting one stretch in each of these management regimes, i.e. open access, private and co-operatives. The study investigated stretches of the river Ganga (Kanpur to Farakka) under open access and its tributaries, river Yamuna (Yamuna Nagar to Panipat) under private (contractor) and river Ghagra (Ghagra ghat to Faizabad) under co-operatives. To have a comparison it is necessary to understand these regimes in terms of rights and duties.

In open access, the river fish biomass is for a free access to any one. There is a free entry to river fishing, which allows anyone to fish anywhere, anytime. Although, there are regulations under Indian Fisheries Act for fishing and responsibility of conservation of fish stock lies with the state governments, but due to unmanageable vast magnitude of this natural resource, institutional arrangements and authority systems inevitably cease in this regime.

Under the cooperative management regime, state government lease out the stretch to fisheries cooperative societies, and conferred all the rights and powers of decision-making regarding fisheries in the stretches to co-operatives. Generally, the stretches were leased for one year, but the lease is likely to be renewed every year, unless there was some serious complaint about fisheries management by the co-operative. The members of society have the right to fish and exclude non-members from fishing. The non-members have the duty to abide by this exclusion.

In the private management regime the fishing rights and power to transfer fishing rights and decision making rested with the individual to whom the stretch is leased out. The stretch is leased out for 1 year based on open auction. In open auction, the lease may continue with same person or may be transferred to others, with higher bid. The lessee or contractor transfers the fishing rights to the fishers on terms and conditions best suited to him. In all the regimes fishing rights rested with fishers, but they have to perform the fishing activities within socially acceptable limits, and allow the non-fishing people to use water to meet their day-to-day requirements.

Management regimes: Regarding the management regimes, under open access, individual fisherman or group of fishermen can fish anywhere in the river, but in few cases, due to declining fish catch, local fishers may prohibit the migrating fishers from fishing in their area. It largely depends upon the mutual relationship between the fishers of different stretches. In case of cooperatives the member fishers, mostly fished in their own stretch. The length of stretches leased to society varied to a greater extent. Accordingly, the fishing area and time spent by fishermen fluctuated for these cooperatives. For private management regimes, the river stretch was generally leased out to contractors annually. These contractors were mostly the fish traders, who generally engaged local fishermen or the professional fishing parties for fish harvesting. Regarding the level of exploitation and follow up of conservation measures, the open access and cooperatives adopt mild fishing practices and try to follow the mesh and fish size regulations, as they have to continue fishing over the years, but for contractor under private regime, as the lease period is 1year, and there is no certainty for future, the fishing gears used are comparatively less mild. The parties engaged for fish harvesting generally, use smaller mesh dragnets, to have the maximum catch. The fishing period under all the management regimes extend almost round the year with lean period or close season during monsoon.

Fisheries requisites and fishing effort under different regimes: The most prevalent fishery requisites included gill net and hook and lines in gears and under open access and cooperatives were either owned or shared by the fishermen; while in private regime these belonged to fishermen (may also be financed by contractor) or provided by contractor. The annual fishing effort was highest for private regime followed by open access and cooperative; while annual and per day catch was maximum for open access. The cost structure was almost similar for open access and private regimes, while very low for cooperatives. These observations may be attributed to intensity of fishing or the fishing effort put in by the fishers under different regimes. The lower cost in cooperative may be due to lower fishing effort and sharing of inputs.

Remunerations and income under different regimes: The remuneration for catch and distribution of profits were the best in open access. These were on the basis of contribution in effort and fisheries requisites. The fishermen having the boat and nets would get higher share than the fishermen sharing these requisites. For private and cooperatives the remuneration and payments largely depended upon the pattern of disposal of catch and mode adopted for payments by respective regimes. It may be daily, weekly or monthly. The contractors generally remunerated the catch of local fishers at some fixed rate/royalty per kg. But, in case of hired fishing party it may be on share basis. In case of cooperatives the remuneration was in term of per cent of market price, after deduction of commission by society, for rendering the services. The profits are distributed among the member fishers according to their share capital.

Per kg price received by the fishers may be recognized as the indicator of impact of these management regimes and fishing rights on the fishermen income. These estimates favoured cooperative regime the most followed by open access. The lowest values for these estimates were under the private regime. The cooperatives directly dispose the catch in local market or at nearby town. In some cases, members of the society themselves performed the marketing functions, eliminating all the market intermediaries, so received much better prices. In open access the catches are auctioned in the wholesale markets and fishermen receive the auction price after deduction of wholesaler's commission. In private regime, the contractor remunerated the fishers catch in fixed rate/loyalty/kg. so, they are deprived of the benefits of market price.

The gross and net annual and per day returns were maximum for open access regime followed by cooperative and private, but the net income per kg of catch favoured cooperatives the most followed by open access, and the least for the private regime. The input output ratios also indicated the superiority of co-operatives and open access regimes over the private as their value for these ratios were more than 2.5 times of the estimated ratio for private regime. It depicted the working efficiency and extent of remuneration of fish catch for different management regimes and revealed that privatisation of the fishing rights in river fisheries would accelerate the process of social dis-equilibrium to broaden the income inequalities. It would push the downtrodden more down to uplift the economically fluent fish traders, who already are well off.

Emerging issues in management

Policy and regulation relook: Entry 21 of List II of Article 246 (3) of the *Constitution of India* puts fisheries in the State list whereas regulation and development of inter-state river and river valleys figure in Entry 56 of Lists I (Union List). The Government of India enacted the Indian Fisheries Act, which came into force in 1897. Under Section 3 of this Act, the states have been promulgating rules. Under this Act the regulatory measures generally comprise limited access, licensing of gear, gear restrictions, leasing and auctioning. The operation of various fishery laws in the country has, however, not yielded the desired results. The preamble declarations are very lofty at the implementation stage hardly anything is achieved. The time is now ripe to have second thoughts on the fishery laws and other allied rules for the development of inland fisheries. The following proposals for legislative reforms merit attention.

- To deal with the conflicts with regard to the management of river basins and that of the inter-state fisheries resources, the inclusion of the fisheries management of the inter-state rivers could be considered in the Concurrent List of the Centre and the State Governments.
- The anachronistic Indian Fisheries Act, 1897 should be repealed and a new comprehensive act should be brought after taking stock of all the changes in the last five decades.
- Keeping in view the diverse local, conditions, the central law may be of limited avail, but related rules should be promulgated with the basic framework of comprehensive Central Act.
- Inland fisheries should be included in the Concurrent List of the Indian Constitution so that the Union Government can also frame laws.
- Though deterrence is not the sole basis of law, the punishment prescribed in fishery law is very mild. Even in the matter of adulteration of food and drugs it becomes difficult to bring offenders to book. Unfortunately, in fisheries, violation of the rules is not taken very seriously by the people.
- An expert group comprising environmentalists, fishery scientists and jurists should examine the possibility of making an offence relating to destruction of habitat, ecosystem health and aquatic life a serious cognizable offence.
- The enforcement machinery needs strengthening, though it may lead to an increase in the financial liability of development departments. Without adequate manpower and social ethics, it is difficult to implement even ideally conceived laws. The duty of conservationists, planners and decision makers does not end by adding a new law to the statute book unless it is administered properly.

Fish stock conservation

- A reliable database on a time series mode to be generated prior to planning and formulation of development strategies for open water fisheries, especially the river/reservoir fishery.
- To initiate awareness for the conservation of biodiversity, revival of commercially viable biomass and protection of the habitat, programme should be taken up in identified areas.
- Conservation and sustainable exploitation measures for river fish taken in one state need to be complemented by the neighbouring states up or downstream of the rivers following globally agreed principles of responsible fishing. Certain well-thoughtout mechanisms for inter-state understanding and coordination would need to be evolved.
- Indiscriminate fishing of juveniles from secluded pools of water created along the banks of the rivers after the flood recedes has been a major cause of depletion of commercially important fish stocks in the rivers. Therefore, these broodstock pools may be protected by declaring them as fish breeding parks/ sanctuaries.
- Certain identified strategic but manageable high-altitude streams/lakes may be adopted under a conservation of biodiversity programme through a ban on fishing, protection of habitat through punitive orders and enhancement of natural population with ranching of certain species with seed of mahseer, snow-trout and other vulnerable species.
- The existing rules and regulations under the Indian Fisheries Act (1897) have provision to control and monitor the use of gear, mesh size as well as observance of fishing on closed seasons. For effective implementation of regulations, the following measures may be considered.
  - (i) Mesh size regulation may be monitored by inspecting landing centers for fish size in particular seasons and parties operating the river stretch be made responsible for effective operation;
  - (ii) River stretches to be leased/auctioned may be done on state level than on district level to minimize fishing pressure per unit length of the river by the lessee;
  - (iii) Lease period should have a flexible component with possibility to extend the period depending upon the effective implementation of conservation measures by the lessee.

Cleaning of rivers

The Government of India initiated River Cleaning Programme in 1985 as GAP-I (Ganga Action Plan) and GAP-II was initiated in 1993 subsequently extended to other rivers in 1995.As per the document cleaning of rivers is a mammoth task requiring the involvement of all stake-holders and also it is not a one time efforts but a continuous one with increase in population and other stresses on such ecosystems. The main objective of the River Action Plan is to improve the water quality of the major rivers, which are the major fresh water source in the country through the implementation of pollution abatement schemes. The list of rivers covered under NRCP (National River Cleaning Programme) is set in Table 9.8.

Table 9.8. Names of rivers in different states covered under different NRCP scheme

Adayar	Ganga	Musi	Tunga
Betwa	Godavari	Narmada	Tungabhadra
Bhadra	Gomti	Penniar	Tambraparani
Brahmini	Khan	Pamba	Pennar
Cauvery	Krishna	Rani-Chu	Vagai
Cooum	Kshipra	Sabarmati	Wainganga
Chambal	Mahanadi	Sutlej	Yamuna
Damodar	Mahananda	Subenarekha	
Dhipu-Dhansiri	Mandovi	Tapti	

Source : National River Conservation Directorate, MOEF, Government of India.

Due to these initiatives implemented in the river Ganga the NRCD reported improvement in water quality. The water quality monitoring of the Ganga River carried out at selected locations reported improved river water quality over pre-GAP period. It is reported that in 1986 the biochemical oxygen demand (BOD) that ranged from 5.5 to 15.5 mg/litre in the critical stretches of Ganga from Kannauj to Varanasi has improved in 2006 and recorded in the range of 1.11-6.78 mg/litre and 3.20-2.25 mg/litre in the stretches of Kannauj to Kanpur, and Allhabad to Varanasi respectively. Similarly, improvement in dissolved oxygen from a range of 6.6 to 5.9 mg/litre in 1986 to 8.4 to 8.8 mg/litre in 2006 has been reported. While improvement in water quality parameters is a positive signal but efforts are now underway through the joint efforts of the CPCB and the CIFRI to assess the impact of this positive water quality improvement in the rivers Ganga and Yamuna on fish diversity and production.

Environmental flows

The concept of environmental flows is that sufficient flow be maintained in a river to sustain its ecological functions including any fish population that is present. It is important to make legal provisions for the control of both the abstraction of water from rivers or channels for agriculture, urban use and industry and the release of impounded water from dams so that environmental flows are respected in river channels and floodplains are inundated annually to the maximum extent possible. A number of methods have been proposed for the assessment of what flows is needed to fulfill the

conditions of environmental flows. But these have been developed in relatively small, highland, salmonid rivers and only recently attention is being paid to development of assessment for large lowland river systems. Ideally, assessment methods should be based on a high degree of technical knowledge and research about the target system and its fish populations. In general, procedure for assessment of the water requirement of fish in rivers should:

(a) take into account the complex ecological requirements of all life stages of fish in rivers;
(b) be easy to understand and use, cost effective as well;
(c) be compatible with available expertise;
(d) be legally robust; and
(e) be generally accepted by all levels of fisheries and water user stakeholders.

It is generally insufficient that environmental flows be calculated only in terms of the total amount of water available to the system as a percentage of annual flow, as is the case with some of the simpler assessment methods, but also should respect critical features of the hydrograph such as timing and shape of the flood. It should be estimated both during wet season and lean dry season. The Government of India, under the Ministry of Water Resources, has set up a task force of experts in 2009 to develop appropriate methodology for our rivers and make an assessment.

Interlinking of rivers

The National River Linking Project (NRLP) envisaged transferring water from the surplus river basins to ease the water shortages in western and southern India while mitigating the impacts of recurrent floods in eastern India. The NRLP constitutes two basic components—the links which will connect the Himalayan rivers and those which will connect the peninsular rivers. When completed, the project would consist of 30 river links and 3,000 storage structures to transfer 174 km^3 of water through a canal network of about 14,900 km. The recent revival of the idea of interlinking of 'surplus' basins with 'deficit' basins has been the result of work done by the National Water development Agency (NWDA) and bears a conceptual continuity with Dr Rao's proposal.

Components of NRLP: The Himalayan component proposes to transfer 33 km^3 of water through 16 river links. It has two sub-components: (*i*) The Ganga and Brahmaputra basins to Mahanadi basin (links 11-14); and (*ii*) Eastern Ganga tributaries and Chambal, Sabramati river basins (links 1-10). The Peninsular component proposes to transfer 141 km^3 water through 14 river links. It has four sub-components: (*i*) Mahanadi and Godavari basins to Krishna, Cauvery and Vaigai rivers (links 1-9); (*ii*) West-flowing rivers south of Tapi to north of Mumbai (links 12 and 13); (*iii*) Ken River to Betwa River and Parbati, Kalisindh rivers to Chambal rivers (links 10 and 11); and (*iv*) some west flowing rivers to the eastern rivers (links 14).

Project benefits: The National River Linking Project envisages to: (*a*) to provide additional irrigation to 35 million ha of crop area and water supply to domestic and industrial use; (*b*) add 34 GW of hydro-power potential to the national grid; (*c*) mitigate floods in eastern India; and (*d*) facilitate various other economic activities such as internal navigation, fisheries, groundwater recharge, environmental flow of water-scarce rivers etc.

Contentious issues: The National River Linking Project (NRLP) has to tackle many contentious issues and these include (*a*) high magnitude of resources, (*b*) environmental concerns, (*c*) social issues, (*d*) cost recovery issues, and (*e*) political issues.

With regard to water issues a detailed strategic analysis of the NRLP for India was carried out by International Water Management Institute (IWMI) and findings are documented in their report. While for fisheries component NAAS organized a Round table with NIE, CIFRI and other departments to discuss the likely impact of river linking on inland fisheries from 21 to 22 May, 2004. Based on discussion of experts it was recommended that impact on fisheries, there could be positive as well as negative impacts. With creation of more water basins and canals, the resource for fisheries and aquaculture is expected to increase, while on the other hand, there could be mixing of fish species between the river basins, loss of certain amount of biodiversity as also entry of some invasive fish species. Further studies with regard to Data mining, Modeling studies and scenario analysis, Scaled-down approach, ensuring Environmental flows in river basins, loss-gain assessment, river ranching, river siltation an dredging, riverine pollution, impact on estuarine and coastal waters, biodiversity changes and taxonomic status are necessary for making correct impact assessment of interlinking of rivers on fisheries. In this context the CIFRI conducted a short-term study for the Ken-Betwa link with regard to likely impact on aquatic ecology and fisheries in 2008. Further, detailed studies in a systematic manner are necessary with a focus on fisheries for the proposed National River Linking Project.

Rehabilitation of river fisheries

The Food and Agriculture Organization (FAO) has published *The Technical Guidelines for Responsible Inland Water Fisheries* in which it has summarized the main processes that need to be undertaken in the planning, execution and follow up of any rehabilitation project.

Prior activities

- Establish database of benchmark rivers and lakes associated and typical fish assemblages
- Assess conditions in target river
- Identify disrupted ecosystem processes
- Prioritize target reaches and possible rehabilitation actions

Implementation

- Define need for and objective of rehabilitation – carry out overall feasibility study
- Assess water quality problems
- Define general scope and scale of project

Policy, legal and financial issues

- Clarify legal situation with regard to various options for rehabilitation
- Clarify social and economic aspects of proposed rehabilitation
- Consult with other stakeholders
- Obtain necessary funding and title or access to any land or water rights needed for project

Basin scale problems

- Control and improve water quality
- Undertake basin-scale operations needed to control excessive sediment loading
- Define environmental flows for target environments, fish communities or species in rivers

Technical issues

- Select methods for rehabilitation of Target Rivers
- Conserve or rehabilitate longitudinal connectivity
- Restore channel diversity and vegetation
- Conserve or rehabilitate lateral connectivity
- Restore seasonal floodplain, floodplain water-bodies and vegetation

Follow-up

- Carry out routine maintenance of fish-passes.
- Monitor effectiveness of measures adopted
- Modify to improve any deficiencies observed.

10. Estuarine Fisheries

Estuaries are the transitional zones between the rivers and sea and have specific ecological properties and biological composition. Estuaries offer immense biological wealth characterized by the diversified rich flora and fauna including fisheries. The term estuary may be defined "as the tidal mouth of a great river, where the tide meets the current". It is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with freshwater derived from land drainage. A more comprehensive definition that an estuary is "an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divided into three sectors: (*a*) a marine or lower estuary, having free connection with the open sea, (*b*) a middle estuary subject to strong salt and freshwater mixing, and (*c*) an upper or fluvial estuary, characterized by freshwater but subject to daily tidal action. The limits between these sectors are variable and subject to constant changes in the river discharge. A new functional definition is "an estuarine system is a coastal indentation that has a restricted connection to the ocean and remains open at least intermittently. The estuarine system can be subdivided into three regions: (*a*) a tidal zone, (*b*) a mixing zone — the estuary proper, and (*c*) a near shore turbid zone. This definition of estuaries includes the adjacent coastal waters. The salinity of the estuarine waters varies between 0.5 and 35‰. Estuarine water is extremely variable in its salinity, while marine and freshwater have distinctive stable salinities.

Classification of estuaries

Based on environment

There is a lack of uniformity among tropical estuaries in terms of size, depth, physical and chemical features and other environmental factors such as the nature of the adjacent marine and freshwater habitats. The tropical estuarine environment can be divided into four broad categories, viz. (*i*) open estuary, (*ii*) estuarine coastal waters, (*iii*) blind estuary, and (*iv*) coastal lake.

(i) ***Open estuaries:*** These estuaries are never isolated from the sea. The extensive delta of the Ganga river forms the countries largest estuarine system (Hooghly - Matlah) in the Indian Ocean. The tidal impact of the system is felt up to 200 km from the mouth. The Mahanadi and Godavari are also open type of estuaries.

(ii) ***Estuarine coastal waters:*** The effect of the discharge from the Ganga (Hooghly) is felt more than 100 km in the Bay of Bengal. The shallow nature of such tropical coastal waters and their physical conditions of lowered salinity and high turbidity make them at least partly estuarine in character, particularly as regards their fish fauna.

(iii) ***Blind estuaries:*** The estuaries in this category are usually relatively small, both

in length and catchments areas. During summer these estuaries are temporarily closed by a sand bar across sea mouth and during this period there is no tidal range and thus no tidal currents. The mouth opens only during the rainy season and at that time a normal estuarine salinity gradient is established. A number of this type of estuaries are located in Tamil Nadu and Karnataka coasts.

(iv) ***Coastal lakes:*** The coastal lakes have some form of connection to the sea and at the same time they receive freshwater through a river or number of rivers. Two of the best examples of coastal lakes in the country are Chilka (Odisha) and Pulicat (Andhra Pradesh) on the east coast. Both support important fisheries. The former is the largest brackishwater lake in India.

Based on the pattern of salinity distribution

Estuaries can be divided into three main groups based on the pattern of salinity distribution, viz. positive, negative, and neutral estuaries.

(i) ***Positive estuary:*** When the freshwater inflow exceeds evaporation, the estuary is defined as positive estuary. In positive estuary, the outgoing freshwater float on top of the saline water that has entered the estuary from the sea and water gradually mixes vertically from the bottom to the top.

(ii) ***Negative estuary:*** When evaporation exceeds the freshwater inflow, the estuary is defined as negative. In a negative estuary the sea and freshwater both enter estuary on the surface and after evaporation they leave the estuary as an outgoing bottom current. Higher rate of evaporation increases the value of surface salinity

(iii) ***Neutral estuary:*** Evaporation and freshwater inflow are in approximate equilibrium and in such situation a static salinity regime occurs. This category of estuaries are almost absent as evaporation and freshwater inflow are never equal.

Geomorphic classification

Based on geomorphology estuaries can be divided into four main groups.

(i) ***Coastal plain estuaries (Drowned river valleys):*** They are the most common types of estuaries and are formed by the lower reaches of river valleys and drowned river mouths. They are formed by a rise in sea level when river valleys became increasingly more flooded by melting glaciers. Estuaries of this type are generally elongated and shallow, branched and irregular in outline and at the upstream end all receive a river or a number of rivers. These estuaries are regarded as true estuaries. Most of the Indian estuaries belong to this category.

(ii) ***Bar-built estuaries:*** The extensive development of sand bars parallel to coastline in the form of a chain of islands, may enclose a large shallow body of water receiving the freshwater discharge of a number of rivers. The enclosed shallow area may develop into a large estuary. Normally, this type of estuaries has narrow connection with the sea, e.g. Vellar estuary of Tamil Nadu.

(iii) ***Tectonically produced estuaries***

(iv) ***Fjords type estuaries:*** Such type estuaries (iii and iv) are not found in India. The former is produced due to land subsidence or land slide or volcanic eruption, whereas Fjord is glacially over deepened valleys into which sea water penetrates.

Estuarine eco-system

In general, estuaries are the most productive natural ecosystem in the world. The reasons for its high productivity are: (*i*) abundant availability of primary productive units (autotrophs), the phytoplankton, phytobenthos (benthic algae) and green rooted plants (mostly mangrove trees) which insure maximum utilization of sunlight for organic production. This organic matter is used as a source of energy by all heterotrophic organism, viz. animals and some groups of bacteria; (*ii*) oxygen content of estuarine water is comparatively high from other natural water-bodies due to tidal currents causing high turbulence; (*iii*) rapid regeneration and conservation of nutrients due to the biological activity of primary consumers, viz. zoo-benthos (filter feeding benthic organism) and zooplankton present in the estuary; (*iv*) estuary also receives enormous quantities of organic detritus from intertidal wetlands around the estuarine system. Organic detritus is an important food in estuaries and is considered as rich source of energy for estuarine organisms; (*v*) most of the tropical estuaries are bordered by mangrove forests. It is reported that mangrove swamps of Sunderbans produce organic detritus from rich mangrove vegetation @ 8 tonnes/ha/year through regular litter deposition; and (*vi*) the estuary is often called as "nutrient trap" as it receives abundant quantities of nutrients from freshwater discharge of river as well as land drainage.

Estuarine water resources of India

The total estuarine water resources of India are estimated to be 1.44 million ha. The state-wise break up (in lakh ha) is as follows : West Bengal, 2.10; Odisha, 4.17; Andhra Pradesh, 0.79; Tamil Nadu, 0.56; Puducherry, 0.01; Kerala, 2.43; Karnataka, 0.08; Goa, 0.12; Maharashtra, 0.10; Gujarat, 3.76, and Andaman and Nicobar, 0.37. The Odisha, West Bengal, Andhra Pradesh, Gujarat and Kerala have rich estuarine resources. The major estuaries, viz. Hooghly - Matlah, Mahanadi, Godavari, Krishna, Cauvery, Vellar and brackishwater lakes of Chilka and Pulicat on east coast and the estuaries of the Narmada, Tapi, Mahi, Mandovi - Zuari and backwaters of Kerala and Vembanad lake on west coast are important fishery resources (Table 10.1).

Estuaries of East coast

Hooghly-Matlah estuarine system

The Hooghly-Matlah estuarine system located (latitude 21°- 23'N and longitude 88°-89'E) in West Bengal is the largest among the estuaries on the Indian coast covering the Gangetic delta called Sunderbans which is the world's largest delta endowed with largest mangrove vegetation (4,264 km^2) in India. The total area of the estuarine system is about 8,029 km^2. The Hooghly estuary (main channel) is a distributory of the river Ganga. The annual flow of freshwater in the Ganga is estimated at 142.6 billion m^3

Table 10.1. Geographical position of important estuaries/brackishwaters of India

Name of the estuary/ lake/backwater	Latitude	Longitude	Area
	East Coast		
Hooghly – West Bengal	21°40'N	87°47'E	8,029 km^2
Rushikulya – Odisha	19°22'N	85°02'E	
Chilka lake – Odisha	19°28'-19°-54'N	85°61'-85°25E	1,165 km^2
Godavari – Andhra Pradesh	16°51'N	82°05'E	
Ennore – Tamil Nadu	13°15'N	80°19'E	
Cooum – Tamil Nadu	13°10'N	80°16'E	
Vellore – Tamil Nadu	11°28'N	79°46'E	
Cauvery – Tamil Nadu	11°07'N	79°50'E	
	West Coast		
Vembanad lake – Kerala	9°28'-10°10'N	76°13'-76°31'E	
Ashtamudi lake – Kerala	8°31'-9°02'N	76°31'-76°41'E	1,200 ha
Korapuzha Estuary – Kerala	11°34'N	75°35'E	
Beypore Estuary – Kerala	11°08'N	75°51'E	
Ponnani Estuary – Kerala	10°46'-10°48'N	75°54'-75°56'E	
Nethravathi-Gurpur Estuary – Karnataka	12°50'N	74°50'E	
Mulki-Pavanje Estuary – Karnataka	12°70'N	74°39'E	
Gangolli Estuary – Karnataka	13°28'N	74°39'E	
Kali Estuary – Karnataka	14°50'N	74°07'E	
Mandovi – Zuari Estuary – Goa	14°54'-15°48'N	73° & 74° 20'E	
Amba Estuary – Maharashtra	18°45'N	73°10'E	
Mahim Estuary – Maharashtra	19°02'N	72°51'E	
Purna Estuary –Gujarat	21°55'N	75°45'E	

resulting from the melting of snow in the Himalayas during the spring, summer, and monsoon from June to September.The river Ganga has an annual runoff of 493 km^3 and carries 616×10^6 tonnes of suspended solids to the Hooghly estuary. Whereas, the annual flow rate is reported to be 67,200, 16,200 and 62,100 million cubic feet from the main Hooghly channel, Damodar and Rupnarayan rivers, respectively, and the latter two rivers are the main tributaries of the Hooghly. It is a positive estuary of mixohaline in nature exhibiting semi-diurnal type of tide. The active tidal regime is felt up to a distance of 200 km which was felt up to a distance of 300 km upstream during pre - Farakka barrage period. Tidal characteristics, spring and neap tide pattern at the mouth of the estuary is the highest for the east coast. Tidal high water elevation is 5.7 m on an average and the highest recorded is 7 m.

Texture of the bed soil and water quality: The estuarine soil is alluvial and mostly silty clay loam in texture. The soil salinity is highest from April to May. The *p*H values range between 7.8 and 8.8. The texture of the estuary bed (sediment) contains 25.0 to 55.0% sand, 25 to 58% silt and 18 to 36% clay. After commissioning of Farakka barrage in 1975, the main Hooghly estuary is fed directly by the Ganga. The additional discharge of freshwater into the system has changed the ecology of the estuary. These changes significantly affect the biological and physico-chemical factors responsible for plankton, benthos and fish production.

Presently, the salinity incursion of the estuary was observed up to Diamond Harbour situated 60 km from the mouth of estuary. The upper freshwater zone has extended downward for a distance of 240 km from Nabadwip (end point of estuary) to Diamond harbour. The middle gradient and lower marine zones were reduced to 25 km and 35 km stretches, respectively, and pushed back towards the mouth of the estuary. The salinity values in the lower zone ranged between 9.60 and 32.50 g/litre, whereas in the gradient and upper freshwater zones the values varied from 0.07 to 18.2 g/litre and 0.04 to 3.3 g/litre respectively. However, the salinity in the main Hooghly channel was always lower than the other distributaries (now considered estuarine inlets) of the Hooghly estuarine system. All estuaries around Sunderbans, viz. Saptamukhi, Thakuran, Matlah, Roymangal and Ichamati, showed high salinity. The water temperature in the main Hooghly channel varied between 16.0° and 33.0°C depending upon the climatic environment as well as season. At present increased values of dissolved oxygen (4.8 to 8.9 mg/litre), phosphate (0.04 to 0.29 mg/litre), nitrate (0.01 to 0.54 mg/litre), and silicate (0.05 to 12.4 mg/litre) were observed in the estuary when compared with pre-Farakka barrage period.

Effect of bore tide on physico-chemical condition: Bore tide is a natural phenomenon by which the estuary bed is raked thoroughly with nutrient rich dilute seawater, which further extracts nutrients from estuary bed making the system fertile. Increased values of salinity, specific conductivity, hardness, phosphate (PO_4^{--}), sulphate (SO_4^{--}), silicate, magnesium (Mg^{++}) and free CO_2 in estuarine water were observed during bore tide during winter and summer when compared with monsoon. Hence, water discharge through the Ganga river system presumably reduced the effect of bore tide in Hooghly estuary during monsoon.

Biotic communities: Plankton production in the estuary showed a bimodal distribution with one peak during winter and the other during summer. The average plankton density in the estuarine system from 1995-96 to 1997-98 varied between 111 and 1,383 numbers/litre. The bulk of plankton is constituted by phytoplanktons. Bacillariophyceae, Chlorophyceae and Myxophyceae are the principal groups in order of abundance. Zooplankton communities were found to be represented by the copepods, rotifers and cladocerans and protozoan in order of abundance.

The distribution and abundance of macro-zoobenthic fauna was observed in the upper freshwater and middle gradient zones than lower marine zone. The average density of macro-zoo benthos varied from 161 to 1,784 numbers/ m^2 and the maximum production was observed during winter in the upper freshwater zone. The overall composition of the bottom fauna was gastropods. The next important groups were annelids and bivalves. So far 27 species of 18 genera and 10 families of polycheate are recorded.

Gross primary production: Maximum production (41.6 to 137.5 mg $C/m^3/hr$) was found in the marine zone, whereas medium production (20.8 to 93.7 mg $C/m^3/hr$) and comparatively low production (20.8 to 70.3 mg $C/m^3/hr$) were observed in the upper freshwater and gradient zones respectively.

Estimation of biological productivity using radioisotope ^{14}C: Solar radiation energy at the water surface ranged from 110 to 286 $cal/cm^2/day$ with an average of 194 $cal/cm^2/day$. Primary producers utilized 54.6% of energy by the process of photosynthesis. The energy fixation efficiencies were 0.133, 0.141 and 0.546% in the freshwater, estuarine and coastal waters respectively.

Fishery: A total of 172 species of fishes are recorded from the estuary, of which 73 occupy the freshwater zone and 99, the higher saline (lower) zone. The impact of the fishery resources of the estuary after commissioning of barrage is the improvement of general habitat of certain prawn and fish resources. As a result, the annual average prawn and fish yield from the estuarine system increased from 3,204 tonnes during 1960-'63 to 61,194 tonnes during 1998–99, and to 117,639 tonnes 2010–11 (CIFRI data). The average contribution of the fish species in this fishery were hilsa, *Tenualosa ilisha* (51%), *Harpadon nehereus* (11.3%), *Pama pama* (5.7%), *Setipinna* spp. (4.7%),

Table 10.2. Size range, season of abundance, feeding habit, length at first maturity of important recorded fish from the Hooghly estuarine system

Species	Size (mm) Max	Size (mm) Range	Season of abundance	Feeding habit	Breeding season	Length (mm) at first maturity
Tenualosa ilisha	539	230-425	Throughout the year (peak July-October)	Microphagous, planktivore	Extended breeding season (peak September-October)	Female 240-270 Av, 340 Male 230-250
Harpodon nehereus	396	20-200	March-July, November - January	Carnivore	April-July	195
Polynemus paradiseus	258	80-150	April-July, September - March	Carnivore	May-July	Female 145 Male 130
Eleutheronema tetradactylum	1.8(m)	150-300	Throughout the year (Peak April-July)	Fry-planktivore Adult -carnivore	October – December	-
Pangasius pangasius	1,342	37-330	February - September	Juvenile - planktivore Adult- omnivore	March-June	540
Osteogeniosus militaris	355	120-200	November-May	Carnivore	March-April	Female 184 Male 164
Mystus gulio	199	80-125	Lower zone: August to February Upper zone July-September	Omnivore	May-August peakJune-July	Female 70-80 Male 50-60

(Continued)

(Table 10.2. concluded)

Species	Size (mm)		Season of abundance	Feeding habit	Breeding season	Length (mm) at first maturity
	Max	Range				
Setipinna phasa	300	90-160	Throughout the year (peak October to January)	Planktivore	August to November	200
Setipinna taty	300	65-140	November to April	–	–	–
Coilia ramcarti	220	50-130	Throughout the year (Peak July-August, November to March)	Carnivore	December to February and August	Female 123
Coilia dussumieri	122	9-122	November - July	Carnivore	March-June and November-December	91
Pama pama	1,524	100-250	Throughout the year (peak October to January)	Larval stage-zooplankton Adult-carnivore/ piscivore	October to June	254
Lates calcarifer	1,500	150-400	Throughout the year	Carnivore	February to May	370-700
Sillaginopsis panijus	443	100-130	Throughout the year (peak November to February)	Carnivore	November to February and August-September	120
Liza parsia	270	100-130	Throughout the year	Detritivore, planktivore	December to March	Female 105-115 Male 95-105
Valamugil cunnesius	300	84-131	June to September	Detritivore, planktivore	May to August	130
Glossogobius giuris	340	80-150	Throughout the year	Carnivore / piscivore	Throughout the year (peak August)	Female-97
Trichiurus pantului	1021	114-830	Through the year (peak November to February)	Carnivore / piscivore	–	162

Trichurus spp. (4.2%) and penaeid prawns (4.35%). Other important fish species were *Polynemus paradiseus*, *Polydactylus indicus*, *Eleutheronema tetradactylum*, *Lates calcarifer*, *Pangasius pangasius*, *Liza parsia*, *L. tade*, *Rhinomugil corsula*, *Pampus argenteus*, *Coilia dusssumieri*, *Mystus* spp., *Johnius dussumieri*, *Sillaginopsis panijus* etc. Among prawn species, *Penaeus monodon*, *P. indicus*, *Metapenaeus brevicornis*, *M. monoceros*, *Parapenaeopsis sculptilis*, *P. stilifera*, *Macrobrachium* spp. were the most important. Declining trend in the availability of certain fish and prawn species, viz. *Liza* spp., *Lates calcarifer*, *Plotosus canius*, *Eleutheronema tetradactylum*, *Pangasius pangasius*, *Penaeus monodon*, *Metapenaeus dobsoni*, and *M. monoceros* in the estuary was observed. Whereas certain freshwater fish, viz. *Eutropichthys vacha*, *Clupisoma garua*, *Wallago attu*, *Sperata seenghala*, *Ompok bimaculatus*, and *Rita rita*, made their appearance in freshwater stretch of the estuarine system. Size range, season of abundance, feeding habit, size at first maturity, recorded from this estuarine system are presented in Table 10.2.

Hilsa fishery: The annual yields of this fish from the estuary vary widely. During pre-Farrakka barrage period (1957-74), the annual landing of this species varied between 114 and 6,573 tonnes with an average of 1,427.6 tonnes while an improve level of yield was observed during post-barrage period. From 1975-76 to 1990-91, and 1991-92 to 1998-99, the average annual landings were 2,471.4 and 6,370.1 tonnes respectively. During 1999-2000 to 2003-04, the landings fluctuated between 6,448.2 and 15,799.0 tonnes with an average of 10,083.5 tonnes. In general about 80-90% of the hilsa are captured during monsoon, i.e. July to October. The hilsa is the major component of estuarine fishery accounting 15 to 20% of the total yield. The peak spawning period of the species is remarkably noticed from September to late October, though the spawning is extended for a prolonged period. The habitat of hilsa in the estuarine system was found improved for its migration, breeding and growth during post- barrage period with higher flow of freshwater in the system. The most important gears are gill nets, boat seine and clap or purse net for catching hilsa. Mesh size in gill net varies from 5 to 12 cm. In this estuary, more than 0.2 million drift gill nets are in operation. Presently, more than 1,800 small-mechanized and 4,000 non-mechanized boats are actively engaged in hilsa fishery.

Winter migratory bag net fishery and dry fish industry: Fishery exploitation by migratory bag net (been *jal*), is a typical feature of the lower zone of the estuary during winter. During this period, a large number of fishermen in groups of fishing parties migrate from different areas of the estuary and set up transitory fishing camps at suitable spots on sea beach in the lower zone of the estuary and they remain engaged in fishing during end of October to middle of February. The total landings of this fishery varied between 24,274.8 and 34,516.8 tonnes from 1998-99 to 2006-07 with an average of 28,536.7 tonnes. The fisheries contributed to the tune of 60 to 65% of the total yield of the estuary. More than 90% catches are marketed as dry fish. The dominant species contributing in this fishery were *Harpadon nehereus* (31-32%), *Setipinna* spp. (16-18%), *Trichiurus* spp. (9-12%), *Pama pama* (8-9%), *Coilia dussumieri* and *C. ramcarti* (5-9%), and prawns (3-4%). These species alone accounted for about 80 to 82% of the total landings of winter migratory bag net fishery. It is reported that 6,248 fishermen are engaged in fishing with 565 crafts (of which 268 mechanized) and 1,629 gears (bag-nets) during 1996-97.

Exploitation of commercially important prawn and fish seed: The Hooghly-Matlah estuarine system is a potential source of cultivable fish and prawn seed which are being used as stocking materials for brackishwater culture. The seed of most commercially important prawn, *Penaeus monodon*, are available extensively along with seeds of other important penaeid (*P. indicus*) and metapenaeid (*Metapenaeus brevicornis* and *M. monoceros*) prawns as well as fishes (*Liza parsia*, *L. tade* and *Lates calcarifer*). Since culture of *Penaeus monodon* (*bagda*) has earned popularity in West Bengal for its high export value, the *bagda* seed trade (market) has established in many parts of the lower estuary (Sunderbans) for more than 25 years. The total arrivals of *bagda* seed in the markets from February to June (5 months) for 1994, 1995 and 1996 were estimated as 779.66, 583.00 and 1,393.76 million in numbers respectively. The seed of giant freshwater prawn, *Macrobrachium rosenbergii* is also available at certain stretch of freshwater and gradient zones of the estuary for a longer period, i.e. from April to June or July. During post-Farraka barrage period, the species migrates further downstream towards the areas of Sunderbans for spawning purposes. The freshwater zone of the estuary is a potential source of hilsa seed. Observations on the seasonal abundance of seed in the Hooghly and Mathla estuarine system over several years made it possible to work out a seed calendar for the system (Table 10.3).

On the whole the lower zone of the estuary alone contributed about 95 to 97% of the total catch of estuary, while upper and gradient zones contributed about 3 to 5% only.

Fishing gear of the estuary: The most important gears of the estuary are bag net, gill net, seine net, drag net and purse net out of 27 types of commercial fishing gear.

Table 10.3. Prawn and fish seed calendar for the Hooghly-Matlah estuarine system

Species (length range in mm)	Centre and month of maximum no. of seed (per standard shooting net/hr) availability			Range of maximum no. of seed (per net per hour) collected during the peak months of availability)	
	No. of seed	Month	Centre	Range of maximum numbers of seed	Peak months of availability
Penaeus monodon (9-17)	2,332	May	Frazerganj	64-2,332	March-June
P. indicus (10-71)	8,940	March	Sagar	9-8,940	February -May
Metapenaeus brevicornis (10-45)	2,240	June	Frazerganj	43-2,240	April-June- and September-November
M. monoceros (9-31)	1,386	May	Frazerganj	18-1,386	April-May/ September
Liza parsia (9-35)	456	January	Frazerganj	14-456	January-April
Macrobrachium rude (15-44)	32	July	Uluberia	4-32	July-September
M. mirabile (13-37)	485	September	Uluberia	22-485	August-October

Some of them are selective for a particular species (hilsa), but mostly a gear takes multi-species catch. Twenty-seven types of gear can be classified into nine major categories, viz. long line, trap and barrier, bag net, drag net, dip or lift net, falling net, gill net and purse net. The percentage share of bag net in the total catch of the estuary is about 72 to 75%. Gill nets are used for getting the fishes at wide range of depths of water column. It contributes about 22 to 25% of the total estuarine catch and rest of the gears contribute only 2 to 6% of the total estuarine catch.

Estuarine wetlands: Vast areas of wetlands comprising flood plain lakes, swamps and brackish water farms (*bheries*) are available in the lower marine zone of the Hooghly-Mathla estuarine system. *Bheries* are compounded low lying area adjacent to estuaries and creeks where culture of fish and prawn is carried out. Presently there are 1,392 *bheries* each ranging from 3 to 260 ha in size, which constitute an area of 43,000 ha in three brackish water zones, viz. low saline (0.15 to 9.5 ppt), medium saline (0.27 to 15.8 ppt) and high saline (6.6 to 36.2 ppt). *Bheries* are very productive, contribute annually about 37,000 tonnes of fish and prawn with an average yield varies from 775 to 1,258 kg/ha/year. The composition of *bheri* fishery comprise mostly *Penaeus monodon*, *P. indicus*, *Metapenaeus brevicornis*, *M. monoceros*, *Liza tade*, *L. parsia*, and *Lates calcarifer*, *Mystus gulio*, *Macrobrachium rosenbergii* etc.

Mahanadi estuary

Odisha has several estuaries, of which Mahanadi estuary (latitude 20°18'N and longitude 86° 43'E) forms the important fishery. It is a medium type estuary, the total approximate area of this estuarine system is 30,000 ha, opens into the Bay of Bengal at Paradip along with two distributaries, viz. Devi and Looni. The tidal influence of this estuary is felt up to 42 km upstream from the sea face where mangroves occupy about 120 km^2 region. Odisha has rich mangroves in the Mahanadi deltaic region in Cuttack district. The tides are semi-diurnal in nature in this estuary with considerable variation between spring and neap tides. The maximum tidal elevation in the estuary is 2.85 m. The annual flow rate is reported to be 66,640 million m^3.

Texture of bed soil and water quality: The texture of the estuary bed contains 79.70 to 92.00% sand, 1.30 to 7.7% clay stilt and 4.3 to 12.6% clay. The predominantly sandy bed of the estuarine stretch appeares to be very less productive. The soil reaction indicated neutral to alkaline and the *p*H varies from 6.8 to 8.3 (average 7.3). The salinity values in the upper freshwater (tidal) zone range between 0.04 and 0.08 g/litre, while in the gradient (brackishwater) and lower marine zones the values vary from 0.04 to 7.61 g/litre and 0.20 to 31.61g/ litre respectively. In summer, the estuary hardly receives any significant amount of freshwater and the salinity at the estuary mouth varies between 16.99 and 31.61 g/ litre. The water temperature regime of the estuarine stretch varies between 28.5° and 30.8°C with minor fluctuations. The transparency of water range from 66.0 to 69.0 cm in the upper estuarine stretch, whereas the values were 35.6 to 47.0 cm in the lower estuarine stretch between Kujang and Paradip. The estuarine water maintains higher *p*H ranging from 8.04 to 8.25 dissolved oxygen content, 6.7 to 7.9 mg/litre. Phosphate values are recorded as 0.02 to 0.38 mg/ litre, 0.03 to 0.41 mg/litre and 0.07 to 0.59 mg/ litre in upper freshwater, gradient and marine zones respectively. Moderate to high nitrate content observed in the upper, gradient and marine zones as 0.05 to 0.41 mg/ litre, 0.07 to 0.85 mg/litre and 0.02 to 0.56 mg/litre respectively. Silicate content is high (8.0 to 15.6 mg/litre) in entire estuarine stretch. The annual fluctuation of gross primary production in the estuary varied from 83.33 to 166.67 (mg C/m^3/hr).

Biotic communities: The average net plankton abundance of the estuary varies between 60 and 280 numbers/litre. Plankton population is poor during monsoon in the estuary than pre-and post-monsoon. A sharp dominance of phytoplankton was observed over the entire estuarine stretch with highest percentage of Chlorophyceae 52.3, Myxophyceae 22.8 and Bacillariophyceae 14.8 in abundance. Among zooplankton, copepode (4.0%), rotifer (2.1%) and cladocera (0.4%) are the major groups. Macro-benthic fauna of the estuary is principally represented by molluscs (gastropods and bivalves), annelid worms, and insects (dipterans).

Fishery: A total of 134 fish species has been recorded from the entire estuarine stretch between Tirtal and Paradip. In earlier days, the annual yields of prawn and fish (dry and fresh) from the estuary varied between 651.0 and 802.2 tonnes from 1960–61 to 1963–64 with an average of 646.3 tonnes. While an improved lsevel of yield was observed (3, 674.7 tonnes) during 1996-97. However, the annual fish production has drastically declined to 110.0 tonnes during 2005-06. The fish and prawn fauna available during 1961-64 were hilsa (2.6 to 38.6%), other clupeids (13.7 to 47.3%), *Mugil cephalus* and *Liza* spp. (22.1 to 44.1%), prawns (12.4%), thread fins (5.4%), *Lates calcarifer* 3.7%, sciaenids (4.9%), catfishes (1.9%) and miscellaneous (10.6%). Presently, a total of 90 species of fish and prawn are recorded in the commercial fish landings and the fish composition mainly comprises of mullets, viz. *Mugil cephalus* and *Liza* spp. (18.2%), prawns (14.2%), *Harpodon nehereus* (10.9%) and others. Presence of both adult and juvenile hilsa is recorded in the estuary during monsoon months. The post-larvae of *Penaeus monodon* were also encountered almost through out the year.

Fishing gears: The main fishing gears operated in the estuary are gill net *(chandijal)*, seine net (*Ghaijal*), bag net, drag nets, small driff nets (*charajal*), large seine (*Berjal*) and boat seine (*Torania*).

Godavari estuarine complex

The Godavari estuarine complex (18,000 ha in area) on the Andhra coast is the second largest estuarine system in the country. It is located between latitude 16° 51'N and longitude 82°5'E). At the estuarine zone, Godavari divides itself into two distributaries, viz. Gautami and Vasistha, the latter is again divided into Vasistha proper and Vanatheyan to meet the Kakinada Bay. On the other hand, two branches of Goutami, viz. Coringa and Goderu, meet the sea through mangrove swamps (180 km^2). The Gautami is the main estuary of the system where tidal influence is felt up to 45 to 48 km from the sea face. The annual freshwater discharge of Godavari varies from

80,137 m^3/sec (cusec) during monsoon months (July to September) to 42 cusec during winter and summer.

Texture of bed soil and water quality: Soil texture of the system is predominantly sandy loam. The present texture of the estuarine bed from Yanam to Narsapur contains 77 to 81% sand, 8 to 11% silt, and 11 to 12% clay; and the soil *p*H of this stretch varies between 7.7 and 8.4. The surface water temperature fluctuates from 24.5° to 32.9 °C. As regards water transparency, a wide range from 10 to 120 cm is observed. The other important chemical parameters of the estuarine stretch are as follows: salinity 0.5 to 33.5 g/litre; DO 6.9 to 10.2 mg/ litre; *p*H 7.5 to 8.2; nitrate 0.02 to 0.05 mg/ litre; phosphate 0.01 to 0.015 mg/ litre, and silicate 0.1 to 16.2 mg/ litre. The maximum rate of gross primary production. 1.619 g C/m^3/day (av. 0.858g/C/m^3/day) indicates the higher productivity of the estuarine system.

Biotic communities: Phyto- and zoo-plankton contribute 18.46 to 46.51% and 53.49 to 81.54%, respectively, in number of total plankton abundance in the estuarine stretch between Yanam and Narsapur. Major groups contributing phytoplankton were Bacillariophyceae, Chlorophyceae and Myxophyceae in abundance. Among zoo-plankton, copepods, rotifers, dinophyceae and cladocerans are the main groups. The bottom macro-benthic fauna is characterised by poor diversity with only molluscs occurring in estuarine stretch The macro-zoobenthic density ranged between 500 and 1,890 numbers/m^2, of these gastropods and bivalves contributed 72.15 and 27.30% respectively.

Fisheries: Earlier studies during 1960s revealed that a total of 185 species of fish was recorded from the estuary among which 72% were euryhaline, 12.2% almost marine and 15% freshwater. Freshwater species were recorded only during flood season. The mullets, viz. *Mugil cephalus, Valamugil speigleri, Liza subviridis, L. macrolepis, L. oligolepis (melinoptera), Valamugil seheli,* constituted one-third of the fish catch. Other important commercial fish species were *Pristipoma hasta (Pomadasys argenteus), Leiognathus* sp., *Gerres filamentosus, Caranx* sp., *Sillago sihama, Gobius* sp., *Sciaena (Daysciaena) albida, Platycephalus maculipinna, Lates calcarifer* etc. Total annual fish landings of the Godavari estuary along with the contribution made by its branches, viz. Vasistha-Vainathayan were 3,916.0 tonnes and 3,156.13 tonnes between1963-64 and 1964-65 respectively. Among the contribution of different fish groups during 1963-64, prawns and crabs were dominant (57.8%) followed by *Mugil* spp. (13.14%), shark and rays 8.9%, pomfrets (6.6%), mackerel (4.75%), clupeids (3.5%), ribbon fish (3.3%) and perches (1.7%). The most dominant species among the prawns were *Metapenaeus monoceros, Penaeus indicus, P. monodon, M. dobsoni, M. affinis, M. brevicornis,* etc. Composition of fish and prawn species during 1964-65 was a bit different from 1963-64. During 1964-65, the major contributors were prawns (29.18%), clupeids (18.1%), *Trichurus* spp. (5.5%), *Mugil cephalus* (4.4%), pomfrets (3.5%), *Arius sona* (2.9%), *Scomberomorus guttatus* (1.5%) and miscellaneous fishes (33.08%). However, the annual yield of fish and prawn was found highest (5,000 tonne) during 1969. Species composition of prawns comprised *Macrobrachium malcolmsonii, Metapenaeus monoceros* (42.6%), *Penaeus indicus* (24.5%), *P. monodon*

(10.9%), *M. dobsoni* (3.9%), *M. affinis* (3.6%), and *M. brevicornis* (2.0%). The average annual landings of fish and prawn from the estuary showed a decreasing trend. Presently, the dominant species contributing the fishery in the estuarine stretch are *Mugil parsia, M. cephalus, Lates calcarifer, Thryssa* spp., *Pseudosciaena coibor, Arius* spp, and *Gerres* spp. A total of 68 species of fishes belonging to 37 families and 12 orders was recorded from the estuarine system besides seven species of prawn and four species of crab. *Anadromous* hilsa, *Tenualosa ilisha* is one of the most dominant species in this estuary during monsoon months (September-November). Upstream migration of hilsa was restricted up to Dowleswaram anicut situated 97 km upstream from the estuary mouth.

Fishing gear: A number of different types of gears are deployed in the estuarine system. The most important gears are drift gill net *(Teluvala)*, bag net (*Gidasavala*), seine net etc.

Krishna estuarine system

Krishna is the second largest estuarine system (Latitude 16° 15'N and longitude 82° 05'E) in Andhra Pradesh. The entire system is estimated to be about 320 km^2. Before it (Krishna proper) meets the sea, it divides into three distributaries, namely Krishna proper in the west, Gollumuthapaya in the east, and Nadimeru in the middle. The tidal effect is felt up to 6 to 22 km from the mouth of the estuary depending on the month of the year. The tidal high water elevation is 2 to 3 m on an average. Inadequate freshwater influx into the estuarine system because of the construction of the barrages across the river has greatly affected the usual flow pattern of the system. A considerable increase in the salinity all over the estuary has been observed barring monsoon. On the whole, the ecology of estuary has undergone a major change.

Texture of the bed soil and water quality: The bed soil of the estuarine stretch contains trace to 8.0% clay, nil to 62.54% silt and nil to 91.43% fine sands as well as 1.23 to 98.0% coarse sand. The soil reaction was slightly acidic (6.32) to alkaline 8.57. Low values of *p*H were observed during summer while higher during monsoon and post-monsoon. The mean surface water temperature of the system varied between 29.16° and 31.67°C indicating extended summer in the area. The salinity value at Hamsala and Gollalamodha located at the lower zone of the estuary fluctuated between 18.4 and 35.6 g/litre. A wide fluctuation of dissolved oxygen values was observed in the estuarine system, which varied between 4.8 and 8.0 mg/litre, while relatively lower DO values were observed in lower zone compared to upper and gradient zones. The entire estuarine system maintained slightly higher *p*H ranging from 7.4 to 8.5. As regards phosphate, nitrate and silicate contents the values ranged from 0.02 to 0.36 mg/litre, 0.012 to 0.45 mg/litre and 0.7 to 13.3 mg/litre, respectively.

Primary production: Gross primary production varies greatly depending upon the climatic factors as well as turbidity of water. Gross and net primary production varies from 25 to 187.5 mg C/m^3/hr and 15 to 156.2 mg C/m^3/hr respectively. Maximum gross primary production is observed during monsoon and post-monsoon months.

Lower is zone more productive compared with upper zone of the estuary.

Biotic communities: The annual production of plankton in the system varies from 249 to 503 nos/litre. Maximum density is observed during pre-monsoon and minimum in the monsoon. The bulk of plankton constituted by phytoplankton (69.3%), represented by Bacillariophyceae (68.23 to 90.08%), Dinophyceae (18.30 to 22.63%), Myxophyceae (3.56 to 6.25%), Chlorophyceae (2.89 to 3.11%) and Xanthophyceae (1.30 to 1.82%) are the principal groups in order of abundance. Zooplankton community (30.7%) is found to be represented by the copepods (45.0 to 62.12%), protozoans (16.15 to 23.0%), rotifers (6.23 to 8.15%) and cladocerans (3.98 to 5.64%) in order of abundance. The average density of macro-benthos varies from 1,091 to 1,217 nos/m^2. The density is maximum in the gradient and upper zones (67%) and minimum in the marine zone (33%). Gastropods 69.2%, bivalves (17.9%), insects (7.2%) and annelids (5.7%) are the main forms. Benthic population did not show any marked seasonal variation.

Fisheries: A total of 47 fish species belonging to 30 families and 40 genera are recorded from the estuary. The availability of freshwater and oligohaline species are meagre as hyper-saline condition is observed in the estuarine stretch almost throughout the year barring a short period of monsoon. Even then a wide variety of fish and prawn diversity was observed in this estuary. The total fish and prawn yield from the estuary during 2004-05 was estimated as 496.1 tonnes. The dominant species contributing the fishery were *Mugil cephalus, Liza parsia, Liza macrolepis*, clupeids (*Tenualosa ilisha*, and *Hilsa kelee), Chanos chanos, Lates calcarifer, Sillago sihama, Mystus vittatus, Scatophagus argus, Etroplus suratensis, Rhinomugil corsula, Polydactylus indicus, Valamugil cunnesius, Rastrelliger kanagurta, Caranx* spp., *Therapon jarbua, Arius* spp., and *Trichurus* spp. in the entire estuarine system. Among prawns, *Penaeus monodon, P. indicus, Metapenaeus monoceros, M. brevicornis, M. dobsoni* were available. Mullets alone contributed to the tune of 80% of the total yield of the estuary of which the contribution of *Mugil cephalus, Liza parsia* and other *Liza* spp. was 48, 21 and 11% respectively. Catfishes, perches, sciaenids, clupeids, penaeid prawns and crabs contributed the rest 20% of the total catch. Presently fishery activities are mainly confined in the lower stretch of the estuary. More than 173 small mechanized and 771 non-mechanized boats are actively engaged in the estuary. The most important gears are gill net (gidasavala/ eduvala/ teluvala), drag net (laguduvala) and cast net (esuruvala).

Muthupet estuary

Muthupet estuary is situated in Nagai district (latitude 10° 20'N and longitude 79° 35'E) of Tamil Nadu. Vennar canal of Cauveri dividing into five channels open to Muthupet estuary and ultimately opens into Palk Bay. The total water spread area of the estuary is estimated to be about 20,000 ha. The 73 species of fishes were recorded from this estuary and of these 2 species were freshwater, 31 species were resident and 40 species were migrants. Out of these, 60 species of fishes were of commercial importance. The annual fish and prawn yield from this estuarine system is about

31 tonnes. The fishery mainly comprised *Tenualosa ilisha, Hilsa kelee, Escualosa thoracata, Nematolosa nasus, Anguilla bicolor bicolor, Chanos chanos, Plotosus canius, Mystus gulio, Strongylura strongylura, Platycephalus indicus, Lates calcarifer, Arius maculatus, Leiognathus equula, Johnius belengari, Scatophagus argus, Pseudapocryptes lanceolatus, Glossogobius giuris* etc.

Other estuaries of east coast

Cauvery is another major estuary in Tamil Nadu, but very little is known about fishing potentials of this estuary. Besides Cauvery, east coast of India has innumerable minor estuaries. Some of them are very productive and form substantial fishery. Information on landing data for these estuaries is available. The annual harvest of fish and prawn was recorded as 7.2 to 21.6 tonnes from Adayar; 72 tonnes from Kazhuveli (782 ha); 13 tonnes from Ponnaiyar (43 ha); 28 tonnes from Gadilam-Paravanan (346 ha); 29 to 83 tonnes from Vellar (262 ha); 139 tonnes from Killai (1685 ha) and 90 tonnes from Coleroon (809 ha); 10 tonnes from Kottaikarai, Kottakudi and Malaltas estuaries and 25.5 tonnes from Vaigai during 1970s and 1980s. Manakudy estuary near Cape Comorin has an area of 14.5 ha. Salinity variation was in the order of 4.75 to 11.38%, dissolved oxygen 3.16 to 3.44 ml/litre; nitrate; 5.01 to 14.32 mg/litre; phosphate, 0.70 to 1.13 mg/litre and silicate 27.0 to 77.9 mg/litre. Species composition of these estuaries mostly comprised *Mugil* spp., prawn, *Leiognathus* spp., cat fishes etc. These estuaries were found to be potential sources of cultivable fish (mullets and milk fish) and shrimp (penaeid) seeds.

Chilka lake: Chilka lake is situated (latitudes 19° 28-19° 54'N and longitudes 85° 05-85°38'E) on the east coast of India in Puri, Khurda and Ganjam districts of Odisha. It is a pear-shaped brackishwater lake connected with the sea through two openings, viz. the first is a natural feeder channel meets the sea through a single mouth at northern extremities of lake. The second one is a man made artificial channel meets the sea (Palur Bay) near the confluence of Rasikullya estuary at southern extremity of the lake. Formation of sand bars in feeder channel mouth due to deposition of sediments reduces the width of feeder channel as well as tidal ingress into the lake. It has a water spread area of 906 km^2 in summer and 1,165 km^2 in flood season. It has vast catchment area of about 3,200 km^2 and receives 200,000 to 275,000 cusecs monsoon runoff along with 10 to 13 million tonnes of silt annually through various distributaries of river Mahanadi. These distributaries are the main sources of freshwater to this lake. Studies during 1995-96 revealed that the depth of the lake varied from 0.45 to 1.44 m; 1.09 to 1.98 m and 1.00 to 3.47 m during pre-monsoon, monsoon and post-monsoon periods respectively.

Texture of the bed soil and water quality: Bed soil (sediment) of the lake contains 44.1 to 97.9% sand, 0.31 to 57.1% silt and 1.0 to 40.8% clay. The *p*H of the bed soil varies between 7.0 and 8.8. The water temperature fluctuates between 23.0 and 26.0°C, 29.5 and 32.5°C and 29.0 and 31.5°C during post-monsoon, pre-monsoon and monsoon respectively. The salinity of the lake is greatly influenced by the river discharge in the monsoon as well as sea water influx during summer. The salinity value in the lake

ranges between 4.9 and 35.4 mg/litre during pre-monsoon season, while monsoon and post-monsoon season the values varied from 0.7 to 14.8 mg/litre respectively. The highest salinity was observed at the areas around Arkhakuda, the confluence of the feeder channel with the lake. The *p*H of the lake water ranged from 8.0 to 8.7. Dissolved oxygen was relatively high (4 2 to 9.1 mg/litre) during post-monsoon period due to violent wind action. Low values of phosphate were recorded throughout the year as 0.04 to 0.12 mg/litre, 0.04 to 0.08 mg/litre and 0.04 to 0.28 mg/litre during pre-monsoon, monsoon and post-monsoon seasons respectively. While moderate to high values of nitrate were found during pre-monsoon (0.28 to 2.52 mg/litre), monsoon (1.4 to 3.60 mg/litre), and post-monsoon (0.06 to 2.49 mg/litre). Primary production from 41.60 to 515.59 mgC/m^3/hr, 41.60 to 135.40 mgC/m^3/hr and 41.46 to114.57 mgC/m^3/hr during pre-monsoon, monsoon and post-monsoon periods respectively.

Biotic communities: The plankton production of the lake varies between 35 and 180 nos/litre in pre-monsoon, 15 and 96 mg/litre in monsoon and 8 and 57 numbers/litre in post-monsoon. The bulk of plankton constituted by phytoplankton and occupied 53.4 to 93.3% of the total population. Among phytoplanktons, Bacillariophyceae, Chlorophyceae and Myxophyceae were the principal groups while zooplankton was represented by the copepods, rotifers and protozoans. The density of macro-zoo benthos varied from 5 to 1,300 /m^2, 7 to 136/m^2, and 3 to 533 /m^2 during pre-monsoon, monsoon and post-monsoon seasons respectively. The dominant groups were gastropods, bivalves and polycheats.

Fisheries: In Chilka lake, 217 fish species comprising 147 genera, 71 families and 15 orders were recorded. The annual fish and prawn yield from the lake varied from 1,269.8 to 5,461.9 tonnes during 1990-91 to 1995-96 with an average of 3,742.8 tonnes. While during 1957-65, the annual fish and prawn yield ranged from 2,603 to 4,455 tonnes with an average of 4,375.36 tonnes. The lowest annual catch of the lake was estimated as 1,594.6 tonnes and 1,269.8 tonnes during 1994-95 and 1995-96 respectively. During the period the commercially important fish species available in the lake were *Tenualosa ilisha, Mugil cephalus, Liza macrolepis, Lates calcarifer, Eleutheronema tetradactylum, Plotosus canius, Mystus gulio, Etroplus suratensis, Pseudosciaena coibor, Nematalosa nasus, Osteogeniosus militaris, Gerres setifer, Strongylura strongylura* etc. Among prawns, *Penaeus indicus, P. monodon, Metapeneaus monoceros, M. dobsoni*, and among crabs, *Scylla serrata* and *Portunus* sp. were most commercially important species. The maximum contributors of the fishery were prawns (16.9%), perches (16.6%), mullets (14.7%), clupeids (14.3%), cat fishes (8.4%), beloniformes (3.6%), threadfins (2.6%) and others (22%). Of late, increase in tidal ingress is being observed in the lake through a new mouth, which has opened during 2000. The additional ingress of sea water into the lake has significantly improved the ecology as well as fishery. As a result, the annual fish yield has increased significantly from 1,432 tonnes during 1994-96 to about 9,000 tonnes during 2000-03. The Chilka lake is a potential source of commercially important prawns (*Peneaus monodon, P.indicus* and *P. semisulcatus*) and fish (*Mugil cephalus,* *Liza macrolepis*, and *Eleutheronema tetradactylum)* seed. The seeds were mostly available at the mouth of the outer channel around Arkhakuda and the Palur canal for almost throughout the year with two peaks, one in January to June and the other in August to September. Principal gears operated in the lake are gill net (*panchijal, dobljal*), and (*bhektijal, khatijal*), drag net (*khadijal, janglajal*), cast net (*khap jal*), sieve net (*bada jal*) etc.

Pulicat lake: The Pulicat lake is one of the biggest brackishwater lakes on the east coast of India. Major portion of the lake located (latitude 13° 26' and 13° 43'N) and longitudes (80°03' and 80°18'E) in the Nellore district of Andhra Pradesh and the rest portion in Chingleput district of Tamil Nadu, where it joins the Bay of Bengal by a narrow mouth. The total area of the lake is 350 km^2. The lake receives freshwater through two seasonal rivulets and Kalangi river. The drainage area is about 4,400 km^2. Presently, the average depth ranged from 0.7 to 3.0 m, whereas, during 1970s the average depth was 1.5 m with maximum being 9 m. Tidal effect is felt up to a distance of 6 to 10 km from the lake mouth and the tidal high water elevation is only 25 to 30 cm.

Water quality: Water temperature fluctuation is medium in the lake and it varies from 20.5° to 30.0 °C. Water transparency ranges from 15 to 50 cm. Dissolved oxygen content is moderately high, which varies between 5.7 and 7.6 mg/ litre. Salinity fluctuates from 28.91 to 7.79 mg/litre and highest salinity observed near the Barmouth area (Tamil Nadu) and also at Sriharikota (Andhra Pradesh) being nearer to sea.

Biotic communities: The overall plankton production in the lake during 1960s was high when compared with present studies; 59 species of phytoplankton and 23 species of zooplankton were recorded during 1960s. Myxophyceae, Chlorophyceae, Bacillariophyceae and Rhodophyceae were the major groups among the phytoplankton. Zooplankton population was mainly represented by protozoans, annelids, copepods, ostracods, decapods etc. Further studies during 1980s revealed that the primary peaks of phytoplankton and zooplankton occurred during May-July and April-May respectively. Higher zooplankton production in the southern sector than that of the northern sector was well reflected in the fish yield of the corresponding sectors of the lake. The average annual fish yield was estimated as 632.6 tonnes and 470.6 tonnes in southern and northern sectors respectively from 1965 to 1972. Presently, 43 species of phytoplanktons and 11 species of zooplankton were recorded from the lake. Among phytoplanktons, Bacillariophyceae, Dinophyceae, Myxophyceae and Euglenophyceae were the dominant groups. Copepods and rotifers were major dominant groups among zooplankton.

Fisheries: A total of 65 species of the fishes were recorded from the lake. The annual fish landing during 1945-46 was reported to be 2,678 tonnes with 48.67% prawns. Thereafter a gradual decline in catch was observed in the lake. The annual average landings of fish and prawn varied from 926.9 (in 1968) to 1,371.4 (in 1972) during 1967 to 1972 with an average of 1,152.86 tonnes. Prawns dominated the catch and contributed about 380 to 635 tonnes. The most dominant prawn species were *P. indicus, P. semisulcatus, P. monodon* and *Metapeneaus monoceros, M. dobsoni* etc.

Mullets form the next group with *M. cephalus* as the dominant species and their contribution varied between 194 and 382 tonnes/year. Other contributors were perches (82 to 135 tonnes), clupeids (72 to 126 tonnes), catfishes (20 to 57 tonnes), sciaenids (18 to 23 tonnes), beloniformes (14 to 30 tonnes), thread fins (9 to 29 tonnes), crab mainly *Scylla serrata* (23 to 102 tonnes) and others (16 to 21 tonnes). During 1980s the annual average catch was recorded at the highest peak of about 9,000 tonnes, which presently declined to 4,545 tonnes and 3,892 tonnes during 2007-08 and 2008-09 respectively. The dominant fish and prawn species, namely *Mugil cephalus, Liza tade, Liza parsia, Chanos chanos, Plotosus canius, Hilsa kelee, Penaeus indicus, P. monodon, M. dobsoni, M. monoceros, M. brevicornis*, in the lake during 1970s and 1980s have shown a sharp decline or total absence in the catch. Presently, the fishery of the lake is mainly dominated by *P. indicus* (50%) and mullets, *Mugil cephalus, Liza tade, L. parsia* (20%) and others (30%). The main gears of the lake are stake nets (*Suthuvalai* and *Kattuvalai)* and drag net (*badivalai)* and peak fishing season is July to October.

Estuaries of the west coast

Vembanad lake

Kerala offers extensive backwaters at the coast of Arabian Sea. The backwaters contribute productive ecosystem and the total fish landings from Kerala backwaters vary from 14,000 to 17,000 tonnes/year. Besides about 88,000 tonnes of live clams and 0.17 million tonnes of dead molluscs shells are collected annually. Vembanad - Kol - Wetland System, one of the Ramsar sites in Kerala (declared in November 2002), is the largest estuarine system of the western coastal wetland systems (09° 00' – 10° 40' N latitude and 76° 00' -77° 30' E longitude), and is spread over the districts Alappuzha, Kottayam, Ernakulam and Thrissur in Kerala. The Vembanad Wetland is a complex aquatic system of 96 km long coastal backwaters, lagoons, marshes, mangroves and reclaimed lands, with intricate networks of natural channels and man-made canals extending from Kuttanad in the south to the Kol lands of Thrissur in the north. The total area of the wetland system is 1521.5 km^2, approximately 4% of the State's geographic area. The total area of lake is about 250 km^2 and extending 80 km from Munambam in the north to Alleppey in the south. The width of the lake varies from 500 m to 4 km and depth from less than 1 to 12 m. The wetland is mostly waterlogged with depths ranging from 0.6 m. A number of rivers, viz. Meenachil, Manimala, Pamba and Achenkovil carry, huge quantities of freshwater in to the lake south of Thanneermukkom barrage and Muvattupuzha river flows into the Cochin backwaters north of the said barrage. Drainage area of these five river basins is about 7,392 km^2 and freshwater flow during monsoon and lean period is estimated at 10,348 million m^3 and 2,817 million m^3 respectively. The Thanneermukkom barrage has divided the lake into two zones, namely a freshwater dominant southern zone (Vembanad lake) and a salt water dominant northern zone. The barrage (1,252 m long) was constructed in 1975 to prevent the intrusion of saline water and also to promote double cropping of paddy in about 55,000 ha of low lying areas around the lake (*Planning Commission Report, Government of India, 2008*). The Vembanad lake is important for its rich flora and fauna including fisheries. The lake serves as a habitat and nursery ground for a variety of fin and shell fishes. It is also famous for its live clam resources and sub-fossil.

Meteorological feature: Temperature at the lake area varies between 21°C and 36°C and the humidity of the air fluctuated from 80 to 95%. The average rainfall is 3,200 mm. Two distinct rainy seasons are observed, one during south-west monsoon and the other north-east monsoon. Bulk precipitation is during south-west monsoon (60%) and rest during north-east monsoon (30%) and summer rains (10%).

Water quality: Dissolved oxygen (6.0 to 7.2 mg/litre) levels were generally adequate in the lake except Punnamada where it was 3.16 mg/litre during pre-monsoon period and some times below detectable levels. Acidic range of *p*H (6.8) was observed during 1989 to 2002. Decline in salinity was observed from the average summer value of 18.47g/litre during pre-barrage period to 2.8 g/litre during post-barrage period. Mean salinity values recorded between 1971 and 2001 were 23 g/litre and 3.87 g/litre respectively and in recent years the averages DO and salinity values were recorded as 6.6 mg/litre and 1.2 g/litre respectively. The phosphate-phosphorus, nitrate-N and H_2S contents were recorded as 0.020 mg/litre, 0.087 mg/litre and 2.59 mg/litre respectively. The gross and net primary production was recorded 0.87 gC/m^3/day and 0.75 gC/m^3/day respectively.

Biotic communities: As regards plankton biomass, pre-monsoon showed highest mean value of 4.7 ml/m^3, followed by 4.4 ml/m^3 and 3.4 ml/m^3 during post-monsoon and monsoon seasons respectively. The abundance of benthic forms in the lake showed maximum mean density of 39 numbers /m^2 during the monsoon .

Fishery: A total of 104 species of fish, 9 species of shrimps and prawns and 5 species of molluscs were recorded from the lake. *Etroplus suratensis*, *Channa striatus*, *C. diplogramme*, a few species of native catfishes, namely *Horabagrus brachysoma*, *Labeo dussumieri*, freshwater prawn (*Macrobrachium rosenbergii*, *M. idella*), *Wallago attu*, are the major species available in the lake. The total finfish landings from the lake are around 20 tonnes and freshwater prawn around 70 tonnes and that of shrimp from 110 tonnes. Among molluscs *Meretrix costa* and *Villorita cyprinoids* (black clam) were the most dominant species. The production level of black clam was found to be 31,431 tonnes during 2000. During 1960s and 1970s, the average annual finfish and shellfish landings from the lake varied from 1,200 to 8,500 tonnes. The commercially important prawn and fish species of the lake are *Metapenaeus dobsoni*, *M. monoceros*, *Penaeus indicus*, *Mugil cephalus*, *Valamugil cunnesius*, *M. parsia*, *Etroplus suratensis*, *Horabagrus brachysoma*, *Labeo dussumieri*, *Lates calcarifer*, *Chanos chanos*, *Thrissocles* sp., *Anchovilla* sp., catfishes, thread fins, silver belies etc. However, the most abundant species are *Metapenaeus dobsoni*, and *Mugil cephalus* contributing 60% and 11% of total catch respectively. *Etroplus suratensis* is available in maximum numbers from June to September, *L. calcarifer* from July to April, and *Chanos chanos* from November to June. The important fishing gears of the lake are stake net chinese net. The other nets, operational are, dragnets, cast nets, boat seine etc. At present the water holding capacity of the lake due to siltation has reduced to an abysmal 0.6 km^3 from 2.4 km^3. Major fishing activities are restricted in the lake areas just below the Thanneermukkom barrage. According to *Planning Commission Report, Government of India, 2008* many euryhaline migratory species are unable to contribute to the fishery of this lake because of the construction of barrage and breeding migration of *Macrobrachium rosenbergii* and *M. idella* is also partly affected by the barrage.

Ashtamudi lake: Ashtamudi lake, another Ramsar site located near the southern part of Kerala is known for its rich clam fishery resources. Due to high rate of fishery, a great reduction of clam *Paphia malabarica* was recorded that made the Kerala government to impose a ban on the fisheries. Salinity is high near the bar mouth-33 ppt which gets decreased to 5 ppt at the upper reach. Dissolved oxygen shows a variation from 1.17 to 2.79 ml/litre.

Estuaries of Karnataka

The Karnataka having a coastline of 300 km is enriched with 26 estuarine environments with a total area of 7,213.5 ha in the three coastal districts: Dakshina Kannada- 5 (1,140 ha), Udupi - 8 (1,885 ha) and Uttara Kannada- 13 with an area of 4,188 ha .The important ones are Nethravati-Gurupur, Mulki, Coondapur, Pavenja, Gangoli, Kali, Aghanashin, Sharavati etc. The total estuarine area of the state is estimated to be about. Vast information on the hydro-biological parameters of some of the estuaries is available. Of these, Nethravati-Gurupur, Mulki estuaries of south Kannada and Kali estuaries of north Kannada are the most important.

Nethravathi estuary: The Nethravathi estuary (12°15'N; 74°50'E) is situated in the confluence of Nethravathi river with Arabian Sea. The tidal influence is felt up to 19 km upstream.

Water quality: The water temperature fluctuates between 27.0°C in November and 33.9°C in May. The *p*H varies from 7.36 to 8.63. Dissolve oxygen ranges from 2.50 mg/litre at 0300 hr to 8.55 mg/litre at 1200 hr. The salinity values varies from 4.06 g/litre in November to 35.81 mg/litre in April. Low nitrate value was observed during pre-monsoon (1.01 to 2.25 µg/litre and post-monsoon (1.42 to 1.92µg/litre when compared with moderate value during monsoon (6.56 to 8.95 µg/litre). Similarly, phosphate value was recorded as 0.79 to 1.26 µg-/litre 1.43 to 1.61 µg/litre and 1.01 to 1.20 µg/litre during pre-monsoon, monsoon and post-monsoon respectively. Silicon content was maximum (54.89 to 65.72 µg/litre) during monsoon and it was poor during pre-monsoon (13.37 to 21.06 µg/litre) and post-monsoon (30.44 to 42.55 µg/litre). Thus, seasonal distribution of nitrate, phosphate and silicate in the estuary indicated marked variations in nutrient concentration. High value of nutrient was recorded during monsoon season.

Biotic communities: Phytoplankton production in this estuary shows a trimodal pattern of distribution during May, June, and November-December. The total density of phytoplankton varies from 1,132 to 65,514 cells/m^3. The major group contributing to phytoplankton were Bacillariophyceae (35 species), Dinoflagellates (9 species), Chlorophyceae (8 species) and Myxophyceae (5 species). Zooplankton density of the estuary varies from 4 to 228/litre. Among zooplankton, copepods and their nauplii were the dominant forms. Larval forms of polychaetes, fish and bivalve were the other common representatives of zooplankton.

Fishery: Nethravathi estuary is rich in finfish and shell fishes. The common shell fishes are *Sillago sihama, Thrissocles mystax, Anadontostoma chacunda, Ilisha indica, Kawala coval, Platycephalus scaber, Lutjanus fulviflama, Gerres filamentosus, Leiognathus* spp., *Sphyraena* sp., *Pristipoma* sp, *Mugil cephalus, Liza parsia, Stelophorus indica, Etroplus suratensis, E. canarensis, Horabagrus brachysoma, Caranx carangus, Belone cancila, Tachysurus* spp., *Pseudosciaena* sp., *Gobius* spp., and *Mystus gulio*. Of these, *Mugil cephalus, Liza tade, Sillago sihama,* and *Tachysurus* spp. were available almost throughout the year, with the former two species were dominant in the catches. Average annual landing of grey mullets was estimated as 2,685 tonnes during 1981-97, for all estuaries of Karnataka. Among mullets, *M. cephalus, Liza tade, L. macrolepis, Valamugil seheli* and *V. speigleri* were the dominant species. The *Metapenaeus dobsoni, M. monoceros, Penaeus indicus* and *P. monodon* were the important species of shrimps. The clams, mussels and edible oysters form the important components of the estuaries of Karnataka. The total harvest of clam from the estuaries of Karnataka varied from 351 to 588 tonnes from 1976 to 1992. The total yield of edible oysters as well as clams and cockle were estimated to the tune of 197 tonnes and 2,184 tonnes, respectively, during 2002-03. The edible oysters were represented by *Crassostrea madrasensis* and *Saccostrea cucullata*. Among clams, *Villorita cyprinoids, Paphia malabarica, Meretrix casta* and *M. meretrix* were the most important species. The important fishing gears of the estuary of Karnataka are shore seines, gill nets, cast nets, hooks and lines. Nethravati estuary is a potential source of brackishwater shrimps (*P. indicus, P. merguiensis, M. dobsoni* and *M. monoceros)* and fish (*Mugil* sp., *C. chanos, L. calcarifer, M. cyprinoids, Scatophagus argus,*and *S. sihama*) seed. Shrimp seeds are mostly available in this estuary during November to May, while maximum number of seeds (1,136/m^3) occur during low tide irrespective of time of occurrence. Availability of seeds is more during day time compared to night.

Apart from having a rich fish and prawn fauna, the other estuaries of Karnataka are equally rich in brackishwater shrimp and fish seed resources. The seed of *C. chanos* were available in the Coondapur and Mulki estuaries for a restricted period during April-May, while seeds of mullets, *Sillago sihama, L. calcarifer* and *Scatophagus* sp. were available in number of estuaries. Important fish seeds are also available in the Kali estuary of North Kannada district. The composition of seeds were *M. monoceros* (68.18%), *M. dobsoni* (22.72%), *Penaeus merguiensis* and *P. monodon* (each 4.55%) in order of abundance.

Mandovi-Zuari estuarine complex: Goa has seven major rivers of which the Mandovi and Zuari with Camberjua canal (latitude 14°54'-15° 48' N and longitude 73° 00' -74° 20'E) form the largest estuarine complex. Both the estuaries open in the Arabian Sea through Aguada and Marmugao Bay. The total area covered by the estuaries in Goa including Mandovi-Zuari estuarine complex is approximately 12,000 ha. In Mandovi-Zuari the tides are of mixed semi-diurnal type and their maximum range is about 2 meter.

Texture of bed soil and water quality: The bed soil of Mandovi is sandier as compared to Zuari contained 70.0 to 91.0% and 69.0 to 84.5% sand respectively. The pH of the bed soil varies from 7.51 to 7.72 in Mandovi and 7.17 to 7.93 in Cumberjua-Zuari. The *p*H of water varies from 6.98 to 8.29. Very low values of phosphate and nitrate were recorded from both the estuaries. The phosphate value ranged from traces. to 0.008 mg/litre in Mandovi and traces. to 0.012 mg/litre in Zuari. The average nitrate content was found to be 0.109 to 0.141 mg/litre and 0.115 to 0.153 mg/litre in Mandovi and Zuari respectively. Silicate content was very poor in both, Mandovi (0.24 to 2.34 mg/litre and Zuari (0.36 to 2.14 mg/litre) estuaries. The fluctuation of primary production in Zuari and Camberjua canal varied from 62.50 to 208.33 mgC/m^2/hr and 93.75 to 187.0 mgC/m^2/hr respectively.

Biotic communities: In Mandovi-Cumberjua-Zuari estuarine complex, the total plankton density varies from 55/litre at Shiroda to 285/litre at Cortalim. In total plankton population, 58.93 to 68.47% and 30.18 to 39.28% by numbers were contributed by phyto-and zoo-plankton respectively. Bacillariophyceae was the dominant group of phytoplankton followed by Myxophyceae and Chlorophyceae. In earlier studies, diatom counts in Mandovi estuary were 474/litre and 61 to 352/ litre during monsoon and post-monsoon respectively, while in Zuari the counts were 336/litre and 25 to 380/ litre during the same corresponding periods respectively. The average density of macrobenthos varied from 716 (Candola) to 1,835/m^2 (Panaji) in Mandovi and 994 (Shiroda) to 1,378/m^2 (Cortalim) in Zuari estuaries respectively. The most dominant group was polycheates (51.8 to 96.3%) followed by malacostraca and molluscs.

Fishery: Mandovi-Zuari estuaries are potential sources of fin, shellfishes and their seeds. The fishery is contributed mainly by *Harpodon nehereus, Polydactylus indicus, Eleutheronema tetradactylum, Arius* sp., *Coilia* sp., *Etroplus suratensis*, mullets, anchovies, sciaenids and prawns. It is reported that the seeds (mostly mysis stage) of commercially important prawns were observed in surface and bottom zooplankton samples. These were *Metapenaeus dobsoni, M. affinis, M. monoceros, Parapeneopsis stylifera, Penaeus merguiensis, P. indicus, P. monodon* and *P. semisulcatus* in order of abundance. Total ingress of penaeid prawn larvae in the Mandovi-Zuari was more during full moon and high tide compared to new moon and low tide periods. Principal gears operated in the Mandovi estuary were trawl nets, stake nets, gill nets, cast nets, bag nets etc. Seines and trawl nets contributed about 60% of the total catch of the estuary.

Damanganga estuary: The Damanganga estuary (latitude 20° 25'N and longitude 81° 0'E) on the west coast is a minor estuary of Gujarat and opens into the Arabian Sea near Daman.

Texture of bed soil and water quality: The *p*H of soil ranges from 7.29 to7.74 and sand content varies from 63.95 to 88.8%. Transparency of water and *p*H values fluctuate from 2.5 to 107.0 cm and 6.80 to 8.70 respectively. A wide range of fluctuation in dissolved oxygen (Traces-9.6 mg/litre) was observed in the estuary. The salinity varies from 0.11 to 31.17 g/litre, higher values observed in the stretch between Nani-Daman and Zari, the lower stretch of the estuary. Phosphate, nitrate and silicate values ranged from Tr. to 0.2 mg/litre, 0.03 - 4.54 mg/litre and 1.08 to 20.88 mg/litre respectively.

Fishery: Presently 23 species of fishes are recorded from the estuarine system. *Harpodon nehereus* (48.75%) and *Liza parsia* (22.35%) contributed maximum to the fishery.

Tapi estuary: Tapi (latitude 21° 20'N and longitude 74° 30'E) is regarded as one of the major estuaries on the west coast. It is the second largest among the estuaries of Gujarat and opens into the Arabian Sea in Surat. Once it was a potential source of fish production, but after the construction of Ukai dam and number of weirs across the river, the congenial estuarine environment has been adversely effected due to inadequate freshwater discharge from the upstream. Presently the tidal impact is felt up to a distance of 45 km. The total area of the estuarine system is about 14,250 ha. The average rainfall is 775 mm.

Texture of bed soil and water quality: Sand content of bed soil range from 71.16 to 88.83% and *p*H varies from 7.30 to 8.12. The water temperature range between 22.5° and 31.0°C. Transparency fluctuate between 15.3 and 93.6 cm. Low transparency was recorded at lower stretch of the estuary, while it was high (74.0 to 93.6 cm at freshwater stretch. The estuary maintained higher *p*H fluctuating from 7.3 to 8.6. Dissolved oxygen is fairly available in the freshwater stretch of the system, while in Chowpati stretch of lower estuary has very poor content of DO (average 0.75 mg/ litre). Nutrients, viz. phosphate, nitrate and silicate contents were recorded as 0.035 to 0.065 mg/litre, 0.043 to 0.063 mg/ litre and 4.46 to 9.70 mg/ litre respectively. The low values of phosphate and nitrate indicated poor nutrient status of the estuary. In the freshwater stretch, the gross primary production ranged between 75.53 and 156.25 $mgC/m^3/hr$ and values of 7.82 to 62.5 $mgC/m^3/hr$ were recorded in the lower stretch of estuary.

Biotic community: The plankton population in the system ranges between 113 and 7,469 nos/ litre, of which phytoplankton contributed 62 to 99%. Bacillariophyceae, Myxophyceae and Chlorophyceae were the principal groups in order of abundance. Zooplankton community was mainly formed by the protozoans, copepods and rotifers. Protozoans were most abundant in the lower estuarine zone, while copepods and rotifers were in the upper freshwater zone. Average macrobenthic abundance of the estuary varies from 98 to 2, 239/m^2. Molluscs (61 to 90%) and annelids (52 to 93%) were most abundant groups at different locations of estuary.

Fishery: Total annual fish yield from the Tapi estuarine system was estimated as 123 and 290 tonnes from 1995-96 to 1999-2000 with an average of 179.6 tonnes presently the most dominant species in the system is hilsa (75 tonnes; 25.86%), while prawns, mullets and crabs contribute to the tune of 31.0, 10.3 and 8.66% of the total catch. The hilsa catch of the estuary showed a gradual increasing trend from 10 metric tonnes in 1995-96 to 75 metric tonnes in 1999-2000, though the upstream migration of hilsa during monsoon is restricted to downstream of weir in the neighbourhood of Surat city.

Narmada estuary: The Narmada is one of the major estuaries on the west coast of India. The esturine system (latitude 20°40'N and longitude 80°45'E) extends from Rajpipla to Bharuch for a distance of about 135 km and opens into Arabian Sea through Gulf of Cambay in the district of Bharuch, Gujarat. The entire estuarine system is estimated to be about 14,250 ha. The usual flow of Narmada river is restricted by commissioning of a dam, as a result a considerable reduction in freshwater availability at the down stream including estuary has been observed. Moreover, the development of sand bars at the mouth of the estuary reduces the tidal ingress into the system.

Texture of bed soil and water availability: The soil texture in the entire estuarine stretch is predominantly sandy soil with 84.5 to 98.76% sand, nil to 11.5% silt and 1.0 to 7.5% clay. The soil reaction indicated highly alkaline and the *p*H ranged between 7.88 and 9.12. Water temperature varies from 22.9 to 30.8°C. Transparency of water fluctuates seasonally as well as centre-wise. Low transparency was recorded in the lower estuarine stretch between Shakkarpura and Ambetha. The transparency of the estuarine stretch ranged from 5.3 to 52.0 cm. Dissolved oxygen was adequate in the stretch (5.3 to 8.5 mg/litre). This stretch maintained slightly higher water *p*H ranging from 7.8 to 8.61. Very low values of phosphate (traces to 0.055 mg/litre) were recorded, while moderate to high values of nitrate (traces to 1.09 mg/litre) were observed in the entire estuarine system. However, silicate content was highest (4.8 to 24.3 mg/litre) in this stretch. The salinity in the estuary varied between 62.4 and 3189.0 mg/litre. As regard primary production, lower rate of gross (36.34 to 88.39 $mgC/m^3/hr$) and net (6.24 to 60.4 $mgC/m^3/hr$) primary production were recorded. Minimum production was recorded during monsoon season.

Biotic community: The plankton population in the system shows a wide range of fluctuation and variation in abundance with regards to its quality and quantity. The average total plankton density varied from 63 to 1,161 nos/litre. The contribution of phyto-and zoo-plankton was 70.42 to 98.70 nos/litre and 1.30 to 29.58 nos/litre respectively. The major groups contributing phytoplankton were Chlorophyceae (11.27 to 88.20%), Bacillariophyceae (4.82 to 52.11%) and Myxophyceae (5.68 to 22.22%), whereas, zooplankton was mostly shared by protozoans (0.52 to 14.61%), copepods (0.26 to 12.68%), rotifers (0.43 to 5.63%), ostracods (1.41 to 2.31%), cladocerans (0.09 to 1.41%) of the total plankton population. Macro-zoobenthic fauna was found to be principally represented by annelids (nil to 93.81%), molluscs (3.33 to 70.37%), malacostracans (0.52 to 12.96%), dipteran (1.70 to 2.86%) and ostracods (0.61 to 3.06%).

Fisheries: Narmada estuarine system is very rich in fishery resources. The estimated average annual fish yield of the estuary during 1990s ranged between 11,000 and 14,000 tonnes. The fish catches in the estuary consisted of *Tenualosa ilisha (hilsa), Mugil cephalus, Liza parsia, L. macrolepis, Harpodon nehereus, Lates calcarifer, Chanos chanos, Eleutheronema tetradactylum, Arius arius, Polynemus indicus, Etroplus suratensis, E. maculatus*, etc, while prawn comprised mainly *Macrobrachium rosenbergii* and *Penaeus indicus*; and *M. rosenbergii* formed the prime fishery of the estuary. The *T. ilisha* alone contributed to the tune of 977.1 to 3,727 metric tonnes for

1974-75 to 1982-83. Highest catch of hilsa was recorded as 15,319 tonnes during 1993-94, which presently declined to 4,866.0 tonnes during 2007-08.

Mahi estuary: Along the west coast, Mahi estuary (latitude 20° 20'N and longitude 73° 05'E) is an important major estuary in Gujarat. The estuary opens into the Arabian Sea.

Texture of bed soil and water availability: The soil texture is predominantly sandy and *p*H varies from 6.73 to 7.69. The water temperature ranges between 18.5 and 37.0 °C and transparency fluctuates from 6.0 to 88.0 cm. The *p*H ranges from 7.83 to 8.16 and dissolved oxygen from 7.14 to 9.26 mg/litre. Inorganic nutrients. viz. phosphate, nitrate and silicate fluctuates from 0.057 to 0.08 mg/litre, 0.48 to 0.65 mg/litre and 4.93 to 10.27 mg/litre respectively. The salinity values ranged from 0.048 to 36.0 g/litre, high and low values of salinity were observed in lower and upper stretches of the estuary respectively. The gross and net primary production varied from 25.0 to 37.5 mgC/m^3/hr and 16.67 to 208.33 mgC/m^3/hr respectively.

Biotic community: The average total plankton population varies from 172 to 295 nos/litre. Phyto- and zoo-plankton contributed 83.14 to 97.84% and 2.16 to 16.27% respectively. The principal components of the phytoplankton are Bacillariophyceae, Myxophyceae and Chlorophyceae while copepods, rotifers, cladocerans and ostracods were the major groups of zooplankton. Macrobenthos density ranged from 71 to 877 nos/m^2 represented by annelids (10.91 to 95.75%), molluscs (12.68 to 58.97%), dipterans (30.45 to 46.84%), malacostracans (26.76%) and ostracods (9.97%) at different sites of the estuary.

Sabarmati estuary: There are 82 rivers and streams passing through Gujarat. Out of these Narmada, Tapi, Mahi and Sabarmati are the important ones. Sabarmati estuary (latitude 22° 19'N and longitude 72° 38'E) of the western India debouches in the Gulf of Khambhat of Arabian Sea.

Texture of bed soil and water availability: The soil pattern is variable. The alluvial plains of the east in the south Gujarat region are known for their fertility on account of their deposits of the rivers like Sabarmati, Mahi, Narmada and Tapi. The soil reaction is alkaline throughout the stretch. The *p*H varies from 7.47 to 8.34. Sand (84.25 to 92.50%) was the major component of soil. Water temperature ranges between 18.5 and 33.5 °C. Transparency varies from 8.0 to 91.0 cm. Dissolved oxygen varies from traces to 10.2 mg/litre. Phosphate, nitrate and silicate contents of the estuarine water varied from 0.002 to 0.174 mg/litre, 0.18 to1.41 mg/litre and 4.68 to 20.28 mg/litre respectively. The gross primary production of the estuarine system varied between nil and 250 mgC/m^3/hr and the net production between nil and 187.5 mgC/m^3/hr. The physico-chemical characters, nutrient levels and productivity indicated that estuarine system is under environmental stress. It is also reported that the river at Gandhinagar receives some excessive pollution pressure owing to the construction of dam.

Biotic community: Annual plankton production in the estuary varies from 3,301 to 822 nos/litre. Phyto- and zoo-plankton contributed 78.33 to 98.42% and 1.58 to 21.67% respectively. The bulk of phytoplankton was constituted by the members of Bacillariophyceae (46.88 to 81.75%) followed by Myxophyceae and Chlorophyceae.

Among the zooplankton, rotifers, copepods and cladocerans were the major groups. The density of macrobenthos varied from 9 to 2,274 nos/m^2. Diptera (mostly chironomid larval forms), tubifex and molluscs (*Thiara* spp.) were the main groups in the order of abundance.

Fishery: Information on fish and fisheries of the estuary is meagre. Fishery activities are fairly common in the estuarine system during monsoon. However, during post-monsoon and winter, fishes, viz. *Labeo bata, L. rohita, Catla catla, Cirrhinus mrigala, Sparata seenghala, Salmophasia bacaila, Notopterus notopterus,* and *Osteobrama cotio*, are available from the freshwater stretch of the estuary. The principal fishing gears are the cast and gill nets.

Mangroves

Mangroves are the salt tolerant tropical and sub-tropical forest ecosystem comprising swamps, woodlands and water spread areas. The mangrove swamps support the rich biomass of bacteria, fungi, algae protozoans etc. along with worms, rotifers, molluscs, crabs, shrimps and fishes mainly. The root systems of these halophytes provide excellent shelter for wide spectrum of organisms. The total area of mangrove in India is estimated at 4,827 km. The East coast of India is endowed with the world's largest mangrove forest of the Gangetic Sunderbans in West Bengal. Sundarbans contribute about 44% of the total mangrove forest in India and are endowed with 30 out of 53 species of true mangroves of the world. Besides these a good number of mangrove associates and obligatory mangroves, weed flora, non-littoral plants, aquatic flora are also available. The other major mangrove formations around the east coast of India are Andaman and Nicobar Islands, Mahanadi (Odisha), Godavari and Krishna (Andhra Pradesh), Cauvery Delta, Pichavaram and Muthupet Delta (Tamil Nadu), while around the west coast are Narmada and Tapi (Gujarat), some estuaries in the river mouths of Maharashtra, Goa

Table 10.4. State-wise distribution of mangroves in India (km^2)

Regions/States	Area (Govt. of India,1987)	Area (Nayak,1993)	Area (% of total) (Kathiresan,1998)
East coast			
West Bengal	1,619	4,200	2,123 (44.0)
Odisha	187	150	211 (4.4)
Andhra Pradesh	480	200	383 (7.9)
Tamil Nadu	90	150	21(0.4)
Andaman and Nicobar Islands	770	1,190	966 (20.0)
West coast			
Gujarat	1,166	260	991 (20.5)
Maharashtra	138	330	124 (2.6)
Goa	5	200	5 (0.1)
Karnataka	19	60	3 (0.06)
Kerala	Sparse	Sparse	Sparse
Total	6,740	4,474	4,827

and Karnataka. In Kerala, mangrove areas are found in the Kumarakom region (Vembanad lake), Kochi, Kannur and Thalassery. The various state-wise distribution of mangrove areas are summarized in Table 10.4.

Mangrove ecosystem plays a vital role in controlling coastal erosion and trapping of the sediments. It also provides coastal nursery grounds for estuarine and near shore organisms including fin and shellfishes. About 60% of Indian's coastal as well as freshwater fish and prawn species are dependent on the mangrove estuarine system. In India, the yield of mangrove-cum-estuarine dependent fishes is estimated at 30,000 tonnes of fish and 1.3×10^5 tonnes of prawns/year.

Problems faced by the estuarine systems in India

Reduction of river discharge: Most of the estuarine systems in the country have been deprived of receiving adequate freshwater discharge because of construction of dams, weirs, anicuts and barrages, on upper riverine stretches. The reduction of adequate volume of river discharge as well as allochthonus source of nutrients is responsible for adverse change in the estuarine environment by altering the specific ecological properties and biological composition including fish habitat. For example, the Prakasam barrage constructed across the river Krishna river at Vijayawada has changed the ecology and fish diversity of the Krishna estuary as the bulk of river water is utilized for irrigation purposes. Presently, the estuary has become hyper saline in nature and the salinity values ranged between 20 and 35 mg/litre during most part of the year. The fishery mainly comprised marine species, viz. *Mugil* spp., *Liza* spp., clupeids, sciaenids, marine catfish, penaeid prawns etc. However, the oligohaline fish and prawn species have almost totally disappeared in the estuary. Similar deleterious effect has also been observed in Mahanadi, Tapi and Narmada estuaries. On the contrary, many-fold increase in fish yield has been observed in the Hooghly estuarine system during post-Farakka barrage period due to higher flow of freshwater into the system after commissioning of the barrage. The area of distribution of marine species, viz. *Polynemous paradiseus* and *Pama pama, Silaginopsis panijus* etc. in the estuary has been increased during post-barrage period as compared to pre-barrage period. Moreover, certain freshwater fish and prawn species, viz. *Eutropiichthys vacha, Clupisoma garua, Rita rita, Wallago attu, Sperata seenghala, S. aor, Catla catla, Labeo bata*, have made their appearance in the upper estuarine zone. The general habitat of hilsa in the estuary has improved for its migration, breeding and growth.

Formation of sand bars: Formation of sand bars are often observed in the mouth of many estuaries (Mahanadi, Godavari, Tapi, Narmada etc.) and brackishwater lakes (Chilka). The sand bars evidently restrict the entrance of tidal water as well as marine fish and prawn species into the estuaries or lakes. To cite an example, 63 to 75% of fish production of Chilka lake has to depend on recruitment from the sea as well as effective ingress of the marine fishes into the lake.

Deposition of silt: Many of the estuaries and brackishwater lakes are getting silted up rapidly due to absence of adequate head water discharge into the estuaries and lakes. High rate of siltation in Chilka, Pulicat and Vembanad leads to

reduction in effective water areas as well as reduction in depth profile. This has not only restricted the tidal ingress of sea water into the lakes but also reduced their water-holding capacity.

Barriers of fish migration: Hydraulic structures (barrages, dams, weirs etc.) on the river stretches form physical obstruction to the migratory fishes like anadromous hilsa and catadromous eel causing spawning and recruitment failure. Moreover, migration of some freshwater species, viz. *Pangasius pangasius*, and *Macrobrachium rosenbergii*, also seems to be affected by these hydraulic structures. It is reported that estimated catch of *M. rosenbergii* from Vembanad lake and the connected rivers varied from 189 to 429 tonnes during 1950s, while the catch has declined to around 70 tonnes during recent years after commissioning of Thanneermukkom barrage on the lake in 1975.

Over-fishing: Presently, exploitation level of natural fish and prawn resources in certain estuarine areas has reached its maximum limit. It has been observed that such over fishing has gradually declined the recruitment level of many important fish populations. Declining trend in the availability of certain fish species, viz. *Liza tade, Plotosus canius, Pangasius pangasius*, and *Lates calcarifer*, in the Hooghly-Matlah estuarine system has already been observed. Over-exploitation and destruction of brackishwater fish and prawn seed for selective stocking of *P. monodon* in coastal aquaculture are apparently the probable reasons for the decline of these fishes. A huge quantity of both commercial and non-commercial prawn and fish seed is being destroyed during selective collection of *P.monodon* seed. The total amount of seed destroyed over a 5 months, from February to June, in recent years was estimated to be 9,139.5 to 19,249.5 million On the whole, the availability of seed of shell and fin fish in the estuarine system has been found declined to a great extent both qualitatively and quantitatively. Commercially important hilsa of the Hooghly are also subject to heavy fishing pressure mainly from small meshed (5 cm) gill nets. Indiscriminate exploitation of young Hilsa (fry) through small meshed nets (bag net and seine net) was estimated as 31.0 to 115.0 tonnes/year from 1984-85 to 1997–98.

Pollution: The rapid pace of industrialization, urbanization and the increasing use

Table 10.5. Heavy metals in sediments of various estuaries of India (ppm)

Sediments source (estuaries)	Manganese	Nickel	Copper	Zinc	Chromium	Lead	Cadmium
Ganga (Hooghly estuary)	732	49	44	151	98	32	-
Godavari	294	91	119	-	128	5	-
Krishna	6,978	149	69	1,482	174	4	-
Cauveri bed and sediment	13,101,968	379,379	3,355	75,347	229,246	3,838	1.83.4
Tapi	1,125	70	128	125	-	-	-
Narmada	1,077	81	136	140	-	-	-

of fertilizers and pesticides in agriculture are mainly responsible for pollution in estuarine waters. The main sources of pollutants are domestic wastes, industrial wastes, pesticides, insecticides, petrochemical substances etc. Some metals are toxic in nature e.g. cadmium, mercury and arsenic. Since the sediments act as reservoirs of metals, an increased level of heavy metals in the sediments of the Hooghly, Mahanadi, Godavari, Krishna and Cauvery estuarine systems has been recorded (Table 10.5) when compared to inter-riverine coastal sediments.

The impact of enormous load of pollutants on the ecology of estuarine waters is particularly severe. As a result, the estuarine/brackishwater ecosystems become non-productive due to the high levels of eutrophication, low levels of dissolved oxygen and acidic pH. Some of the pollutants are found to be more toxic to fish and prawns.

Destruction of mangroves: Mangrove provides excellent shelter for a wide spectrum of organisms. Many prawn and fish species use this as breeding or nursery ground. Almost all species of penaeid prawns (*Penaeus* spp., *Metapenaeus* spp.) and fishes, viz. mullets (*Mugil cephalus* and *Liza* spp.), *Chanos chanos, Lates calcarifer,* threadfins, sciaenids, *Osteogeneiosus militaris* etc., are not resident breeding species in the mangroves or estuaries. But they utilize mangrove areas as nursery grounds for their development from early larval stages to advance juvenile stages. There are some species *Mystus gulio, Rhinomugil corsula, Etroplus suratensis* and many more utilize mangroves as breeding grounds. Presently, the total area of mangroves in India is gradually decreasing from 6,740 km^2 in 1987 to 4,827 km^2 in 1998. Particularly, Sunderbans the world's largest mangrove forest has drastically reduced from 4,189 km^2 to 2,123 km^2 in 1998. Therefore, reduction of mangrove is a serious threat to many commercially important fish and prawn species.

Recommendations for conservation of estuaries

- The estuarine environment should be judiciously exploited so that natural resources of fish and prawn and their recruitment levels are not damaged or destroyed.
- Remedial measures should be taken with regard to intensive fishing or over exploitation of hilsa or other important species in the estuarine system.
- Periodic dredging or other physical devises may be required in the silted areas to maintain the productivity.
- Maintenance of adequate head water discharge, for protection of ecological habitats and natural production function.
- The mesh size of fishing gears for drift gill net, drag net, seine net and bag net should be adjusted to ensure non-capture of juvenile stocks of prawn and fish.
- Intensive seed collection from wild for stocking estuarine impoundments should be stopped and only hatchery produced seeds should be used for stocking.
- The breeding periods of finfishes are to be critically studied to suggest regulatory measures for their exploitation by observing closed period in time and space.

- There is an urgent need to protect estuarine environment from pollution hazards by agricultural, industrial and domestic effluents.
- Mangrove ecosystem which is fragile but yet highly productive is constantly undergoing changes (seasonal/short-term and/ or succesional/long-term) due to its dynamic nature through various natural and biotic influences. Hence, an accurate and up-to-date information base on the status of mangrove vegetation, continually overtime, is a pre-requisite for the sustainable management of mangrove forests. Remote sensing and geographic information system serve as valuable aids in providing fast, efficient and accurate information to detect the changes. The information thus gained can be utilized for the effective planning and management of mangrove forests, so as to save these delicate and highly valuable ecosystems for posterity and sustainable utilization.

11. Reservoir Fisheries

Reservoirs, the 'man-made lakes' covering more than 1% of the country's land surface are created primarily for irrigation, power generation and other water resource development purposes. These water-bodies have become the prime inland fisheries resource of India due to many reasons. Development of reservoir fisheries has many economic and social advantages. The marine capture fisheries is fast approaching a plateau and the inland aquatic ecosystems like rivers face degradation due to anthropogenic habitat changes. The aquaculture development projects are capital intensive and constrained by many environmental risks. In view of these and considering the enormous resource size and untapped production potential, the reservoirs have become the focus of future fisheries development plans in India. Nearly half of the projected demand of 3 million tonnes of additional fish by the end of XII Plan may come from the reservoirs. Thus, national efforts to enhance fish production from India have to rely heavily on reservoirs. However, application of technologies and creation of an enabling governance environment would be needed to achieve the optimum production from the reservoirs.

Definition, classification and distribution

Reservoirs are defined as 'man-made impoundments created by erecting a dam of any description on a river, stream or any water course to obstruct the surface flow' and they are classified as small (<1,000 ha), medium (1,000 to 5,000 ha) and large (>5,000 ha). There are many anomalies regarding classification and nomenclature of impounded water-bodies, being maintained by various state authorities. For instance, the word 'tank' is often loosely defined and used in common parlance to describe some of the small irrigation reservoirs in the three southern states of Tamil Nadu, Karnataka and Andhra Pradesh. In these states, a large number of small man-made lakes have been designated as tanks, thereby precluding them from the estimates of reservoirs. There is no uniform definition for a 'tank'. In the eastern states of Odisha and West Bengal, ponds and tanks are interchangeable expressions, while in Andhra Pradesh, Karnataka and Tamil Nadu, tanks refer to a variety of water-bodies, some of them are actually irrigation reservoirs, qualifying for inclusion under small and medium-sized reservoirs. The 'peninsular tanks' is also considered as water-bodies created by dams built of rubble, earth, stone and masonry work across seasonal streams, as against reservoirs, formed by dams built with precise engineering skills across perennial or long seasonal rivers or streams, using concrete masonry or stone, for power supply, large-scale irrigation or flood control purposes. Irrespective of the purpose for which the lake is created and the level of engineering skill involved in dam construction, both the categories fall under the broad purview of reservoirs. From limnological and fisheries points of view, the distinction between small reservoirs and tanks seems to be irrelevant.

Moreover, numerous small reservoirs fitting exactly into the description of the south Indian 'tanks' are already enlisted as reservoirs in the rest of the country. The first attempt to remove the anomalies in nomenclature, especially with regard to the small reservoirs was taken during the National Consultation held at the CIFRI, Barrackpore in January 1997. Accordingly, some of the large (>10 ha) irrigation tanks were brought under the fold of reservoirs, encompassing all man-made impoundments created by erecting dam on a river, stream or any water course. Dug-out water-bodies like village tanks and all water bodies less than 10 ha have been excluded from the purview of reservoirs. It has also been agreed to classify uniformly reservoirs of the country into small (< 1,000 ha), medium (above 1,000 to 5,000 ha) and large (> 5,000 ha) based on their hectarage. During 1995, the country had 19,370 reservoirs, covering more than 3 million ha of reservoirs (Table 11.1) which included 19,134 small reservoirs with an area of 1,485,557 ha, 180 medium reservoirs covering 507,298 ha and 56 large reservoirs with a water surface area of 160,511 ha. Tamil Nadu has highest area of small reservoirs with 8,895 units, followed by Karnataka with 4,651 units and Andhra Pradesh with 2,898 units. Madhya Pradesh is at the top in total area as well as in the area of medium reservoirs. Andhra Pradesh, Gujarat and Rajasthan too have more area of medium reservoirs. Karnataka has the maximum number of large reservoirs (12 units) but its area is lesser than that of Andhra Pradesh with seven units.

Table 11.1. Distribution of small reservoirs and irrigation tanks in India

State	Small		Medium		Large		Total	
	No.	Area (ha)	No.	Area (ha)	No.	Area (ha)	No.	Area (ha)
Tamil Nadu	8,895	315,941	9	19,577	2	23,222	8,906	358,740
Karnataka	4,651	228,657	16	29.078	12	179,556	4,679	437,291
Madhya Pradesh	6	172,575	21	169,502	5	118,307	32	460,384
Andhra Pradesh	2,898	201,927	32	66,429	7	190,151	2,937	458,507
Maharashtra	-	119,515	-	39,181	-	115,054	-	273,750
Gujarat	676	84,124	28	57,748	7	144,358	711	286,230
Bihar	112	12,461	5	12,523	8	71,711	125	96,695
Odisha	1,433	66,047	6	12,748	3	119,403	1,442	19,198
Kerala	21	7,975	8	15,500	1	6,160	30	29,635
Uttar Pradesh	40	218,651	22	44,993	4	71,196	66	334,840
Rajasthan	389	54,231	30	49,827	4	49,386	423	153,444
Himachal Pradesh	1	200	-	-	2	41,364	3	41,564
Northeast	4	2 239	2	5,835	-	-	6	8,074
Haryana	4	282	-	-	-	-	4	282
West Bengal	4	732	1	4,600	1	10,400	6	15,732
Total	19,134	1,485,557	180	527,541	56	1,140,268	19,370	3,153,366

No., Number of units

Limnological profile of Indian reservoirs

India being a country of continental proportion, its reservoirs are spread over various types of terrains, and soil types exposed to diverse climatic conditions, receiving drainage from a variety of catchment areas. Indian reservoirs are situated, by and large, at a tropical regime with rich nutrient status conducive for good organic productivity. The peninsular reservoirs are characterized by narrow range of fluctuations in water and air temperature during different seasons, a phenomenon which prevents the formation of thermal stratification. Many reservoirs in the Upper Peninsula undergo transient phases of thermal stratification during summer, but wind-induced turbulence churns the reservoirs facilitating the availability of nutrients at the trophogenic zone. Plankton, benthos, and periphyton pulses of Indian reservoirs coincide with the months of least level fluctuations and all these communities are at their ebb during the months of maximum level fluctuations and water discharge. Oligotrophic tendencies shown by some of the reservoirs in the Western Ghats and the Northeast are mainly due to poor nutrient status and other chemical deficiencies. Mainly, poor water quality is the direct result of catchment soil. In most cases, despite low levels of phosphate and nitrate, the production processes are not hampered. This phenomenon is attributed to quick turnover of nutrients and their quick recycling. A close examination of physico-chemical data pertaining to more than 100 reservoirs in the country leads to the conclusion that production propensities of each reservoir are determined by a variety of factors. The vertical gradient of dissolved oxygen, however, conveys the status with high level of accuracy.

Biotic communities

The heavy discharge of water during monsoon results in high flushing rate in most of the reservoirs, retarding colonization by macrophytic communities. Similarly, inadequate availability of suitable substrata retards the growth of periphyton. Plankton, by virtue of drifting habit and short turnover period, constitutes the major link in the trophic structure and events in the reservoir ecosystem. A rich plankton community with well-marked seral succession is the hallmark of Indian reservoirs. Blue-green algae form the mainstay of plankton community in vast majority of the man-made lakes were studied. The overwhelming presence of cyanobacterium, *Microcystis aeruginosa* in Indian reservoirs is remarkable.

In most of the reservoirs, aquatic macrophytes are totally absent or their population is too insignificant to be taken into account. They are generally restricted to isolated patches of *Vallisneria maxima, Hydrilla spiralis* and mats of *Spirogyra vericellata,* found in the protected bays and coves. Main factors adversely affecting the benthic community in reservoirs are the rocky nature of the bottom, frequent water level fluctuations and the loss of substrata due to rapid deposition of silt and other suspended particles. Literature on periphyton of the reservoir ecosystem is meagre. This community constitutes an important component of food for the browsing fishes which contribute substantially to the total fish biomass of the tropical reservoirs. Apart from the limited littoral region in reservoirs, it is the frequent level fluctuation that prevents the growth of periphyton on natural substrata.

Although the ichthyofauna of a reservoir basically represents the fauna of the parent river system, fish species diversity usually suffers a setback at the time of impoundment on account of the sudden environmental changes. As the lotic (running water) habitat transforms into a lentic (standing water) one, many species perish, some escape to more conducive environments and a few others adapt to the changed situation. Indian reservoirs, however, preserve a relatively rich variety of fish species. Large reservoirs harbour 60 species of fishes, of which at least 40 contribute to the commercial fisheries. The fast-growing Indo-Gangetic carps occupy a prominent place among the commercially important fishes. Recently, many exotic species have contributed substantially to commercial fisheries. The groups enjoying countrywide distribution are the catfishes, featherbacks, air-breathing fishes and the minnows (Table 11.2).

Table 11.2. Common fish species of reservoirs in India

Group	Species
Indian major carps	*Labeo rohita, L. calbasu, L .fimbriatus, Cirrhinus mrigala, Catla catla*
Mahseers	*Tor tor, T. putitora, T. khudree, Neolissochilus hexagonolepis*
Minor carps including snow trout and peninsular carps	*Cirrhinus cirrhosa, C. reba, Labeo kontius, L. bata, Puntius sarana, P. dubius, P. carnaticus, P. kolus, P. dobsoni, P. chagunia, Schizothorax richardsonii, Thynnichthys sandkhol, Osteobrama vigorsii, Hypselobarbus kurali, H. periyarensis, Crossocheilus periyarensis*
Large catfishes	*Spearota aor, S. seenghala, Wallago attu, Pangasius pangasius, Silonia silondia, S. childrenii*
Featherbacks	*Notopterus notopterus, Chitala chitala*
Air-breathing cat fishes	*Heteropneustes fossilis, Clarias batrachus*
Murrels	*Channa marulius, C. striatus, C. punctatus, C. gachua*
Uneconomic fishes	*Ambassis nama, Esomus danricus, Aspidoparia morar, Amblypharyngodon mola, Puntius sophore, P. ticto, Oxygaster bacaila, O. phulo, Laubaca laubaca, Barilius barila, B. bola, Osteobrama cotio, O. vigorsii, Gudusia chapra*
Exotic fishes	*Oreochromis mossambicus, Hypophthalmichthys molitrix, Cyprinus carpio specularis, Cyprinus carpio nudus, C. carpio communis, Gambusia affinis, Ctenopharyngodon idella*

Determinants of productivity

Reservoir represent fluviatile as well as lentic characters, both temporally and spatially. While the tail end of the reservoir, where the river joins, is always in flowing condition, the dam zone has stagnant, lentic water. During monsoons, due to continuous inflow into and outflow from the dam, the whole reservoir is akin to a running water habitat, while during lean flow seasons, the reservoir becomes almost stagnant. The sudden water-level fluctuations with inflow and outflow of water for irrigation and power generation cause changes in standing crop of reservoirs affecting the production process. Moreover, reservoirs are situated in different geo-climatic regions, receiving drainage from varying types of catchment areas with the different design and purpose of dams. All these diversities make each reservoir different in their morpho-edaphic characters. The habitat variables determining productivity of reservoirs are classified into morphometric, climatic and edaphic. Effects of these variables are outlined in Fig. 11.1.

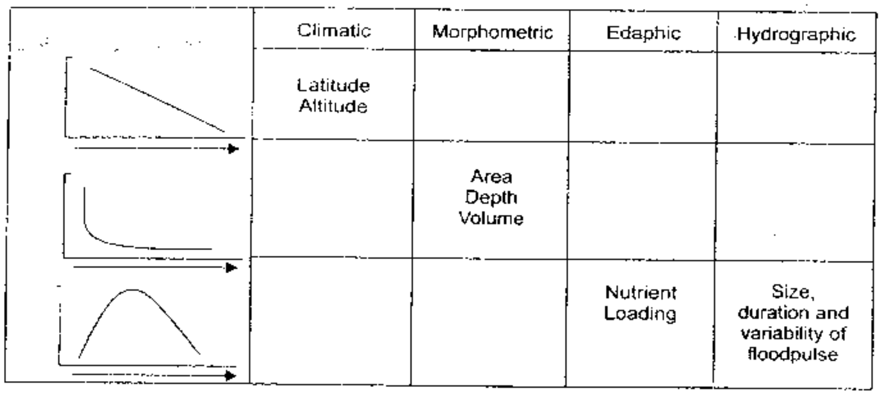

Fig 11.1. Generalized effects of climatic, morphological, edaphic, and hydrological factors on lake productivity

Morphometric factors

Depth is the most important among the morphometric factors that can be correlated with productivity because shallow lakes have larger proportion of substrates in euphotic zone as compared to deeper ones where most of the substrate is locked up in aphotic zone. Shore development is another useful index in determining productivity denoting degree of irregularity in shoreline. Another character is sudden fluctuations in water level because plankton pulses coincide with period of least level fluctuations, and all biotic communities are in their lowest ebb during maximum level fluctuations. A stable reservoir level is more conducive to growth of organisms.

Climatic factors

The most important climatic factor is latitudinal location of reservoir, which determines quantum of solar energy available for photosynthetic activities (Fig.11.2). The latitude also determines air temperature that plays important role in thermal and nutrient regimes of reservoirs. In south India, especially in Kerala, southern Tamil Nadu and southern Karnataka, range of fluctuations in air and water temperatures across the seasons is narrow, which prevents formation of thermocline in reservoirs. Thermal stratification is limnologically important because in thermally stratified lakes, water columns above (epilimnion) and below (hypolimnion) thermocline does not mix up and thereby rich nutrients get locked up at the bottom. Where stratification occurs, its early breaking is required for good production from lake because longer duration of stratification is an unproductive trait. Fortunately, wind induced turbulence

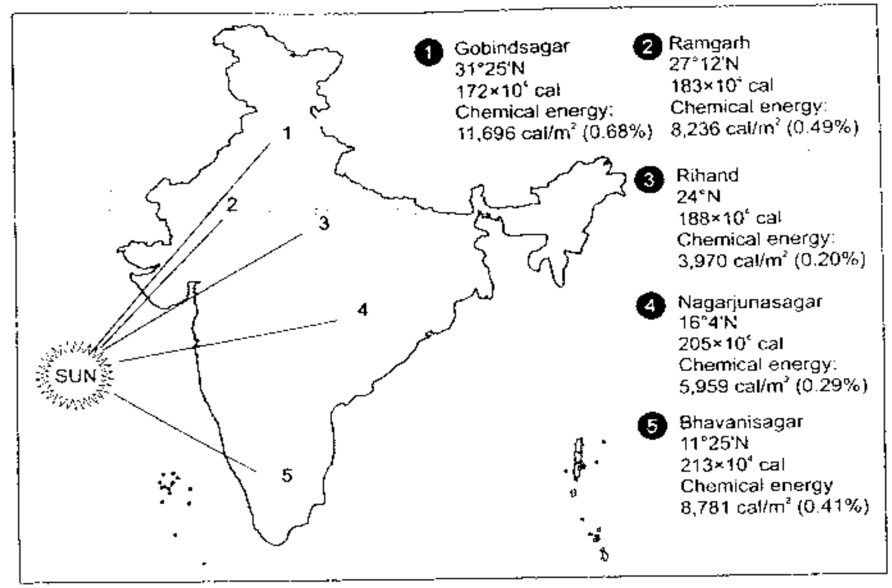

Fig 11.2. Effect of latitudinal location in primary productivity of reservoirs

during the monsoons usually breaks thermocline in Indian reservoirs. Thus, wind is an important meteorological factor that helps mixing of water, facilitating nutrient transport. The rainfall at catchment area is also very important than rainfall at reservoir site. The soil status of the catchment area affects the nutrient status of the reservoir. Thus, in many reservoirs, in spite of poor soil quality of the basin, the productivity is high by virtue of allochthonous nutrients.

Edaphic factors

The physico-chemical characteristics of water and soil are the major determinants of biogenic productivity of reservoirs. Water transparency is one such physical variable with significant bearing on production. The poor light penetration accountable to suspended matters like silt and clay, retards productivity, but poor visibility due to planktonic bloom is a positive index of production. Another key variable is dissolved oxygen, the main source of which in water is absorption from air and through photosynthesis. The dissolved oxygen of the reservoir is removed through respiration of organisms and purification of organic matter. Thus the available dissolved oxygen in water depends on the balance of the above two processes. Dissolved oxygen below 5 ppm can adversely impact the biota. A *p*H in the alkaline range, but not above 8 is considered conducive to productivity. A total alkalinity over 50 ppm and hardness above 70 ppm are indicators of better productivity. The electrical conductance reflects total dissolved solids, and it gives a reliable indication of edaphic quality of water (Table 11.3).

Table 11.3. Physico-chemical features of reservoirs in India (range of values)

Parameter	Overall range	Productivity		
		Low	Medium	High
Water				
*p*H	6.5-9.2	< 6.0	6.0-8.5	> 8.5
Alkalinity (mg/litre)	40-240	< 40.0	40-90	> 90.0
Nitrates (mg/litre)	Tr.-0.93	Negligible	Up to 0.2	0.2-0.5
Phosphates (mg/litre)	Tr.-0.36	Negligible	Up to 0.1	0.1-0.2
Specific conductivity (µmhos)	76-474		Up to 200	> 200
Temperature (°C)	12.0-31.0	18	18-22	> 22
(with minimal stratification, i.e. > 50°C)				
Soil				
*p*H	6.0-8.8	< 6.5	6.5-7.5	> 7.5
Available P (mg/100 g)	0.47-6.2	< 3.0	3.0-6.0	> 6.0
Available N (mg/100 g)	13.0-65.0	< 25.0	25-60	> 60.0
Organic carbon (%)	0.6-3.2	< 0.5	0.5-1.5	1.5-2.5

Chemical stratification

Aside from physico-chemical characters of water and soil as discussed above, the vertical distribution of some of the chemical constituents of water acts as a reliable index of productivity of reservoirs. The upper trophogenic layer of water is characterized by high rate of photosynthesis due to presence of light in contrast to lower tropholytic layer. In upper photosynthetic zone, carbon-dioxide is taken up from bicarbonates by photosynthetic organisms and oxygen is liberated during photosynthesis. Thus, trophogenic zone is characterized by increase in oxygen and decrease in carbon-dioxide and bicarbonates. In tropholytic zone, oxygen is consumed for purification of organic matter. A strong decline in oxygen (oxycline) and *p*H coupled with an increase in bicarbonates and carbon-dioxide towards bottom of water indicates high rate of production process in a lake. Oxygen and carbon-dioxide are two complementing agents in metabolism influenced by temperature. When carbon-dioxide in epilimnion decreases, an increase in oxygen is expected. On the contrary to this process, when carbon-dioxide in hypolimnion increases, there is decrease in oxygen level (klinograde curve). Thus, productivity of a lake is estimated from the nature of the oxygen curve. The klinograde curve of oxygen is considered to be productive character against orthograde when oxygen value is more or less uniform from surface to bottom.

Trophic dynamics and energy flow

A reservoir is known to pass through three distinct phases after its formation, viz. initial high fertility phase, trophic depression phase and final fertility phase. A newly formed reservoir inundates vast areas of forest and agricultural lands causing decay of submerged vegetation. This results in release of nutrients causing initial fertility leading to intense development of fish food organisms – plankton, bottom microflora and fauna. This stage lasts for 2–3 years and is followed by trophic depression stage,

caused by rapid utilization of nutrients by flora and subdued release of nutrients from reservoir-bed due to sedimentation. This phase is marked by low production of fish-food organisms and lower fish growth, hence lesser production. In Indian reservoirs, trophic depression generally exists for shorter duration and it varies from reservoir to reservoir. After depression period, the reservoir gradually recovers with accumulation of nutrients. The final fertility of reservoir on stabilization is somewhere near half the magnitude of initial phase, which gets adjusted to the basic productivity of basin depending on the watershed runoff and inflow. But in Indian reservoirs it has been shown that final fertility would be of much higher magnitude than initial, and reservoir productivity improves after ageing.

A basic knowledge of aquatic ecology is helpful in managing production aspects of reservoirs. The aquatic ecosystem consists of biotic communities of producers (autotrophs), consumers (heterotrophs) and decomposers (saprophytes). The phytoplankton is the largest group, involved in autotrophic production processes, called primary producers, being in the first trophic level and controlling basic productivity or 'primary production' of the ecosystem. The primary consumers are in the second trophic level represented by zooplankton and some fishes (grazers and browsers). Secondary consumers or carnivores are in the third trophic level, including insect larvae, fishes etc. Tertiary consumers belong to next higher trophic level represented by large predators or top carnivores. The decomposers, bacteria, fungi, also play a leading role in mineralizing organic matter and recycling nutrients. During energy transformation operating on the above trophic pyramid, the energy fixed by primary producers passes through different trophic strata and efficiency of the conversion is reduced to a tenth from one level to the next higher level.

Energy flow: The biotic communities (producers, consumers and decomposers) in an ecosystem are linked with one another with energy chains. Energy flow and nutrient cycles are two important principles of ecology. Complete knowledge of inter-relationships among organisms, energy flow and nutrients from one level to other and role of environmental parameters in energy transformation processes are very important for understanding ecosystem. This study of productivity is now receiving much importance and ecologists are keen to know the efficiency with which solar energy is converted to chemical energy by producers (photosynthetic efficiency), and efficiency with which this energy is utilized by consumers (ecological efficiency). The studies conducted in Bhavanisagar, Nagarjunasagar, Rihand and Gobindsagar reservoirs have shown that photosynthetic efficiency was high in productive reservoirs like Bhavanisagar (0.412%), Nagarjunasagar (0.290%) and Gobindsagar (0.682%) but low in unproductive Rihand (0.202%). It is interesting to note that energy harvest as fish was much low in Nagarjunasagar (0.055%) as compared to Bhavanisagar (0.290%), which showed that management failed in harvesting fish from Nagarjunasagar though it was productive (Fig.11.2).

Productivity of a lake is dependent on biogenic capacity to transform solar energy into chemical energy. The energy fixed at primary producer level passes through trophic chain and fraction of it ends up as fish flesh (trophic dynamics). Therefore, the structure

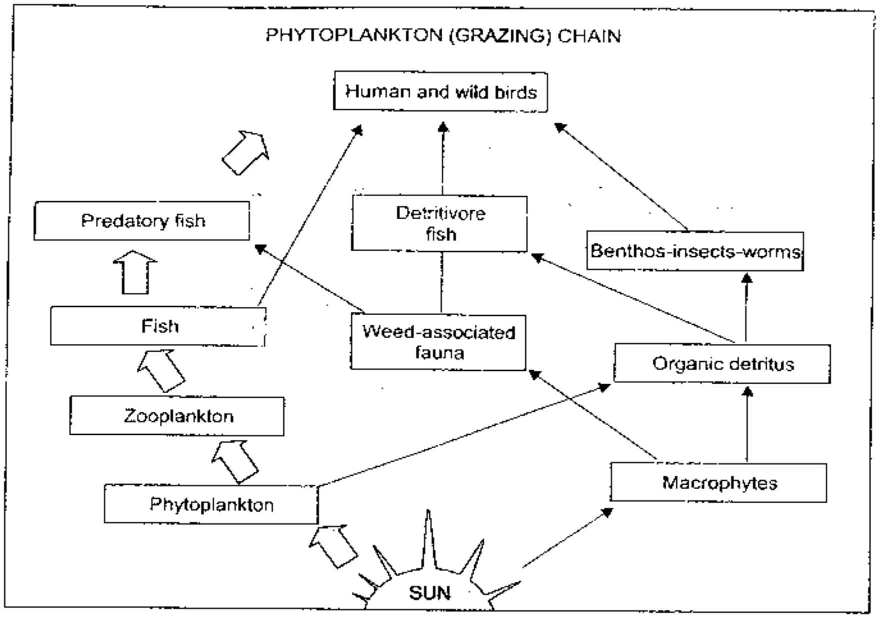

Fig. 11.3 Grazing chain in plankton-based energy transfer.

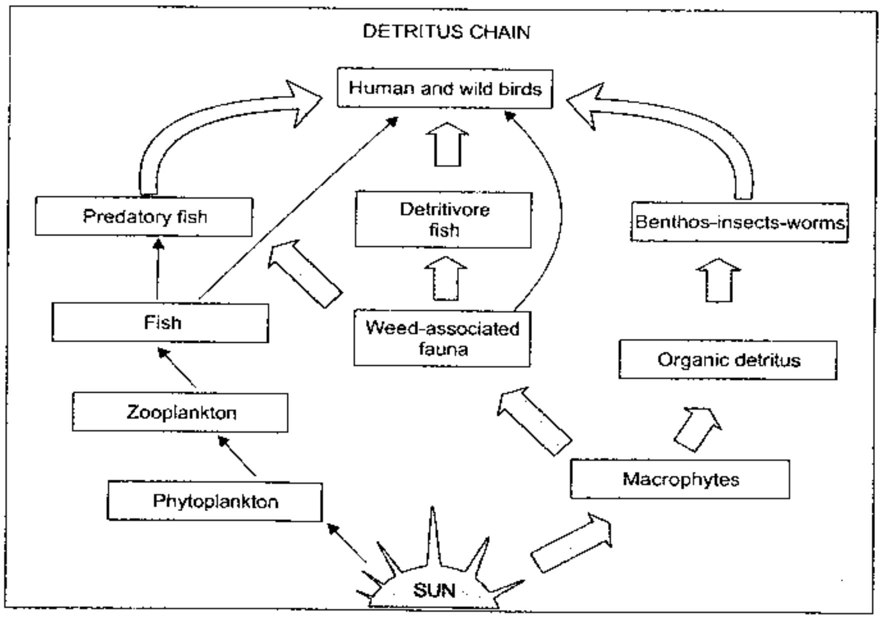

Fig. 11.4 Detritus chain in macrophyte-based energy transfer.

of different food biotic communities assumes great significance to reservoir fishery management. Community metabolism or the transfer of energy from one trophic level to the other can be a major criterion for selecting management options, especially the species selection in culture-based fisheries. In an ecosystem, the biological output or the production of harvestable organisms can be at various trophic levels. Under a grazing chain, a phytoplankton > zooplankton > minnows > catfishes system or a phytoplankton > zooplankton > fish system prevails. In macrophyte dominated system, the primary energy at the macrophytes level is invariably channelled through detritus chain. There are different detritus chains such as macrophytes >detritus> detritivore system, phytoplankton > detritus > benthos > bottom feeders system and macrophytes > associated fauna > air-breathing fish system. Two typical systems generally found in reservoirs are depicted in Figs 11.3 and 11.4. Shortening food-chain will lead to higher rates of fish production but in reservoir management there is little scope for changing community structure of plankton to increase primary productivity. However, alterations in species spectrum of fish may be done, and for this only stocking of fish is a successful tool in management.

Fish production trends and potential

The fish production statistics from inland sources are inaccurate all over the world due to many reasons and reservoirs are no exception to this. Nevertheless, it has been established that the fish yield from Indian reservoirs is rather poor varying from 0.05 kg/ha in Bihar to 35.5 kg/ha in Himachal Pradesh with national average of 20 kg/ha. The average national yield from small reservoirs in India is nearly 50 kg/ha, which is also low (3.9 kg/ha in Bihar to 188 kg/ha in Andhra Pradesh) (Table 11.4), which is well below the rates achieved in many other countries such as >800 kg in China, 300 kg in Sri Lanka and 100 kg/ha in Cuba.

Fish production potential: Prioritizing culture-based fisheries of reservoirs holds the key for increasing inland fish production in India. Based on the average fish yields

Table 11.4. Fish yield from reservoirs of India (kg/ha)

State	Small	Medium	Large	Pooled
Tamil Nadu	48.50	13.74	12.66	22.63
Uttar Pradesh	14.60	7.17	1.07	4.68
Andhra Pradesh	188.00	22.00	16.80	36.48
Maharashtra	21.09	11.83	9.28	10.21
Rajasthan	46.43	24.47	5.30	24.89
Kerala	53.50	4.80	–	23.37
Bihar	3.91	1.90	0.11	0.05
Madhya Pradesh	47.26	12.02	14.53	13.68
Himachal Pradesh	–	–	35.55	35.55
Odisha	25.85	12.76	7.62	9.72
Average	49.50	12.30	11.43	20.13

Source: Sugunan,1995

Table 11.5. Actual and potential production from categories of reservoirs in India

	Area (ha)	Present production (tonnes)	Potential production (tonnes)
Small	1,485,557	74,200	743,000
Medium	507,298	6,500	127,000
Large	1,160,511	13,000	116,000
Total	3,153,366	93,700	986,000

of 422 reservoirs, it has been estimated that small, medium and large reservoirs yield fish at the rate of 49.50 kg/ha, 12.30 kg/ha and 11.43 kg/ha respectively. Applying this at national scale, fish production from 1,485,557 ha of small, 507,298 ha of medium and 1,160,511 ha of large reservoirs, could be 74,129 tonnes, 6,488 tonnes and 13,033 tonnes from small, medium and large reservoirs respectively. But, with moderate increased yield rate of 500, 250 and 100 kg/ha for small, medium and large reservoirs, respectively, the production is expected to be 743,000, 127,000 and 116,000 tonnes for small, medium and large reservoirs respectively. Cumulatively this would boost up the present production of all reservoirs from the current 64,000 tonnes to nearly 1 million tonnes (Table 11.5).

Reservoir fisheries management

Fisheries management of reservoirs is based on the principles of 'enhancement', which is defined as a range of management practices/processes by which qualitative and quantitative improvement is achieved from water-bodies through exercising specific management options. This is something intermediate between culture and capture fisheries. Enhancement *inter alia* includes 'culture-based fisheries (stock and recapture)', 'stock enhancement (enhanced capture fisheries)', 'species enhancement (introduction of species)', 'environmental enhancement (fertilizing water-bodies)', 'management enhancement (introducing new management options)' and 'enhancement through new culture systems (cage culture, pen culture, FADs, etc)'. Reservoirs offer scope for one or more forms of enhancement. The most suitable management strategy for a particular reservoir is chosen, based on its morphometric, edaphic and biological characteristics. The two most common forms of enhancement followed in Indian reservoirs are culture-based fisheries and stock enhancement.

Culture-based fisheries is generally practised in the small reservoirs, while the medium and large reservoirs are managed on the basis of stock enhancement, also called enhanced capture fisheries. However, it must be borne in mind that the area alone is not the criterion for determining whether a reservoir is managed on the basis of culture-based fisheries or stock enhancement. A number of other considerations such as depth, predator pressure and fishability also come into play. A set of broad guidelines for distinguishing small reservoirs, which are suitable for culture-based fisheries, from the medium and large reservoirs that are primarily used for stock enhancement are given in Table 11.6. In addition to their physical attributes, impoundments are defined by factors including species diversity, fertility and structural

Table 11.6. Distinguishing features of small, medium and large reservoirs

Small reservoirs (for culture-based fisheries)	Large and medium reservoirs (for stock enhancement)
Single-purpose reservoirs mostly for minor irrigation	Multi-purpose reservoirs for flood-control, hydro-electric generation, large-scale irrigation, etc
Dams neither elaborate nor very expensive. Built of earth, stone and masonry work on small seasonal streams	Dams elaborate, built with precise engineering skill on perennial or long seasonal rivers. Built of cement, concrete or stone
Shallow, biologically more productive per unit area	Deep, biologically less productive per unit area
May dry up completely in summer. Notable changes in the water regime	Do not dry up completely. Changes in water regime slow. Maintain a conservation-pool level (i.e. dead storage level)
Sheltered areas absent	Sheltered areas present by way of embayments, coves, etc
Shoreline not very irregular. Littoral areas with a gentle slope	Shoreline more irregular. Littoral areas mostly steep
Oxygen mostly derived from photosynthesis. No stratification and significant wave action	Thermal and chemical stratification can occur. Oxygen derived from significant wave action and photosynthesis
Breeding of commercially important species not commonly observed	Breeding of commercially species mostly occur in the reservoir
Trophic burst and depression phases do not occur	Trophic burst and depression phases do occur
Complete fishing or over-fishing possible. Fish stocks have to be built through annual stockings	Complete fishing not possible. Recruitment through natural breeding possible
Correlation between stocking rate and catch per unit effort possible	Correlation between stocking rate and catch per unit effort not possible
Low predation pressure. Total elimination of predators also possible	Predation pressure can be high. Total elimination of predators not possible
Culture-based fishery models applicable as recruitment and mortality (both fishing and natural mortality) are known	Capture fisheries models applicable, but natural mortality and recruitment can only be indirectly estimated

complexity of the aquatic habitat. The goal of fishery management is to control these factors to produce a harvestable surplus while maintaining a dynamic equilibrium within the ecosystem.

Culture-based fisheries in small reservoirs

Management of culture-based fisheries involves stocking of fish into the reservoir, allowing the stock to grow utilizing the natural fish food resources and harvesting them at an appropriate size (Fig.11.5). Therefore, the number of fish to be stocked, the size at which they are stocked, the period of growth and the size at which they are harvested play a key role in the success of culture-based fisheries in small reservoirs. In this regard, the key management decisions to be made are:

(i) Estimation of fish yield potential,
(ii) Selection of fish species for stocking,
(iii) Stocking rate and size, and
(iv) Period of growth and size at harvesting

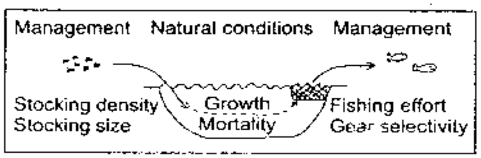

Fig 11.5. Working of culture-based fisheries in small reservoirs

Estimation of fish yield potential: It is essential to assess the fish yield potential of the reservoir for formulating appropriate stocking strategies, especially stocking density. Fish yield potential of the water body is determined by its biotic and abiotic characteristics. Several methods are in vogue to assess the fishery potential of small reservoirs by deriving equations based on area, depth, catchment area and the chemical parameters of soil and water. Among them, the morpho-edaphic index (MEI) method is widely accepted. This method combines the morphometric as well as chemical parameters and is most suited to the Indian reservoirs, considering that the ionic composition and depth are important parameters under Indian conditions. This method involves calculation of MEI as:

$$MEI = \frac{\text{Specific conductivity } (\mu\text{mhos/cm})}{\text{Mean depth (m)}}$$

Fish yield potential is then calculated using the formula:

$$\text{Fish yield in kg/ha/year (C)} = 0.9897\ MEI^{1.3888}$$

Selection of fish species and stocking rate: The selection of species for stocking is guided by chances of the stocked species to thrive in the reservoir and effectively utilize the food resources and converting them into fish flesh at the quickest possible time.

Basic principles that govern selection of species for stocking are:

- The stocked species should find the environment suitable for maintenance and growth
- It should be a quick growing with high efficiency of food utilization (shortest food chain)

- The size of the stock should be chosen with the expectation of getting the desired results.

One of the important criteria for stocking policy is to know the amount of food available per individual in the environment. This factor has a considerable bearing on population density hence production. In multi-species systems, fish can occupy different niches where competition is avoided or at least minimized. Species competition for space and food can occur if niches overlap for any life history stage. In the small reservoirs under consideration all the three Indian major carps *(Labeo rohita, Catla catla* and *Cirrhinus mrigala)* and the freshwater prawn *(Macrobrachium rosenbergii)* can be ideal candidate species.

Stocking rates need to be fixed for individual water-bodies or a group of them sharing common characteristics such as size, presence of natural fish populations, predation pressure, fishing effort, possible stock loss, minimum marketable size and multiplicity of water use. The number of fish to be stocked is based on the growth of individual fish and the total possible yield of the reservoir. In other words, it is a function of the total biomass of fish and the weight of the individual fish at harvest.

The main consideration in determining the stocking rate is growth of individual species stocked, the mortality rate, size at stocking and the growing time. A formula to calculate the stocking rate (Welcomme, 1976) is given below.

$$S = \{qP/W\}\ e^{-z\,(tc-to)}$$

where S, number of fish to be stocked (in number/ha); P, natural annual potential yield of the water body; q, proportion of the yield that can come from the species in question; W, mean weight at capture; t_c, age at capture; t_o, age at stocking; -z, total mortality rate.

P can be estimated through MEI method and the range of mortality rates can be found out from the estimated survival rate. The methodologies for calculating stocking rate as described above are only indicative. Higher stocking densities might be possible due to increased nutrient status of the reservoir through extraneous inputs (e.g. higher organic loading), larger catchment area feeding the water body and other favourable conditions (e.g. absence of predatory species, etc). In such cases, yield rates much higher than what is calculated through the formula is possible.

Stocking size: The size of stocking is important from economic as well as biological points of view. Biologically, the larger the fish stocked the better its chances for survival and thus even lesser number of individuals can be stocked. But growing fish to fingerling size is an expensive proposition and it is economically expedient to stock at a lower size in larger numbers. This can be done only when the ecosystem is free from or has lesser number of predators. The discretion of the manager is therefore important to determine the size at stocking. In any case, fingerlings of > 100 mm size are always considered to be safe and give the best results. In data-deficient situations, stocking of 80-100 mm size fingerlings is always recommended.

Period of growth and size at harvesting

Normally, the stocks are replenished annually in small reservoirs and thus the growth cycle is annual and the stocked fish grow to 0.7-1.0 kg at harvest depending upon the water quality and species stocked. However, fish can grow to a harvestable size (starting from 0.5 kg onwards) in a culture-based fishery in 6-8 months. Thus, the seasonal reservoirs that retain water up to 6-8 months can be used for culture-based fisheries. However, it must be borne in mind that the fish harvested at a lower size will give higher yield rate in terms of kilogram/ha. Therefore, depending upon the requirements and acceptance of the market, the size at harvest can be determined.

Staggered stocking and harvesting: The practice of staggered stocking and harvesting is known to yield better efficiency and economic returns. It allows replenishment of harvested stock at regular intervals and thereby optimum utilization of the inherent productivity of the water-body. Further, it also permits catching of fish only above certain size and voluntary release of smaller fishes back into the reservoir. Higher level of motivation and awareness among fishers is required for practising this method.

In several small reservoirs of Tamil Nadu, staggered stocking and harvesting is yielding better results and is, therefore, recommended for adoption. However, caution should be exercised to avoid overstocking and subsequent low growth rate due to reduced availability of food.

Stock loss: Loss of juvenile and adult fish through the overflowing spillways poses a serious problem in reservoirs. The situation is further worsened by heavy escape of fingerlings and adults through irrigation canals. Development of fisheries in such water bodies, therefore, requires suitable screening of the spillway and the canal mouth. Such protective measures have already been installed in some of the reservoirs. They are paying dividends by enhancing fish yield from the reservoir. However, caution is to be exercised to see that the screens across spillway do not get clogged during flood season, which may threaten to damage the dam. In some of the reservoirs fishes have also been observed to move up the spillway into the reservoir, whereas in others the spillways provide an insurmountable barrier to fish moving up the dam. To minimize losses by way of escape of fish through spillway and canal, it would be an economic proposition to have an annual cropping policy so that the reservoir is stocked in September-October and harvested by June end. However, this depends on the growth of fish and the general productivity of the water body.

Impact of culture-based fisheries in small reservoirs

Scientific studies have shown that fish yield is significantly correlated to stocking. Success in management of culture-based fisheries in small reservoirs depends more on recapturing the stocked fish rather than on their building-up a population. The smaller water-bodies have the advantage of easy stock monitoring and manipulation. Thus, the smaller the reservoir the better the chances of success in the stock and recapture process. In fact, an imaginative stocking and harvesting schedule is the main theme of fisheries management in small, shallow reservoirs. The basic tenets of such a system involve:

- Selection of the right species, depending on the fish food resources available in the system,

- Determination of stocking density on the basis of production potential, growth and mortality rates,
- Proper stocking and harvesting schedule, including staggered stocking and harvesting, allowing maximum grow-out period, taking into account the critical water levels, and
- In case of small irrigation reservoirs with open sluices the season of overflow and the possibilities of water level falling too low or completely drying up, are also to be taken into consideration.

Aliyar reservoir in Tamil Nadu, where culture-based fisheries was tried by CIFRI, is a standing testimony to the efficacy of the staggered stocking. The salient features of the management options adopted in Aliyar were:

- Stocking limited to Indian major carps (earlier, all indigenous, slow-growing carps were stocked),
- Increasing the size of stocking to 100 mm and above,
- Reducing the stocking density to 235-300/ha (earlier rates were erratic ranging between 500 and 2,500/ha),
- Staggering the stocking, and
- Regulating mesh size strictly and banning the catch of Indian major carps< 1 kg in size.

A direct result of the above management practice was an increase in fish production from 1.67 kg/ha in 1965-66 to 194 kg/ha in 1990. Successful stocking has also been reported from a number of small reservoirs in India. In Markonahalli, Karnataka, on account of stocking the percentage of major carps has increased to 61 % and the yield increased to 63 kg/ha. Yields in Meenkara and Chulliar reservoirs in Kerala have increased from 9.96 to 107.7 kg/ha and 32.3 to 275.4 kg/ha, respectively, through sustained stocking. In Uttar Pradesh – Bachhra, Baghla and Gulariya reservoirs, registered steep increase in yield through improved management with the main accent on stocking. An important consideration in Gulariya reservoir was to allow maximum grow-out period between the date of stocking and the final harvesting, i.e. before the levels go below the critical mark. The possible loss due to the low size at harvest was

Table 11.7. High yields obtained in small reservoirs due to adoption of culture-based fisheries

Reservoir	State	Stocking rate (number/ha)	Yield (kg/ha)
Aliyar	Tamil Nadu	353	194
Tirumoorthy	Tamil Nadu	435	182
Meenkara	Kerala	1,226	107
Chulliar	Kerala	937	316
Markonahalli	Karnataka	922	63
Gulariya	Uttar Pradesh	517	150
Bachhra	Uttar Pradesh	763	140
Baghla	Uttar Pradesh	-	102
Bundh Beratha	Rajasthan	164	94

made good by the number. Bundh Beratha reservoir in Rajasthan, stocked with 100,000 fingerlings a year (164/ha) resulted in a fish yield of 94 kg/ha; 80% of which constituting catla, rohu and mrigal (Table 11.7).

Other forms of enhancement in small reservoirs

Although culture-based fisheries is considered as the most common form of fisheries enhancement, scope exists for other forms of enhancement such as 'species enhancement', 'environmental enhancement', 'enhancement through new production systems' and 'integrated production systems'.

Species enhancement and exotics: Decline of indigenous fish stocks due to habitat loss, especially that caused by dam construction is a universal phenomenon. All the major river basins have been affected, but the extent of such fish species loss is not assessed to any reliable degree. Planting of economically important, fast-growing fish from outside with a view to colonizing all the diverse niches of the biotope for harvesting maximum sustainable crop from them is species enhancement. The new species so inducted into the system could be exotic or indigenous. In case the fish is inducted to a place outside its normal range of distribution, the species is called 'exotic' and the act is called 'introduction'. Species enhancement in small reservoirs can be done either through inducting indigenous species or introduction of exotics; the latter is subject to the prevailing rules and regulations of the government (Box).

INTRODUCTION OF EXOTIC FISH SPECIES IN INDIA

In India, fish transferred on trans-basin basis within the geographic boundaries of the country is not considered as exotic and there are no restrictions on them. Thus, catla is not regarded as exotic to Cauvery or such other peninsular rivers. This is despite the fact that the species is outside its normal range of distribution and peninsular rivers have habitats, distinctly different from that of Ganga and Brahmaputra river systems. The small west-flowing drainages of the Western Ghats, the two large west flowing drainages, Narmada and Tapti, and a number of east flowing rivers of peninsular India, have ichthyofauna different from the Ganga and Brahmaputra river systems. Catla, rohu and mrigal have been stocked in the peninsular reservoirs for many decades now, with varying results. In some of the reservoirs in Southern India, they have established breeding populations. The hallmark of the country's policy on introductions is the heavy dependence on Indian major carps.

The country's policy on stocking reservoirs, though not very explicit, disallows the introduction of exotic species into the reservoirs. Despite this, several exotic fishes have found their way into Indian reservoirs and some of them have established as breeding populations, as the case of silver carp in Gobindsagar reservoir in Himachal Pradesh. Common carp is very popular in reservoirs of the northeast where it enjoys a favourable microclimate and a good market. Silver carp, grass carp and tilapia are not normally encouraged to be stocked in Indian reservoirs, though they are stocked regularly in a few small reservoirs of Tamil Nadu and the northeast. Recently, the more dangerous African catfish is being reported from more and more reservoirs in the country causing concern.

There is a case for examining the virtue of selective introduction of some exotic fish species in small reservoirs, which have no connections with the rivers, or those, which dry up completely in summer. However, such introductions should be made only after proper policy decisions are taken at the national level.

Environmental enhancement: Improving the nutrient status of water by selective input of fertilizers is a common management tool adopted in intensive aquaculture. However, a careful consideration of the possible impact on the environment is needed before this option is resorted to in reservoirs. It is generally believed that most of the lakes and reservoirs may have sufficient nutrient inputs and any excessive nutrient loading can lead to pollution. However, scientific knowledge to guide the safe application of this type of enhancement and the methods to reverse the environmental impacts, if any, is still inadequate. On account of these, this management tool is not commonly applied in India. China is known to have used this practice in a big way to augment production from small reservoirs. Cuba, taking a cue from China has tried manuring of small reservoirs using both organic and inorganic fertilizers. Thailand has also adopted this practice in a selective manner.

Fertilizers are less effective in soft water with total alkalinity < 20 mg/litre. Soft waters have inadequate carbon (usually in the form of carbon-dioxide and bicarbonate) for good phytoplankton production. Hence productivity can often be enhanced by applying lime to low alkalinity-impounded waters. The application of lime equivalent to 2,000 to 6,000 kg/ha calcium carbonate is generally sufficient to maintain total alkalinity above 20 mg/litre. Fertilization of reservoirs as a means to increase water productivity by abetting plankton growth has not received much attention in India. Multiple use of the water-body and the resultant conflict of interests among the various water users are the main factors that prevent the use of this management option. Surprisingly, fertilization has not been resorted to even in reservoirs, which are not used for drinking water and other purposes. Documentation on fertilization of reservoirs in India is scarce. Attempts to improve the plankton productivity of Vidur reservoir by the application of super phosphate gave highly encouraging results. As soon as the canal sluice was closed, 500 kg super phosphate with P_2O_5 content of 16 to 20% was applied in the reservoir when the water spread was 50 ha with a mean depth of 1.67 m. As an immediate result of fertilization, the phosphate content of water increased from nil to 1.8 mg/litre and that of soil from 0.242 to 0.328%. Similar improvements in organic carbon and Kjeldal nitrogen have been reported from soil and water phases on account of fertilization. Experiments were also conducted with urea in the same reservoir.

Application of lime was tried in some upland natural lakes for amelioration of excessive CO_2 and acidity at the bottom. This measure, together with the application of superphosphate in Yercaud Lake in Tamil Nadu, raised the *p*H of water from 6.2 to 7.3 and decreased the CO_2 in bottom water from 38 to 6.5 mg/litre. There was a corresponding increase in species number and biomass of plankton. Fertilization in Vidur reservoir resulted in a marked increase in benthic and plankton communities and doubling of the primary production rate. After two successive applications of fertilizers, significant limnological changes took place including the presence of free carbon-dioxide and decrease in *p*H and dissolved oxygen at the bottom layer of water. The methyl orange alkalinity increased from 44 to 108 mg/litre from the surface to bottom, indicating high organic productivity. Phosphate fertilization triggered the tropholytic activities mineralizing the organic matter and producing carbon-dioxide.

As a direct benefit from the fertilization, a 50% increase in fish production, along with three-fold increase in the size (average weight of catla, rohu, mrigal, *Labeo fimbriatus* and *L. calbasu*) were achieved.

Artificial eutrophication as a decisive management option was tried in India for the first time in Kyrdemkulai (80 ha) and Nongmahir (70 ha) reservoirs of the northeast by applying poultry manure (10 tonnes/ha), urea (40 kg/ha) and single superphosphate (20 kg/ha). Fertilization can play a key role in many small reservoirs of India, which require correction of oligotrophic tendencies. A number of reservoirs in Madhya Pradesh, the northeast and the Western Ghats receiving drainage from poor catchments show low productivity, necessitating artificial fertilization. Chinese experience in fertilizing small reservoirs for increasing productivity has been reassuring. In Shishantou reservoir, a management strategy comprising fertilization by organic and inorganic manures and feeding resulted in phenomenal production hike from 1,500 kg/ha to 6,000 to 7,000 kg/ha during 1985 to 1989. Before fertilization, the plankton biomass in Shishantou was 1.5 mg/litre, which was raised to 6.5 mg/litre through application of organic fertilizers at the rate of 6,375 tonnes/ha. The plankton biomass, after dropping during the peak precipitation period, picked up to 20.51 mg/litre during the post-rainy season months, with corresponding increase in fish production.

Integrated production systems

Small reservoirs are also amenable to integrated aquaculture since the culture-based fishery can be effectively combined with piggery, duckery and poultry rearing. Many of the waste products from these animal husbandry practices act as a fish food or fertilizer enabling higher stocking densities and fish yield. However, this approach has limitations from the aesthetic and hygienic point of view, especially when the reservoir is a source of drinking water supply. Sometimes, the littoral areas of reservoirs are used for agriculture, especially for farming of leguminous crops, which would add to the productivity of the soil. Such increase in fish production and rural earnings can make a significant contribution to the nutritional requirements of the rural community.

Stock enhancement in medium and large reservoirs

Fish production system in majority of medium and large reservoirs is based on the principle of enhanced capture fisheries (stock enhancement) as the essence of management strategy here lies in capture of self-sustaining stocks. This process involves heavy initial stocking, followed by conservation of habitat to allow natural breeding and recruitment, regulated fishing and supportive/corrective stocking whenever necessary. In such water-bodies, the main emphasis would be to build a breeding population that can support a sustainable catch on a regular basis without having to stock annually. At the same time, there is scope for stock manipulation through adjustment in fishing effort, observance of conservation measures and gear selectivity. Selective restocking can also be resorted for correcting imbalances in species spectrum and to fill the vacant ecological niches. It must be borne in mind that the area alone is not the criterion for determining whether stock enhancement is to be practised. A number of other considerations such as depth, predator pressure breeding grounds, habitat and fishability also come into play.

Under an enhanced capture fishery regime, fish productivity depends on a number of factors such as a conducive environment for primary production, a good food web (well balanced biotic communities structure that ensures good conversion of primary energy into fish flesh), self-sustaining fish stock(s) that contribute to high yield and good post-harvest and marketing arrangements. In other words, there is a need for an enabling habitat, good fish stock(s) and good post-harvest arrangements.

Various management processes involved in reservoir fisheries are:

- Environment management
- Stock management
- Fish stock monitoring
- Craft, gear and effort management
- Unconventional production systems
- Other management measures
- Harvesting and post-harvest management

Environment management

The main focus of environment management centres on: (*i*) a conducive habitat for primary producer organisms to flourish and produce carbon at a high rate, and (*ii*) maintain the habitat at optimal levels to suit the life-cycles of all organisms including fishes. In open waters, the harvestable biotic communities often belong to the nekton, which, in turn, is dependent on plankton, macrophytes or benthos. Any sensitive environmental parameters that adversely affect any of the component communities in the trophic chain are bound to affect the fish production. Thus, the capture fisheries management in reservoirs needs to be environment-friendly, aiming at conservation of the whole food chain.

Eco-degradation of reservoirs has been on the increase due to the rapid pace of industrialization, poor environment management in the catchment and a variety of other factors. Apart from the direct entry of industrial, municipal and thermal wastes, the pollution load carried by the upstream rivers is also accumulated in the reservoirs. The environmental degradation in reservoirs is caused mainly by the waste discharge from industrial, municipal and agricultural sources and the thermal power plants. High rate of siltation due to poor catchment management also affects the biological productivity. In many cases, the water quality of reservoir is influenced by the catchment area situated hundreds of kilometers away from the lake. For instance, soil erosion in the distant catchment areas lead to high sediment load and siltation in reservoirs, posing hazards to fish populations. The reservoir fisheries management therefore, entails protection of both terrestrial and aquatic ecosystems from environmental degradation.

The major habitat constraints that come in the way of effective reservoir management are siltation and pollution from thermal, domestic, agricultural and industrial sources. Excessive siltation leading to drastic decrease in the water-holding capacity and even damage to concrete hydraulic structures is a common problem in reservoirs. Apart from diminishing the water-holding capacity of the reservoir and shortening its life, siltation also affects the biota by blanketing the benthic and periphytic community. It also hampers the recruitment by destroying the breeding grounds and retards the overall productivity of the ecosystem. A number of reservoirs have been selected, of late, as sites for thermal power plants due to their dual utility as perennial source of water supply and disposal point for heated effluents and fly ash. The main ecological consequences of a hot-water discharged into the aquatic ecosystem are increase in water temperature, change in chemical composition and change in metabolism and life history of aquatic communities. Thick mat of fly ash deposited at the bottom bed over the years seal the nutrients away from the water phase and destroy breeding grounds of fish.

A number of reservoirs contiguous to towns and cities face threat from sewage pollution. Although from the fisheries point of view, organic loading within certain limits does not hamper the productivity, sewage load in excess can cause aseptic conditions, adversely affect the biotic communities, retard productivity and render the fish unfit for human consumption. Moreover, the problem needs to be addressed from public health and aesthetic points of view. Wastes emanating from industries such as chemical plants, textile mills, heavy engineering plants, paper mills, iron and steel factories and rayon are often dumped into the reservoirs causing hazards. Hazardous and toxic substances such as pesticides and heavy metals are also carried to the reservoirs through the effluents and the rain washings from the catchments. These substances are highly persistent and thereby contaminate the entire bio-geochemical cycle of static systems like reservoirs.

Stock management

Management of fish stocks in reservoirs entails maintenance of enough quality stocks in adequate numbers to sustain a fishery. This involves several steps such as: stocking; conservation the fish habitat including breeding, dwelling and feeding grounds; fishing gear and effort regulations; mesh regulations; closed season; regulations on exotic fishes

Stocking: Stocking is *sine qua non* for the reservoir fisheries for building-up stocks of fast-growing species in the ecosystem to colonize the diverse niches. It is important to stock the species that may breed and ultimately get naturalized in the system through autostocking. This is imperative to meet the long-term objective of obtaining a sustained yield. Management involving persistent stocking not only pushes up the input cost, such systems may also create many practical difficulties in raising the stocking material in adequate quantities.

The initial period of reservoir formation (trophic burst) is the right time to stock the desirable species into the reservoir. Heavy stocking with fast growing fishes on a short food chain is essential during this phase along with protection of breeding grounds. This will facilitate establishment of desirable species which converts primary energy into fish flesh at a more economic rate and in the reservoir. Any lapse in this important

management measure might lead to proliferation of undesirable species like minnows, which, in turn, become forage to predators, thus establishing a long food chain. There are many instances of establishment of such long food chains in India (Nagarjunasagar, Tungabhadra and Hirakud) which is difficult to reverse. These reservoirs harbour good standing crops of plankton and benthos, which are poorly converted into fish flesh.

However, naturalization of inducted species is quite often beset with many problems unless the species are selected with care. It needs to be ensured that the species stocked should find the habitat conducive to their biological and physiological requirements, they have an edge in the competition for food and finally, the environmental conditions favour their requirements of feeding, spawning and larval development. Recruitment failure due to the erratic hydrographic conditions that break the breeding rhythm have been found to be the single major factor responsible for the failure of stocked fishes to hold out in reservoir.

Selection of species for stocking: The principles to be followed in the selection of species for 'stock enhancement' are summarized below:

1. The species should have a fair chance of establishing itself as a naturalized population.
2. The species should find the environment suitable for growth and reproduction.
3. It should be quick growing, ensuring high efficiency in food utilization.
4. A fishery comprising herbivoures with a short food chain is preferable, as they have a better conversion of primary production to fish flesh.
5. Existing laws and regulations should not be violated and necessary clearance need to be sought for introducing species where applicable.
6. Seed should be readily available or can be raised in large numbers near the reservoir.
7. Cost of stocking and managing the species must be such that the operation becomes economically viable.

Fish populations in a newly impounded reservoir will be invariably too thin for the amount of fish food available in the system, leaving a void between carrying capacity and actual production of fishes. To fill this gap, there is a need to build a higher population density, which is achieved by addition of species to the original fish populations. In addition, information on differences, if any, in the growth rates of the endemic and stocked species, and the time taken by the stocked species in attaining harvestable size would provide insight into the production dynamics of the system. Both intra- and inter-specific competitions are to be considered in the stocking programme. Situations where two or more species use a similar resource such as food or space lead to overcrowding and poor growth rate.

Indian reservoirs, by and large, have a wide ranging representation of biotic communities. Phytoplankton comprising Cyanophyceae, Chlorophyceae, Dinophyceae and Bacillariophyceae dominate over the zooplankton such as copepods, cladocerans, rotifers and protozoans. Benthos is represented by insect larvae and nymphs, oligochaetes, nematodes and molluscs. There is a rich growth of periphyton on the submerged objects, but the large magnitude of water level fluctuations does not favour the establishment of aquatic macrophytic communities. Significantly, many of the above niches with the exception of insects, Cyanophyceae and molluscs are shared between Indo-Gangetic major carps, carp minnows and weed fishes, necessitating control on the latter two groups. The ecosystem-oriented management policy places due emphasis on trophic strata in terms of shared, unshared and vacant niches. As mentioned earlier, the two main pathways through which primary energy finds its way to fish flesh are the grazing chain and the detritus chain. Based on this fact, either plankton feeding or detritus feeding fishes are considered suitable for stocking Indian conditions (Figs 11.3, 11.4).

Today, reservoir fisheries in India largely centre on development of carp fisheries. Their unmistakable role has been demonstrated in the Gangetic as well as peninsular reservoirs. Major carps, by virtue of their feeding habits and fast growth rate are indispensable in reservoir management. However, the Indian major carps are ill suited to utilize phytoplankton, the most dominant fraction of plankton. Development of other endemic species as stocking material has not made much headway in the country although some of them have a proven track record in ensuring an efficient energy transformation rate. *P. pangasius,* subsisting on a molluscan diet is a species to be considered in the detritus-based, mollusc-rich reservoirs of the country. *Puntius pulchellus,* the peninsular species is a well-known macrophyte feeder and *Thynnichthys sandkhol* is reported to consume *Microcystis,* the common blue green alga in Indian waters. Diversification of stocking material is essential for establishment of a multi-species fish stock that utilizes all food niches of the ecosystem. In reservoirs, where annual draw down is not pronounced and water level fluctuations are not steep, phytobenthos and macrovegetation develop in various degrees. The grass carp, *Ctenopharyngodon idella* can be considered for such water-bodies. The common carp is being stocked in many reservoirs. This sluggish fish does not survive normally in the warm, deep-basin reservoirs of the south, especially when infested with predators. However, this prolific feeder could carve out a place for itself in the reservoirs of the northwest and northeast and in some of the peninsular reservoir like Krishnarajasagar.

Stocking rates: Amount of food available in the new environment has a considerable bearing in determining stocking rates and hence production. Fish production from unit area is a product of individual growth rate and population density. From a study of growth rate of various species in a particular body of water, it is possible to assess their optimal stocking density. The sizes of fingerlings that are stocked in Indian reservoirs come under the pre-recruit phase and so, up to the size of entering the exploited phase they are prone only to natural mortality. Therefore, a knowledge of the natural mortality rate is essential as due compensation can be provided for it while computing optimum stocking rates. While estimating optimum stocking rates for such populations, about which no reliable estimates of natural mortality are available, it is felt that assumption of higher natural mortality rate would be desirable as a little overstocking would be less harmful than understocking.

A number of methods are in vogue for calculating the stocking rate. Essentially, the number of fingerlings to be stocked is the total biomass to be harvested divided by the biomass of individual fish. However, as all fish stocked are not harvested, some addition will be needed to compensate for the possible stock loss due to mortality. A general stocking formula, which can be applied universally, irrespective of the size of the reservoir is given below. This is the most popular formula among the fishery managers as unskilled workers without any difficulty can estimate this. The fish yield rate can be estimated from the primary productivity studies. While estimating the percentage loss, chances of survival of the stocked fish in the light of predator pressure, escapement through the outsets and overfishing are to be taken into consideration:

$$\text{Stocking rate (no./ha)} = \frac{\text{Total yield (kg/ha)}}{\text{Individual growth rate of fish (kg)}} + \text{loss (\%)}$$

Fish stock monitoring

Experience in a number of medium and large reservoirs prompts us to conclude that stocking can be considered as successful only if the stocked fish survive, grow, breed regularly and their natural breeding contributes to effective auto-stocking. In some cases, despite persistent stocking, the transplanted species have failed to show up in the catch, thereby rendering the expenditure incurred in stocking as waste. This is primarily due to stock monitoring/management measures. It is essential to ensure that the stocked fishes grow to maturity and breed naturally and the juvenile achieve desired levels of survival so that the natural recruitment takes place. A number of measures are required for this. A standard stock assessment method needs to be used to monitor the population dynamics of the reservoir to monitor the stock. There should be restriction on fishing till the fish stocked in the first few years mature and breed in the reservoir. Other steps needed are: (*i*) protection of brood stock, (*ii*) protection of breeding grounds, (*iii*) protection of feeding grounds of juveniles, and (*iv*) enforcement of mesh regulations to prevent catching of young ones. Despite all this, there might be some reservoirs where stocked species will fail to establish.

Initial stocking: It is very essential to continuously monitor the fish stock in the reservoir to make appropriate decisions. Standard population dynamics models are available for this purpose. During the initial 2-3 years, there should be heavy stocking and restricted fishing activity to allow the stocked fish to grow to adult size and breed. During this period, gear that target stocked fishes should be banned altogether, but the gear for predators and other uneconomic species can be allowed.

Protection of breeding and feeding grounds: Fish species have diverse breeding habits. The Indian major carps are known to migrate to the breeding grounds situated upstream. Tilapia makes nest at the littoral zone and common carp breeds on aquatic vegetation. Indian major carps migrate to the breeding grounds upstream through narrow shallow streams they become easy prey for fishers. These brooders need to be protected while moving to and at the breeding grounds to allow them to complete the breeding. Similarly, the juveniles flock the shallow areas and fishing should not be in such places. In stock enhancement, the breeding population is established during the early phase of management. However, need for stocking might arise whenever there is a breeding failure or when stock is lost due to monsoon failure, flooding of spillways etc.

The following are the essential aspects of successful enhanced capture fisheries:

- The right species should be selected for stocking.
- Stocking should be done heavily for a few years during the early phase of reservoir formation (during trophic burst stage).
- Fishing should be restricted during the first few years after stocking to allow the stocked fish to mature.
- Breeding and feeding grounds should be protected.
- Catching of broodstock and juveniles should be prevented through appropriate measures.
- Stock assessment should be done through standard population dynamics modeling.
- Supportive restocking should be done when breeding failure or stock loss occurs.
- The community should be organized into highly motivated and empowered group so that they can manage the resource effectively.
- Necessary marketing and financing channels should be provided in order to protect the fishers from unscrupulous money lenders and middlemen.

Aspects of reservoir fisheries in India: Other aspects of fish stock monitoring are discussed here.

Seed production infrastructure: Stocking is the key to success in both culture-based as well as stock enhancement regimes. Most of the instances of low yield from reservoirs in India can be attributed to non-compliance of stocking size and numbers. The established carp seed industry in the country caters largely to the aquaculture sector and the huge demand from reservoirs often remains unmet. This calls for creating an adequate supply chain for fingerlings for stocking in reservoirs. In areas where large numbers of small reservoirs are taken up for development, a cluster approach would be ideal and also cost-effective. Wherever land-based nurseries are not available, pen and cage culture for *in-situ* raising of seed material would be most desirable.

Unplanned stocking: The Indian experience of stock enhancement has been very revealing. The Indian rivers are known for their rich faunistic diversity and many of the native species are considered to be superior to the introduced ones in their growth performance. Still, almost all reservoirs are routinely stocked with Indian major carps. While there are some instances of successful transplantations where the stocked species established good breeding populations in the reservoirs leading to increased yield rates, in many cases, stocking attempts were rarely governed by any ecosystem considerations. These irrational stocking efforts were not only wasteful exercises, but they also proved to be detrimental to the native fish stocks from the conservation and yield optimization points of view. The policies adopted in Indian reservoirs mainly consist of stocking fingerlings of a species or a combination of species without giving any consideration for the purpose of stocking. No criteria are followed in respect of stocking rates, species mix based on the biogenic capacity of the reservoir and without any follow-up to achieve establishment of naturalized populations. On many occasions, the main consideration for rate of stocking and the species selection is the availability of fingerlings.

Crafts and gear

Crafts: Coracle, a saucer shaped country craft, is the major fishing craft used in the reservoirs of peninsular India. It is made of a split bamboo frame, covered with buffalo hide. Apart from being simple and inexpensive, coracle is durable and has very good manoeuvrability in choppy waters. It is also a versatile craft used for laying and lifting of nets, besides navigation and transport of fish and other material. Coracles of Krishnarajasagar are prepared by wrapping HDPP over the bamboo frame with the help of coal tar as an external covering in place of hide. This modified version of coracle is cheaper and more durable.

Unlike Gobindsagar, where all the fishermen posses their boats, reservoir fishermen, in general, are too poor to own boats. In many reservoirs like Vallabhsagar and Hirakud, the fishermen could get their boats with the help of subsidy and other financial assistance from the Government or funding agencies. In Vallabhsagar, boats are distributed by the State among the fishermen at a subsidy of 50 %, while in Hirakud, they get it from various schemes under NABARD and NCDC. Wooden boats are used for fishing in a number of reservoirs, especially in north India. Flat bottomed, locally fabricated boats ranging in length from 3 m to 7 m are used in Kyrdemkulai, Hirakud, Malampuzha, Gobindsagar, Gandhisagar and Rihand. A plank-built, flat-bottomed canoe, 2 m to 3 m in length is the most popular fishing craft of Gandhisagar. In the same reservoir, the repatriates from the erstwhile East Pakistan used the Bengal type dinghy, which is 5 m to 7 m in length and have the additional facility of setting sails for wind propulsion.

Mechanized boats are not used in reservoir fishing in any appreciable extent. A 9.1 m long wooden, mechanized boat has been introduced by the Central Institute of Fisheries Technology (CIFT) in Hirakud reservoir, but they are too expensive for the fishermen. It is significant to note that large water bodies like Nagarjunasagar, Tungabhadra and Krishnarajasagar have no motorized craft neither for fishing nor for fish transport.

Dugout canoes, carved out of palm trees are used in Yerrakalava reservoir. In most of the reservoirs in the country the fishermen rely on improvised materials. Reservoir fishermen show considerable ingenuity in fabricating makeshift rafts out of discarded old tyres, logs, used cans, etc. In a vast majority of Indian reservoirs, where the catch is not very remunerative, no boats are used and the fishermen depend entirely on these improvised devices.

Gear: The presence of underwater obstacles restricts the use of active gear in reservoirs and the choice is often limited to passive gear such as simple gill nets. The most common among them is the *Rangoon* net, an entangling type of gill net without a footrope. Another entangling type of net used in reservoirs is *uduvalai*, which has a reduced fishing height and is usually operated in shallow marginal areas to catch small fish. Shore seines of various dimensions and mesh sizes are employed in many reservoirs. Although a number of other fishing gear such as long lines, hand lines, pole and line, cast nets, dip nets, etc. are in use, their contribution to the total catch is very insignificant.

Unlike the marine fisheries, very little attention has been paid over the years towards improvement of gear in the inland sector, barring an attempt to upgrade the reservoir fishing gear by two experts under the aegis of FAO/ UNDP programme during 1960s. A number of improvements have been suggested by the experts to the fishing techniques followed by the reservoir fishermen. Apart from the introduction of frame net, they have suggested improvements on the design of gill nets, beach seines and long lines. Unconventional methods such as electrical fishing, use of light as fish lure, the use of echo-sounder for fish detection and survey of bottom topography were also suggested. The main emphasis of gear improvement was the modification of gill nets. Russian experts designed two nets, viz. Sebgul I and Sebgul II, which were gill nets with modified rigging pattern. While ensuring a proper fixing of webbing on head and foot ropes, a uniform hanging coefficient was ensured. Similarly, the sideways movement of the webbing was checked to maintain effective area of the net. Experiments were conducted in Bhavanisagar reservoir to check the efficacy of the new design and no appreciable superiority was found for Sebgul nets over the *Rangoon* nets.

The CIFT, Kochi has experimented with gill nets of various colours and found yellow and orange colored nets yielding better catch than the white coloured ones. It has been observed that 77% of the carps were caught by entangling and the rest by gilling. The usual method of increasing the entangling capacity of gill net is by decreasing the slackness of webbing which can be achieved by suitable modifications in the hanging of the net. Gill net being a highly selective gear, its sustained use can lead to serious distortions in fish populations. For instance, selective removal of carps by the gill nets can result in situations leading to domination of carp minnows, predators and other undesirable fish.

Trawling: Trawling has been attempted only in two reservoirs, viz. Gandhisagar and Hirakud. The findings with regard to species selectivity of different type of trawling indicate efficacy of various types of trawling in increasing the productivity of commercial carps and checking the predator and weed fish populations. After experimental trawling with single-boat bottom trawling, two-boat bottom trawling and two-boat mid-water trawling under different speeds, it has been found that more than 92% of the total catch consisted of economic species of fishes such as catla, rohu, murrels, mullets and featherbacks in two-boat mid-water trawling. This was in sharp contrast to the bottom trawling, of both single boat and two boat variety, which yielded mostly (64 to 91%) the non-commercial species of fish. The two-boat mid-water trawling at a speed of 3 to 4 knots have been recommended for exploitation of commercial species and single and two-boat bottom trawling 2 to 3 knots for eradication of uneconomic species of fishes.

Unconventional production systems

Cage and pen culture: Production systems, such as cage and pen cultures are becoming increasingly popular in India, although they have a definite role to play in augmenting fish production from open water, especially the reservoirs. It is now widely accepted that the pen enclosures erected in the reservoir margins can be used as nurseries

to raise stocking material to obviate the necessity for constructing land-based nursery farms, which are cost-intensive. Similarly, the rearing of fish in pens up to marketable size enables easier stock manipulation and total harvesting. In case of some hardy species such as common carp and tilapia, cages can also be used for raising stocking material. However, non-standardization of farm practices and the materials to be used in cage and pen culture still acts as a major retardant for large-scale adoption of these culture systems in Indian reservoirs.

Species selection: Main criteria for the choice of candidate species for cage and pen culture are discussed here:

- Fast growth rate,
- Adaptability to the stresses in enclosures due to crowded conditions,
- Ready acceptance of artificial feeds consisting mainly of cheap agricultural byproducts,
- High feed conversion rates,
- Resistance to diseases, and
- Good market demand.

Under the Indian conditions, the Gangetic major carps (*C. catla, L. rohita, C. mrigala*), murrels, the Chinese carps (*Hypophthalmichthys molitrix, Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) satisfy these requirements to a great extent. Selection of species, however, is mainly dictated by the local demands and availability of quality seed and other inputs in adequate quantities.

Site selection: Appropriate site selection is important for successful use of pens and cages. Sheltered, weed-free, shallow bays are the ideal locations for installing pens and cages. The sites should have adequate circulation of water with wind and wave action within moderate limits. Water level fluctuation is the most important consideration in site selection for the pen culture operations in reservoirs. A scrutiny of the contour map and the monthly fluctuation patterns of reservoir levels will enable the location of suitable sites which retain sufficient water for the required period of time. Sites which dry out during summer will be ideal, as it is easier to erect pens on dry land, to be inundated later as the water level increases. Similarly, some bays of the reservoir retaining water for sufficient period can be identified and cordoned off by erecting barricades.

Floating fish cages can be constructed out of a variety of materials including metal, wood, bamboo and netting. Fairly fine-meshed nylon netting can be used for nursery purposes. Cages made of monofilament woven material of 1.0 mm to 3.0 mm mesh size are light and easy to handle but these last only for six months to one year, depending on their thickness. Knotless nylon webbing of 3 mm to 6 mm mesh size and knotted nylon webbing of 7 mm to 15 mm mesh have been found to be very durable as cage material. A battery of cages can be buoyed up within a bamboo catwalk, which will serve as a working platform, floated by sealed empty barrels. Circular and box-like cages of varying dimensions on conduit pipe structures, which can be easily assembled, and suitable flotation systems have been designed in India. Similarly, self-floating cage with HDPP pipe structure has also been experimented with success.

Pen culture has a special relevance in reservoir management, since it has been widely recognized as a means to rear, *in situ*, the fingerlings for stocking. The number of fingerlings required for stocking the reservoirs in the country is so enormous that it is impossible to raise all of them in land-based nursery farms, which makes pen nurseries *sine qua non* for reservoir management. Nevertheless, pen culture on a regular basis has not been practised anywhere in India except at Tungabhadra reservoir. The factors that hamper the standardization of pen culture technique are:

- the steep level fluctuations,
- wind and wave action,
- lack of suitable pen materials,
- weed infestation and the related harvesting problems, and
- non-synchronization of suitable water levels and the spawn availability.

The water retention time is important, since the rearing has to be completed before the water level in the pen goes down the critical limit. In reservoirs with high draw down, the water retention time is very limited. Sometimes the filling takes place so late that no spawn of desirable carps will be available when the water level attains the desirable limit. Recent advances made by research institutions to breed fish for protracted time give hope for solving this problem. The pen walls limiting the water circulation to some extent, the accumulated feed and fertilizers cause eutrophication leading to weed infestation fouling of water and fish kills.

Other management measures

Pre-impoundment surveys: In India, pre-impoundment surveys conducted during dam construction invariably lack a fisheries perspective. However, in case of river Narmada, the Narmada Control Authority has conducted a socio-economic survey of the Narmada basin with the objectives of addressing fisheries development in the reservoirs created by the impoundment of the river and its tributaries.

The pre-impoundment surveys help providing a framework for future fisheries and other development activities in the reservoir, which *inter alia* encompass the following aspects:

- The native ichthyofauna in the river stretch above and below the dam, and their likely chances of survival,
- Breeding habits of fishes and the possible impact of impoundment on their recruitment,
- Survey of breeding grounds in relation to submergence, both above and below the dam,
- Hydro-biological characteristics of water and soil with special emphasis on the nutrient and thermal regime,
- Assessing the needs for creating infrastructure such as, hatcheries, nurseries, ice plants, etc.,
- Site selection for pen nurseries, cages, etc.,
- Possibilities for cleaning the area of submergence of trees and other obstructions,

- Inventory of fishing villages, together with demographic details on fisher population and fishing craft and gear.

The following account deals with some of the important pre-impoundment activities:

Timber clearance: Opinion is divided on the wisdom of removing timber from the reservoir bed. While it is mostly appreciated that a reservoir bed free from obstructions facilitates the use of active fishing gear and leaves room for many other management options, many workers feel the necessity to leave at least the non-commercial timber intact for a variety of purposes such as, reducing wave action, flocculating the colloidal clay turbidity, providing habitat for fishes and substrata for periphyton deposition. Timber clearance has been tried in a number of reservoirs in India, both before and after the impoundment. In Chillar and Benisagar reservoirs of Madhya Pradesh, trees were cut from the lake bed and auctioned before the reservoirs were filled. Harsi, Jamoia and Ghatera reservoirs are examples of complete clearance of datepalm trees from the marginal areas during the summer months. Forest area of about 61.4 km^2 was cleared in Hirakud, when the bed was exposed during draw down. Clearance of forest has also been undertaken in many of the impoundments created under the Narmada River Basin Project.

The need for timber clearance is largely dictated by the cost of such clearance and also the needs of the major users of the impoundment. In the post-impoundment stage when fisheries development is normally planned, the fishery managers should make a careful assessment of the status of timber clearance from the reservoir and take appropriate decisions with regard to the deployment of the gear. Since gill nets are the predominant gear in Indian reservoirs, the timbers, if even left uncleared would not impede the fishing activities. The only obstructions that the gear would encounter would be during shore seining, if at all practised for removal of minnows and weed fishes.

Removal of predators and weed fishes: Presence of predatory and weed fishes poses impediments in survival and growth of economic species in many Indian reservoirs. Keeping these unwanted populations under check is a very difficult management problem, especially in large reservoirs. A small population of predators helps to crop the trash fishes, which compete for food with the economic species. However, no scientifically sound methods are available to keep a limited population of predatory species. Repeated use of gill nets of appropriate mesh size, use of long lines, traps, etc are suggested for control of the uneconomic and undesirable populations.

Manipulation of reservoir level with a view to checking the breeding and destruction of the young ones of predators and the minnows has been tried in several countries. However, this is not practicable in many Indian reservoirs since water release pattern is dictated by priority sectors like irrigation and power generation. Poisoning of selected sheltered areas, arms and coves as practised in some other countries has also limited use in India due to the multiple uses of water and objections from the other water users. *Alivi*, the giant shore seine of Tungabhadra has been successfully used to remove trash fish in large numbers. Judicious use of this gear, with a condition that the juveniles of economic species are released back, can go a long way in containing the trash fish population.

Recent findings with regard to the efficacy of trawling in checking predators and trash fishes are of interest. Bottom trawling in Gandhisagar was found to catch 64 to 91% of the unwanted fishes and this has been recommended as a method to crop the predators and carp minnows. Nevertheless, applicability of this method is limited to places where the bottom is free from obstructions.

Exotic fishes and their role in the reservoir fisheries: In spite of an already rich and diverse fish genetic resource of India, more than 300 exotic species have been introduced into the country so far. While a vast majority of them are ornamental fishes, which remain, more or less, confined to the aquaria, some others have been introduced in aquaculture and open water systems with varying degrees of success. *Oreochromis mossambicus, Hypophthalmiichthys molitrix, Ctenopharyngodon idella, Cyprinus carpio communis, C. carpio specularis* and *C. carpio nudus* have gained entry into the reservoir ecosystem through accidental or deliberate introduction. Among them, tilapia, silver carp and common carp could make a negative impact on the fisheries in various reservoirs in the country. Impact of the recently introduced African catfish (*Clarias gariepinus*) is yet to be assessed.

Tilapia: The tilapia *O. mossambicus* was first introduced into the pond ecosystem of the country in 1952 and soon it was stocked in the reservoirs of south India. By the end of 1960s, most of the reservoirs in Tamil Nadu and those in the Palakkad and Trissur districts of Kerala were regularly stocked with this fish. Performance of tilapia in ponds of south India has been discouraging mainly due to its early maturity, continuous breeding, over-population and dwarfing. It is reported to mature at 6 cm length at an age of 75 days and to breed at an interval of one month under the tropical conditions. The warm waters of the tropical reservoirs in India have provided a conducive habitat for the tilapia and it has established a secured position in a number of south Indian reservoirs. The fears of its stunted growth have been allayed as the average size of tilapia did not decline as much as it did in ponds. Size of tilapia in the commercial catches of reservoirs has been very good, as opposed to the unmarketable size reported from the ponds. The average size of tilapia from Tamil Nadu reservoirs has been 1.5 kg during 1960s, with the minimum size of 500 g. Similarly, tilapia weighing 2.5 kg was very common in Malampuzha reservoir, Kerala during 1960s, with an average size of 1.5 to 1.75 kg. The present size of 0.5 to 0.7 kg in Malampuzha and 0.68 kg in Tamil Nadu reservoirs are well within the limits of market preference, their continuous slide in size over the years is a cause of concern as it is feared that if the fall in size continues, it may become unmarketable.

Tilapia has dominated and virtually eliminated all other fishes including the stocked Gangetic carps in a number of reservoirs in Tamil Nadu. Vaigai, Krishnagiri, Amaravathy, Uppar and Pambar reservoirs in Tamil Nadu are harboring sizeable populations of tilapia since 1962, contributing substantially to commercial catches.

Silver carp: Silver carp (*Hypophthalmichthys molitrix*) was introduced in India in 1959 and unlike tilapia, it has not strayed into many reservoirs. However, silver carp has attracted more attention from the ecologists and fishery managers, generating a more animated debate. Importance of silver carp in reservoirs emanates mainly from:

- its reported ability to utilize *Microcystis*
- the impressive growth rate, and
- its propensities for affecting the indigenous species, especially *Catla catla.*

The most spectacular performance of silver carp has been reported from Gobindsagar reservoir, where after an accidental introduction, the fish formed a breeding population and brought about a phenomenal increase in fish yields. Silver carp is instrumental in enhancing the fish production from the reservoir from 160 tonnes in 1970-71 to 1,200 tonnes in 2000. Many workers have suggested the over-intensity of feeding in respect of silver carp, as reflected by the gorged and full conditions of gut all through the year. Silver carp, being a cold-water fish, when introduced into a warm regime, consumed food much in excess and grew faster as expected of a true poikilotherm. A similar latitude-induced change worth noticing is the age at maturity. The fish mature when they are five to six years old in North China, four to five years in Central China and two to three years in south China. In India, it breeds just at the age of one year under optimum conditions.

It is significant to note that despite its entry into a number of Indian reservoirs, by accident or otherwise, silver carp failed to get naturalized anywhere except Gobindsagar. Considering that the reservoir, with its temperate climate, is closer to the original habitat of the fish and has a distinctly cold water hypolimnion due to the discharge from Beas, the silver carp seems to have found a congenial habitat for growth and propagation. Although introduction of silver carp was never cleared by the Committee of Experts constituted by Government of India, the fish is being stocked in a number of reservoirs in the country. Nowhere did the fish make an impact as it did in Gobindsagar. Therefore, fears regarding the threat of extinction of catla from the Gangetic and peninsular India posed by silver carp are perhaps misplaced.

Common carp: The three varieties of the Prussian strain of common carp, viz. the scale carp *(Cyprinus carpio communis)*, the mirror carp (*C. carpio specularis)* and the leather carp *(C. carpio nudus)* were introduced in India during 1939. They were stocked in several high altitude ponds and lakes during 1950s. Later, in 1957, the Chinese (Bangkok) strain of the common carp was brought into the country, primarily for aquacultural purposes, considering its warm water adaptability, easy breeding, omnivorous feeding habits, good growth and hardy nature.

Like tilapia, common carp soon found its way to all types of reservoirs in the country. Relative ease at which the fish could breed in controlled conditions prompted the departmental fish farms throughout the country to produce the seed of common carp in large numbers and to stock them in the reservoirs. However, such stocking attempts were devoid of any ecological reasoning. The Bangkok strain of common carp has been stocked in a large number of reservoirs in the plains and European strain was introduced in the reservoirs of temperate zones and high altitudes. But their performance in reservoirs is erratic, despite heavy stocking.

Common carp is not a suitable fish for stocking in Indian reservoirs, especially the larger ones, for diverse reasons. Being a sluggish fish, its chances of survival in a predator-dominated reservoir are very poor. They are not frequently caught in a passive fishing gear like gill net, due to its slow movement and bottom dwelling habit. It is no wonder, despite a regular stocking for 13 years (involving 537,000 fingerlings), not a single common carp was ever caught from Nagarjunasagar. Obviously, the stocked fishes failed to survive among the marauding predators. This has been the fate of common carp stocked in all the deep reservoirs, with a few exceptions such as Krishnarajasagar. A more important disqualification is its propensities to compete with some important indigenous carps like *Cirrhinus mrigala, C. cirrhosa* and *C. reba* with which common carp shares food niche. Instances where the presence of common carp has resulted in the decline of *Cirrhinus* sp. are available in Girna and Krishnarajasagar.

The mirror carp has a dubious distinction of jeopardizing the survival of a number of native fish species, after its introduction in some of the upland lakes of Kumaon Himalayas, the Dal Lake in Kashmir, Gobindsagar and the reservoirs of the north-east. In the Dal Lake, common carp found a favourable environment by virtue of the shallow lake basin, extensive submerged vegetation, and rich food resources. By virtue of the specific ecological advantage, the fish propagated itself profusely to the peril of indigenous snow trout like *Schizothoraichthys niger, S. esocinus,* and *S. curvifrons.* The snow trout had the twin disadvantages of low fecundity and the stream breeding behaviour. Mirror carp has caused similar damage to the snow trout in Gobindsagar reservoir and *Osteobrama belangeri* in Loktak Lake of the northeast. Analogy of events related to the common carp and snow trout sends out enough signals regarding the potential harm the former can do to the ichthyofauna in the plains.

Economic and social dimensions of reservoir fisheries: Reservoir fisheries development has some interesting economic and social dimensions which deserve a mention. Producing 1 million tonnes of fish from aquaculture entails high investment in the form of pond preparation, feed, seed, medicines, labour and other inputs, apart from heavy demands on water, a resource which is becoming increasingly scarce day by day. Developing 1 ha of fish pond will cost ₹ 2 to 3 lakh, in addition to other inputs. At an average yield of 2 tonnes/ha (as obtained under FFDA ponds) producing 1 million tonnes of fish from aquaculture ponds will cost a formidable ₹ 10,000 crore only for pond digging, leave alone other inputs. Conversely, increasing yield from reservoirs cost virtually nothing. The only expenditure involved is stocking, which is very negligible, as opposed to the heavy capital investment required in aquaculture. There is also a social dimension of reservoir fisheries development. The profit obtained in aquaculture ventures accrues to an entrepreneur, investor or a group of individuals as 'return on investment'. On the contrary, the benefits due to increased fish production obtained in the reservoir (under a good governance regime), are shared by a large number of fishers, the key stakeholders. There is this large cake and each stakeholder gets a slice, albeit small. Thus, the reservoirs provide opportunities for inclusive growth, which is economically sound and socially justifiable.

Post-harvest and marketing arrangements

Inadequate marketing channels and marketing infrastructure also act as disincentives for the community to produce more fish, as small reservoirs are mostly located in hinterlands away from main markets. Therefore, accessing markets is an essential pre-requisite for the success of small reservoir fisheries. The emerging new retail marketing opportunities in India can be suitably utilized to the advantage of fishers. Proper arrangements, including post-harvest processing and value- addition will go a long way in improving production, and these aspects need to be integrated into the management/processes. Similarly, collective arrangements for marketing can give producers greater bargaining power and the setting up of more cold-chains, wherever required. The emerging marketing opportunities and consumption pattern in the country, especially the supermarket culture, can be suitably utilized to the advantage of fishers. Proper arrangements including post-harvest processing and value-addition will go a long way in improving production and these aspects need to be integrated into the management/development process.

Ownership of fishing rights and policy support

Ownership of reservoirs does not always vest with the Fisheries Department and in many cases, it has no access and authority to manage the fisheries in reservoirs. In an ideal situation, even if the reservoir is owned by other Departments, at least the fishing activities should be within the purview of the Fisheries Department of the respective State Governments. The DAHDF and NFDB can take a lead in persuading the States to follow a common policy on this issue. The State Fisheries Departments need to shift from a 'revenue generation' approach to a 'development approach' and similarly, the enforcement (command and control) approach should give way to a participatory (co-management) approach. Stocking should be the responsibility of the community that manages a reservoir and the focus of the State agencies should be to encourage/enable/empower them to undertake this responsibility. The role of government agencies/NFDB shall be to facilitate/promote/ demonstrate the process of stocking and provide incentives in the form of initial seed money/revolving fund or soft loan. The process of stocking by the Fisheries Departments should be discouraged. The need is to create a demand for fish seed from the reservoir sector, which the fish seed industry can meet. Outsourcing and contract seed rearing on 'buy back arrangements' are also worth trying.

The challenges

There are a number of challenges that need to be overcome while trying to realize the production potential of the reservoirs. These can be summarized under two broad categories, viz. Technology challenges – the poor application of scientific management tools, and Governance challenges–the lack of enabling environment.

Technology challenge: Technologies for developing reservoir fisheries are relatively simple and do not demand very high technical skill. These can be applied by anybody with some basic management skill and normal intelligence. Still, the rate of adoption of scientific advice for reservoir fisheries is very low, and most of the man-made lakes in the country are still being managed on a very arbitrary manner, leading to low productivity. Many things need to be done to correct the situation. For starters, one has to decide on the appropriate fishery management system to be followed in a particular reservoir. Very few people understand the fish production processes as applied to reservoirs. Some considers reservoir as a capture fishery resource and some others believe this is culture fisheries, but in fact it is neither. A range of 'enhancement' practices are to be followed depending on the conditions available at the reservoir. Selection of the right management practice holds the key for success. Fisheries management of reservoirs is best explained as 'enhancement', which is defined as a 'range of practices/processes by which qualitative and quantitative improvement is achieved from water bodies through exercising specific management options'. This is something intermediate between culture and capture fisheries.

Governance challenge: As mentioned above, it is not the complexity of technology that comes in the way of achieving higher production from Indian reservoirs, but it is often the lack of appropriate governance arrangement that prevents development. The reservoirs in India are common property resources, generally managed based on community activity. Thus, organization of the community that manages the system plays a key role. Quite often, on account of inadequate awareness, empowerment and motivation, the community remains incoherent and disorganized whose members at times act at cross purposes. This not only weakens their ability to negotiate with the other sections of the society, but also make them easy prey to the unscrupulous elements like money lenders and middlemen. This is the bane of reservoir fisheries throughout the country. In isolated pockets, where the community is well organized and works under good institutional support in the form of effective cooperative societies, Self Help Groups (SHGs), etc., very high yield and equitable distribution of profit are reported.

Organization of community: A well motivated community is *sine qua non* for successful management of enhanced capture fisheries. This is due to the fact that the stock management can be done only through participatory approach and not through enforcement under a 'command and control' regime as being done now. The reservoir fisheries will be successful only when the community that fishes in the water-body is under a sound governance set up and the community owns and manages the fish stock. Co-management, where the representatives of the community and government take part in decision making process, is the most ideal for the reservoir. All stakeholders should take part in the decision making process and the benefits accrued by implementing improved scientific norms should be equitably shared by all stakeholders. The State (the State Government, Local Self Governments, National Fisheries Development Board (NFDB, etc.) has to play a pivotal role in improving the governance systems of reservoirs by providing an enabling policy environment for this purpose. In the absence of sound policy support for reservoir fisheries sector, the availability of public finance is also limited. Once this problem is addressed, there may be enough money to create the right infrastructure and to loosen the hold of usurious moneylenders on the reservoir fisher's community. To summarize, the major governance challenge in reservoir fisheries is the lack of:

- appropriate community organizations,

- institutional arrangements, and
- an enabling policy environment

Resolving the governance issues, together with creation of market infrastructure and post-harvest processing, all under an enabling policy environment, will trigger the process of increasing fish production from reservoirs.

The way ahead

Reservoirs, for sure, are a major fishery resource, but they remain highly dispersed under a plethora of control regimes with very weak governance and policy support. It is an uphill task to bring all the reservoirs under a proper fisheries management framework due to a multitude of challenges as explained above. A national action plan embracing the following aspects is essential to plan and execute such a mammoth task:

- To begin with, all reservoirs in the country need to be brought under a GIS-based inventory database. For this purpose, some existing anomalies (in some States) on definition of the reservoirs need to be resolved.
- The reservoirs need to be identified based on their morphometric, edaphic and biological characteristics in order to choose the best management strategy including the suitable target species.
- Depending on the above characteristics, management decisions such as stocking requirements, seed production options, development of enhanced capture fisheries norms, need for HRD and empowerment, etc. can be determined.
- All these are fed into a computer-based management system that generates advice for the policy-makers at macro-level as also for the reservoir managers at a micro level.
- A cluster approach will be ideal for developing seed production infrastructure, market links, marketing infrastructure and centres for processing and value-addition.

Strong policy support at the national and State levels is essential for realizing higher productivity in reservoir fisheries. Fisheries being a State subject, action for creating such policy environment is eventually the responsibility of State Governments.

Nevertheless, DAHDF and NFDB can build capacity in the States and act as facilitators for creating policy guidelines.

The reservoirs of India can produce much more fish than what they do today. The resources remain highly scattered and under various policy/control regimes. The governance arrangements of these community-based resources are not effective, which account for most of the maladies. The guiding philosophy of reservoir fisheries should be to ensure that the fruits of increased production should percolate down the communities that include traditional fishers, local communities and sometimes the rehabilitated oustees. Private public partnership (PPP) is welcome, but while engaging private players, the interest of fisher communities should be protected. Government also has the responsibility to ensure that national policies on environment and exotic species are not violated. What needs to be done include:

- utilizing all available scientific advice on the subject,

- building capacity in the States,
- guiding the State players to bring reservoir fisheries under a common policy framework for development, and
- creating a development vehicle that facilitates and coordinates action plans and ensures production, processing, value-addition and marketing of fish.

It is an uphill task, but well within the realm of possibility through concerted action.

12. Floodplain Wetland Fisheries

Wetlands are dynamic ecosystems and are among the most precious natural resources on earth. Roughly 12% of the earth's surface is covered by wetlands; of this 15% is under 'floodplain wetlands'. Wetlands that are situated along the floodplains of rivers are called floodplain wetlands. Low gradients, floods and tectonic activities in river basins contribute to the genesis of these water bodies. High fluctuation in water level is an inherent characteristic of these ecosystems. The dynamic ecological character caused by the cyclic changes in the hydrology and morphometry, water chemistry and sediment characteristics leads to growth of unique faunal and floral associations. These biological communities are adapted to spatial and temporal changes in environment, leading to high degree of biodiversity; hence are considered as biologically sensitive habitats. They play a vital role in the recruitment of fish populations in the riverine ecosystems and provide breeding, nursery and feeding grounds for several commercially important fish species. In India, floodplain wetlands are conspicuous features along the Ganga, Brahmaputra and Barak river basins, where these water-bodies support livelihood to thousands of people through collecting edible plants, agriculture, water transport, irrigation, subsistence and commercial fisheries, besides harbouring rich biodiversity. These wetlands provide opportunity for high level of economic activities, particularly fisheries, in India's eastern and north-eastern states like Uttar Pradesh, Bihar, West Bengal, Asom, Arunachal Pradesh, Meghalaya, Manipur and Tripura. These valuable natural resources contribute immensely to the country's food basket through fisheries. They are part of cultural heritage and are being used for sport and recreation, thus playing vital role in the social fabric of these states. Floodplain wetlands vary widely in size, shape and the extent of riverine connection, offering tremendous scope for expanding fisheries if managed scientifically. However, majority of these water-bodies are currently reeling under environment perturbation, swampification, shift in species spectrum and anthropogenic threats, adversely affecting their productivity. This could threaten the long-term sustainability of the ecosystems and contribution of their fisheries to food supply. Hence, rational management, conservation and careful monitoring are needed to sustain this vital resource, their ecology, fishery and biodiversity; both in terms of sustainability and economic value. This chapter attempts to bring out the current status, ecology, fisheries and fish production potential of floodplain wetlands in India and their management strategies with policy issues.

Definition

The term 'floodplain' includes the flat lands bordering rivers and streams that are subjected to periodic or permanent flooding, which tend to be most expansive along the lower stretch of the river. The excess water, the river channel cannot handle at various times is spread on to these floodplains. The term 'wetlands' comprise varieties of aquatic habitats with unique characteristics. Under the 'Ramsar Convention' 1971, 'wetlands' are defined by Articles 1.1 and 2.1. The article 1.1 provides that "wetlands are areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters". The article 2.1 provides that wetlands "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water not deeper than six meters at low tide lying within the wetlands". This definition gives us a broad view, including virtually all types of fresh and brackish water-body, whether static or flowing and some parts of sea as well. Water regime and macrophyte communities are the major driving force influencing ecological status and productivity of wetlands. In India, wetlands are distributed from cold arid zone of Ladakh to coastal zone of maritime states, therefore they are classified according to their location (coastal and inland), topographical location (upland and lowland), origin (natural and manmade), water retention period (perennial and seasonal), ecological status (oligotrophic, mesotrophic and eutrophic), water quantity (deep and shallow), water quality (freshwater and saline), thermal regime (coldwater and warm water), productivity (productive and non-productive) and floristic composition (macrophyte choked, macrophyte clear), etc. While the term 'floodplain wetlands' represent the wetlands situated along the floodplains of rivers; mostly lentic in nature and excludes the lotic component of the river such as the main river channel, the levee region and the flats. Floodplain wetlands are unique due to their origin, physiographic location, hydrological characteristic, ecological features, fish diversity and production dynamics. These water-bodies are basically freshwater ecosystems associated directly or indirectly with rivers originating from Himalayas in the basins of Ganga-Brahmaputra and Barak, which covers nearly one-third (1,099 thousand km^2) of the total geographical area of the country.

Distribution in India

Floodplain wetlands are characteristic features along the rivers Ganga, Brahmaputra and Barak basin, especially along their middle and lower stretches in the eastern and north-eastern parts of India. The eco-regions, drainage, demography and tributaries along which the wetlands are situated are given in Table 12.1. Locally known as *tal, jheel, maun, chaur, dhar, boar, beel, charha* and *pat,* in different states, these wetlands occupy an estimated area of over 354,213 ha. By virtue of the unique geographic, topographic, physiograph and hydrographic features of the Ganga river basin most of the tributaries of the river, viz. Ghaghra, Burhi Gandak, Bagmati-Adhwara, Kamla Balan, Kosi and Mahananda in Uttar Pradesh, Bihar and West Bengal support floodplain wetlands. Similarly, the tributaries of river Brahamputra, viz. Subansiri, Jaibharli, Dhansiri, Pagladiya, Dibang, Lohit, Burhidihing, Dikhow, Jhanji, Manas, Burhi Dihing, Dhansiri, Kopili and Digaru, are of meandering type, these rivers are intersected by a large number of floodplain wetlands. The Barak river basin, in Meghalaya, Manipur, Mizoram, Nagaland, Asom and Tripura, forming part of Brahamputra basin, also

Table 12.1. Floodplain wetlands along Ganga, Brahmaputra and Barak basins with their eco-regions and demography

Basin	Length in India (km)	Eco-regions	Drainage (mill/ ha)	Area (% of India)	Population (av./ km^2)	Basin states	Tributaries on which wetlands are situated
Ganga	1,114	Hot, sub-humid with moderate rainfall	86.15	26.2%	414	Uttarakhand, Uttar Pradesh, Himachal Pradesh, Haryana, Delhi, Rajasthan, Madhya Pradesh, Bihar, West Bengal	Ghaghra, Tons, Yamuna, Gomti and Chhoti Sarju, Sarda, Ramganga, Chambal, Burhi Rapti, Gandak, Burhi Gandak, Lakhandei, Baghmati-Adhwara, Kamla, Kosi, Bhagirithi, Hooghly, Icchamati, Mayurakshi, Dharub, Dharakla, Jalangi, Churni, Kalindi, Dharub, Dharala, Pagla, Behula, Torsa and Mahananda
Brahmaputra	2,525	Hot humid to warm with high rainfall	19.44	5.9%	149	Asom Arunachal Pradesh, Meghalaya, Nagaland, Sikkim, West Bengal	Dibru, Burhidihing, Dishang, Dikhow, Jhanji, Kakodonga, Dhansiri, Sonai, Kapili, Kulsi on south bank and Dihang, Aai Pontemeri, Mora, Jiadhal, Subansiri, Manas,Dhansiri, Dhansiri, Kameng, Pagladia, Champabati and Saralbhanga on north bank
Barak	916	Hot humid to warm, high rainfall zone	4.17	1.4%	24	Asom, Meghalaya, Manipur, Mizoram, Tripura, Nagaland	Barak, Sonai, Sushma, Dhaleswari and Longai

support floodplain wetland formation. Uttar Pradesh has a floodplain wetland spread of nearly 152,000 ha, majority of which are situated in the basins of Ganga, Yamuna, Ramganga, Ghaghara, Gomti and Rapti rivers. West Bengal has more than 150 floodplain wetlands spread across the districts of Nadia, 24 Parganas, Cooch-Behar, Hooghly, Murshidabad, Malda and Midnapore, covering an effective area of 42,500 ha, which is about 22% of the total freshwater area of the state. These wetlands are an important natural resource playing a vital role in fisheries, rural economy and environment of the State. The area of these wetlands range from 2 to 600 ha, however, most of them are between 20 and 25 ha in area, Asom has 1,392 floodplain wetlands spread over 100,000 ha. These, include 322 wetlands along the river Barak. The wetlands associated with the river Brahmaputra, Barak and its tributaries are estimated to cover 100,000 ha. Floodplain wetlands in Bihar are spread over 40,000 ha, mostly along the northern part of the state. Individual area of these range from 4 ha (Mahisath wetland) to 600 ha (Larail wetland). Other important wetlands of the state are Dabadih (100 ha) and Kamaldha (300 ha). Important floodplain wetlands in Manipur are Pumlenpat (3,500 ha), Kharungpat (2,000 ha), Ikoppat (2,000 ha), Takmu (500 ha), Withou (270 ha), Leinganpat (270 ha). Khullakpat (300 ha), Sanapat (52 ha) and Utrapat (41 ha), besides those associated with the Loktak lake. The area, distribution and local names of floodplain wetlands in Ganga, Brahmaputra and Barak basins with the districts in which they occupy are given in Table 12.2. The floodplain wetlands however, need to be delineated afresh for fisheries purposes as the area reported for many of the wetlands are taken from old official records. This area might have undergone changes during the course of time.

Classification of floodplain wetlands

Based on the origin, the floodplain wetlands are mainly classified into ox-bow lakes, tectonic depressions and waterlogged areas.

Ox-bow lakes: Ox-bow lakes are cut-off river meanders; generally formed as a river cuts through a meander neck to shorten its course, blocking-off the old channel and then migrating away from it. They may be crescent-shaped, horseshoe-shaped or serpentine. They may retain connection with parent river or remain cut-off. After formation, their original morphometry, hydrodynamics and ecological characters changes from riverine to lacustrine conditions. The Ganga and Brahmaputra, including their tributaries are known for meandering characteristics and shifting of the river course. The ox-bow lakes possess high biogenic potential, support rich biodiversity including that of fish and are important fisheries resources. Due to continuous siltation and accumulation of detritus ox-bow lakes are becoming shallower. The hydrodynamics of these water-bodies are influenced by the river water incursion, quality of inflowing water from the catchments and the amount of precipitation. Most of the wetlands in Bihar, West Bengal, Barak and Brahmaputra valleys are typical examples of ox-bow lakes.

Tectonic depressions: Tectonic depressions are either shallow depressions formed by tectonic activity by caving in of land or dead riverbeds generally connected to the principal rivers and/or receive backflow from the rivers during floods or from the

Table 12.2. Distribution of ox-bow lakes in the Ganga, Brahmaputra and Barak river basins

State	Basin	District	Local names	Area (ha)
Uttar Pradesh	Ghaghra, Tons, Yamuna, Gomti, Choti Sarju, Sarda, Ramganga, Chambal, Burhi Rapti	Ballia, Azamgarh, Mau, Basti, Deoria, Gorakhpur, Jaunpur, Rae Bareilly, Pratapgarh, Allahabad, Barabanki, Sitapur, Unnao	*Tal, Jheel*	152,000*
Bihar	Gandak, Burhi Gandak, Lakhandei, Baghmati- Adhwara, Kamla, Kosi	West Champaran, East Champaran, Muzaffarpur, Darbhanga, Sitamarhi, Madhubani, Samastipur, Purnia, Saharsa, Begusarai, Khagaria, Munger	*Maun, Chaur, Dhar*	40,000
West Bengal	Bhagirithi, Hooghly, Icchamati, Mayurakshi, Dharub, Dharakla, Jalangi, Churni, Kalindi, Dharub, Dharala, Pagla, Behula, Torsa, Mahananda	Nadia, Murshidabad, Burdwan, Maldah, 24 Parganas, Hooghly, Birbhum, Cooch Behar, Midnapur, Dinajpur	*Beel, Charha, Baor*	42,500
Arunachal Pradesh	Kameng, Siang, Dibang, Dihang, Tirap, Lohit	East Kameng, Lower Subansiri, East Siang, Dibang valley, Lohit, Tirap	*Beel*	2,500
Asom Brahmaputra basin	Lohit, Buhri dihing, Dibru, Jhanji, Dikhow, Dimow, Manas, Kapili, Sonai, Pagladia, Dhansiri, Kakodanga, Kollong, Subansiri, Aai, Jhanji, Champabati, Kakodanga, Dibru, Dishang, Pontemeri	Tinsukia, Dibrugarh, Sibsagar, Jorhat, Lakimpur, Golaghat, Dhemaji, Sonitpur, Darang, Nagaon, Morigaon, Nalbari, Kamrup Barpeta, Goalpara, Dhubri, Kokrajhar	*Beel*	92,000
Barak basin	Barak, Sonai, Sushma, Katakhal, Dholeswari, Longai, Rukni	Karimganj, Hailakandi, Cachar	*Beel*	8,000
Manipur	Iral, Imphal, Thoubal	Imphal, Thoubal, Bishunipur	*Pat*	16,500
Meghalaya	Someshwari, Jinjiram	Khasi hills, Garro hills	*Beel*	213
Tripura	Gomti, Manu, Khowai	North Tripura, South Tripura, West Tripura	*Beel*	500
Total				354,213

Source: Sugunan *et al.* (2000); *Pathak *et al.* (2004).

huge catchments area following monsoon rains. This type of wetlands are found in the north West Bengal, east Uttar Pradesh and parts of Bihar in the Ganga basin and some in Brahmaputra valley of Asom. Wetlands of this category are generally shallow, irregular in shape and support high productivity. These wetlands are mostly located in the low-lying and flood-prone areas of rivers Ganga, Kosi, Burhi Gandak, Kiul Harohar, Gandak and Ghaghra, etc. Information on their extent and magnitude is not properly assessed however, according to *Rastriya Barh Ayog* flood-prone area in the country has been estimated at about 40 million ha.

Waterlogged areas: The distribution of waterlogged depression in riverine belt of different rivers is presented in Table 12.3.

Table 12.3. Distribution of waterlogged depressions in different river basins

River basin	Catchments (km^2)	Flood-prone area (km^2)	Waterlogged area (lakh ha)
Ganga	19,322	12,920	1.98
Kosi	11,410	10,150	1.82
Burhi Gandak	9,601	8,210	2.08
Kiul Harohar	17,225	6,340	1.25
Gandak	4,188	2,530	1.19
Ghaghra	2,995	1,130	1.25

Waterlogged wetlands are mostly perennial in nature and called *chaur* in Bihar, *bela chaur* in West Bengal. Annual replenishment of flood water greatly influences their ecological, hydrological and biotic features. These water-bodies form nursery and feeding grounds of many freshwater fishes coming along with inflow of river water. Presently, the surface areas of most of these *chaurs* are heavily infested with floating weeds especially water-hyacinth, whereas their marginal areas are infested with noxious weeds like *Ipomoea*, *Typha* and *Scirpus*. The fish species inhabiting in these ecosystem are mostly the members of the families Clupeidae, Nopteridae, Cyprinidae, Bagridae, Siluridae, Schilbeidae, Heterpneustidae, Belonidae, Ambassidae, Nandidae and Channidae, etc.

River pool ecosystem

These wetlands are formed when the river shrinks during dry months and some deep portion is left in the main river channel. The river pools are seasonal in nature and disappear when the river attains its full spate during flood season. In fact, these disconnected part of river act as sanctuary for many riverine fishes trapped during pool formation period.

Swamps

These wetlands, popularly known as *daldal*, are formed mainly due to excessive eutrophication accelerated by natural and man made processes like organic enrichment, disposal of solid wastes, domestic sewage, industrial effluents, siltation, sedimentation, etc. In fact the floodplain swamps are ecologically damaged ecosystem and represent

a transitional stage between semi-aquatic and terrestrial ecosystem. The soil of swamps are muddy and spongy in nature and quite rich in terms of organic content; bottom detritus and toxic gases, namely hydrogen sulphide, methane and free ammonia. These ecosystems provide congenial condition for the marshy vegetation and growth of fishes like *Wallogo attu, Clupisoma garua, Heteropneustes fossilis, Clarias batrachus, Mystus vittatus, Anabas testudineus, Notopterus chitala, Channa gachua, C. marulius, C. punctatus, C. striatus, Nandus nandus*, etc.

Marshes

This class of wetlands is located in the narrow belt of *tarai* region, near the foothills of eastern and north-eastern Himalayan states. Marshes are rainfed, semi-aquatic and poorly drained depressions with little water, excessive saturated sediments. Marsh ecosystems are infested with emergent and marginal aquatic weeds. These ecosystems provide congenial environment for the growth of fishes like *Wallogo attu, Anabas testudineus, Channa gachua, C. punctatus, C. striatus*, etc. These water-bodies are habitat of many species of algae, fungi, macrophytes, insects, molluscs, crustaceans, amphibians and fishes and notable source of freshwater fishes belonging to families especially Clupeidae, Notopteridae, Bagridae, Siluridae, Schilbeidae, Heteropneustidae, Belonidae, Ambassidae, Nandidae and Channidae. Though productivity status of these wetlands are extremely high, but unfortunately due to ecological degradation, over-exploitation, unscientific exploitation, demographic pressures and conflicting land use practices, these water-bodies are going out of productive use. The production potential of this resource class is immense with significant development prospects.

Floodplain wetlands

Water residence and renewal time are the two most important factors affecting the ecology and fisheries of floodplain wetlands. Thus, the classification using these characteristic is much more relevant from the ecological and fisheries point of view than the previously discussed ones. Floodplain wetlands receive water either from rivers during flood season or through precipitation and surface run-off. Based on the water renewal pattern, floodplain wetlands can be categorized into 'open' type and 'closed' type.

Open-type floodplain wetlands: Floodplain wetlands which are situated directly along the margin of rivers with continuous exchange of water with river and *vice versa* or retain their connections with parent river through channels and receive riverine water for most part of the year. The hydrodynamics of open floodplain wetlands are influenced by river water and affect the ecology of wetland ecosystem. As the flood water brings brood fishes and enormous amount of fish eggs, juveniles, young and brooders of various finfish and shellfish species. The productivity of these wetlands is extremely high. The organisms inhabiting these systems comprise a mix of lotic and lentic communities. The ichthyodiversity of ox-bow lakes are extremely high and they are sustaining populations of many species belonging to the major families like Clupeidae, Notopteridae, Cyprinidae, Bagridae, Siluridae, Schilbeidae, Heteropneustidae, Belonidae, Ambassidae, Nandidaed, Channidae, etc. The fish species inhabiting in open ox-bow lakes are both lotic and lentic in nature. These ecosystems are basically a capture fisheries resource and fishers are harvesting fishes with the help of traditional gear like gill nets, cast nets, lift nets, various types of traps, etc. using country boats.

Closed-type floodplain wetlands: Floodplain wetlands, which are permanently disconnected from the parent river due to river course changes, sedimentation, construction of embankment and roads or other structure by man. They receive water from monsoon runoff and direct rainfall. This restricts the lateral expansion of water and consequent ingress of brooders and fish seeds into the wetlands. The cut-off nature influence the hydrological character, nutrient dynamics, abundance of biotic communities, recruitment and production potential of these wetlands. These wetlands, in most cases, are dominated by macrophytes. Process of eutrophication in closed floodplain wetlands is extremely high as compared to the open type wetlands. The fish fauna in these ecosystems are mostly devoid of riverine component. Recruitment of fishes happens through breeding of fishes within the system.

On-site and off-site functions

Floodplain wetlands are ecosystems that provide numerous goods and services, not only to the local population living in its periphery but also to communities living outside the wetland area. They offer enormous on-site and off-site benefits and functions. The on-site functions include regulation of ecological processes that contribute to a healthy environment, recycling of nutrients and human waste, watershed protection, reducing flood heights, improving water quality, reducing runoff and erosion, providing habitat for plant and animal life, provide food and nutrition security for humans and other biota and helping sustain groundwater recharge. They are spawning and nursery grounds for many fishes and feeding and nesting ground of migratory birds. Besides these ecological functions, they are of great economical values as their water is used for domestic consumption namely drinking, bathing, washing and production of various types of animal and plant-based aqua foods, especially fin fishes, shellfishes, deep water paddy, water chestnut (*Trapa bispinosa*) and *Euryale ferox*, etc. They provide space for human settlement, cultivation, energy production and habitat for animals; provide resources such as food, water, raw materials for building and clothing for people. The off-site benefits include climate regulation, information function in the sense that wetlands contribute to mental health by providing scientific, aesthetic, social and spiritual aspects. The diversity in functions that wetlands perform makes them highly valuable ecosystems.

Morphological characters

Floodplain wetlands are comparatively shallow and mostly lentic in nature except during flood season when there is flow of flood water. Their shore lines are irregular and areas vary widely. During monsoon months the spread over area of water increases considerably, whereas in winter and summer the water level shrinks. The physical character of these wetlands varies considerably across various states where they exist. The physical features of some of the wetlands in west Bengal and Bihar are depicted in Table 12.4.

Table 12.4. Salient physical features of wetlands in West Bengal and Bihar

State/District	Wetland	Area (ha)	Depth (m)	Type
		West Bengal		
Nadia	Boror	9.2	1.9-3.5	Closed
	Kulia	26.5	1.0- 2.0	Closed
	Bhomra	83.0	1.0-3.5	Closed
	Mogra	60.0	1.7-5.0	Closed
	Palda	159.0	3.3- 6.4	Open
	Padma	60.0	1.2-3.5	Closed
	Saguna	40.0	2.2	Closed
Hooghly	Dekole	117.6	1.0-1.8	Closed
	Kol	81.6	1.5-3.5	Open
Murshidabad	Baloon	200.0	1.6-1.9	Closed
	Bhandardaha	437.5	4.0-17.0	Open
Cooch Behar	Khorardoba	50.0	0.4 -1.5	Closed
	Goraichara	50.0	4.0 - 6.8	Open
Bardhaman	Bansdaha	26.0	1.7 - 6.5	Closed
Midnapore	Sarasanka	24.0	0.2-1.8	Closed
North 24 Parganas	Akaipur	32.0	0.3-1.8	Closed
	Gopalpur	131.0	4.5-12.6	Closed
	Media	120.0	1.0- 1.5	Closed
Maldah	Ghurnamani	40.0	1.4-3.6	Open
	Haripur	30.0	1.0- 4.5	Open
South Dinajpur	Bhaluka	40.0	1.4- 3.6	Open
	Patari	30.0	1.0- 4.5	Open
North Dinajpur	Moranadi	35.0	3.7	Closed
	Nehali	30.0	1.0	Closed
		Bihar		
East Champaran	Amua	45.0	3.9-7.2	Closed
	Lalsaraia	40.0	3.3-8.2	Closed
West Champaran	Sirsa	72.0	4.6-7.4	Closed
	Majhoria	130.0	2.4-5.5	Closed
	Chilron	120.0	1.9-4.8	Closed
	Turkolia	98.0	5.2-8.5	Closed
Muzaffarpur	Motipur	62.0	3.9-4.3	Closed
	Monika	98.5	3.4-4.2	Closed
Begusarai	Bahuara	44.5	0.8-3.5	Closed
	Rajaura	30.0	1.1-4.0	Closed
	Marda	33.0	1.3-1.3	Closed
	Karunama	22.0	2.5-3.6	Closed
Khagaria	Kasraia	23.0	4.7-11.3	Closed
	Lakhmania	12.0	1.8-3.35	Closed

Source: Sugunan *et al.* (2000) and K Mitra (Personal communication).

Physico-chemical features of water and soil

A perusal of the available data on water quality reveals that floodplain wetlands of Ganga river basin are more or less alkaline (*p*H 6.8-9.7) in nature, whereas the wetlands of Brahmaputra basin are acidic to slightly alkaline (*p*H 6.2-7.7) in nature. The concentration of dissolved oxygen is optimum, except in Asom and Bihar, where the lower values reach as low as 0.05 to 0.7 mg/litre in some wetlands. The total alkalinity and specific conductivity range of water indicated moderate to high productivity. The dissolved organic matter, which determines the chemical oxygen demand (COD) is high. The high values may be attributed to constant loading of detritus and sedimentation due to death and decay of macrophytes and inputs from runoff. The nutrient status of water is poor in respect of both nitrate and phosphate. It appears that the nutrients are locked up, either in soil phase or utilized by macrophytes. Silicate levels are low to moderate, while higher level of chloride is reported from Asom, Bihar and Manipur. Calcium and magnesium levels are also low to moderate in these wetlands. The water quality parameters of floodplain wetlands in Asom, West Bengal, Bihar and Manipur are summarized in Table 12.5.

Table 12.5 Mean range of water quality parameters in floodplain wetlands of Uttar Pradesh, Asom, West Bengal, Bihar and Manipur

Parameters	Uttar Pradesh	Asom	West Bengal	Bihar	Manipur
*p*H	6.8-8.0	6.2-7.7	6.8-9.7	6.8-9.4	6.8-7.2
DO_2 (mg/litre)	5.0-8.9	0.7-13.6	3.2-12.5	0.05-14	4.8-5.4
Alkalinity (mg/litre)	130-217	6.0-164	27.3-282	80-610	34-43
Hardness (mg/litre)	-	10.0-169	16.0-208	12-270	40-49
Transparency (cm)	-	17-98	85-226	275-390	20-110
Sp. conductivity (m mhos)	280-540	7.7-335	55.0-899	370-1,136	65-75
Dis. organic matter (mg/litre)	2.6-3.8	2.8-4.8	1.2-2.4	2.5-6.0	-
Nitrate (mg/litre)	-	Tr-0.03	Tr-1.01	0.1-0.89	0.03-0.08
Phosphate (mg/litre)	Tr-0.14	Tr-0.04	Tr-0.63	Tr-0.5	Tr-0.008
Silicate (mg/litre)	Tr-0.27	2.8-5.2	1.64-7.7	10.0-20.0	1.0-3.5
Chloride (mg/litre)	-	14.7-34.3	2.8-78	20-24	20-26
Calcium (mg/litre)	-	5.0-64.3	4.3-65.3	25.0-38.0	4.0-7.5
Magnesium (mg/litre)	-	1.8-84.6	2.5-122	1.44-12.9	5-9

Source: Sugunan *et al.* (2000), Sugunan and Bhattacharjya (2000), *Annual Progress Reports* of CIFRI; Tr= trace.

Studies made so far indicated that the open wetlands have better water quality, compared to the closed and moderately weed infested wetlands. Wetlands in Asom are poor in major nutrients, viz. nitrogen and phosphorus. Water quality of wetlands in Brahmaputra basin is more conducive for biological production than those of Barak valley. Low values of specific conductivity, hardness and alkalinity are characteristics of wetlands in Manipur.

In majority of the floodplain wetlands, the bottom soil is rich with respect to organic carbon, available nitrogen and phosphorus. Soils of these wetlands are enriched by organic matter and inorganic minerals through deposits of decaying vegetation, incursion of river water and surface run-off from land. The major soil quality parameters

of some wetlands in West Bengal, Bihar and Uttar Pradesh are shown in Table 12.6. The soils of floodplain wetlands in West Bengal are rich in plant nutrients as reflected by high values of specific conductivity. In contrast to other nutrients, the available phosphorus is lower in closed wetlands and higher in open wetlands. Soil of wetlands in Asom are acidic in nature, which is not conducive for good fish production and microbial activity. The mean values of organic carbon indicated that the wetlands of Brahmaputra valley were more productive than those of Barak valley. Available soil phosphorus was poor in most of the wetlands in Asom. Available nitrogen was comparatively low in both Brahmaputra and Barak valleys from fisheries point of view. However, in spite of acidic nature of the soil and water, wetlands in Asom are

Table 12.6. Soil quality of some wetlands in West Bengal, Bihar and Uttar Pradesh

Parameter	Wetland					
	Bhomra	Talbona	Sarasanka	Kole	Haripur	Baloon
			West Bengal			
*p*H	7.5-7.7	7.83	4.1-7.4	7.54-8.6	7.5-7.9	9.3-7.0
Sand (%)	87	78	75-84	63	63	74-77
Silt (%)	3.5	11	3.0-6.0	6.0-13.0	3.0-26.0	7.4-7.5
Clay (%)	7	11	12-20	6.5-25	4-26	15-19
Conduct. (mmhos)	530-537	42	220-370	240-444	220-960	1,100
Org. carbon (%)	3.9-7.9	2.4	2.6-4.4	0.1-0.6	1.1	0.1-1.5
Total N (%)	0.1-0.6	0.2	0.1-0.12	0.4-0.5	0.16-0.3	-
P (mg/100 g)	86.6-78.9	47.6	28.4-63.9	11.2-20.7	3.1-46.5	-
C : N ratio	11.8-18.6	9.7-12.8	11.9-12.8	8.0-11.7	8.1-13.8	-
	Rajora	Bahuara	Monika	Motipur	Sikandarpur	Chilron
			Bihar			
*p*H	7.5-7.8	7.3-8.0	7.7-7.8	7.5-7.7	7.5-7.6	7.2-7.6
Sand (%)	70	66	62	79	83	92
Silt (%)	13.5	18	30.5	17.5	15	6.7
Clay (%)	15.4	15	3.5	2.7	1.9	0.3
Conduct. (mmhos)	413-	576-714	279-307	693-864	868-1084	857-1030
Org. carbon (%)	0.99-1.52	1.37-2.36	1.29-1.77	3.27-4.95	4.71-5.85	3.4
Total N (%)	0.2	0.2-0.3	-	-	-	-
Total P (mg/100 g)	Tr.	Tr.-0.4	1.0	1.2-1.4	2.4-2.6	Tr.
C : N ratio	6.3	7.5	-	-	-	-
	Mundiari	Lohsartal	Bansidah	Dahital	Sangara	Bahausi
			Uttar Pradesh			
*p*H	8.2	7.8	7.4	7.3	7.0	7.2
Sand (%)	85	75	94	87	68	76
Silt (%)	9.5	20.8	4.3	9.0	21.3	16.5
Clay (%)	5.5	4.0	2.0	4.0	10.7	7.5
Conduct. (mmhos)	359	464	404	289	244	262
Org. carbon (%)	1.3	1.79	1.0	1.1	2.57	1.72
Avail. N (mg/g)	382	470	315	488	395	507
Avail. P (mg/g)	30	38	22	102	18	62
C:N ratio	-	-	-	-	-	-

Source: Sugunan *et al.* (2000), Pathak *et al.* (2004), *CIFRI Internal Reports*; Tr= trace.

conducive for capture fisheries and culture based fisheries. The soils of wetlands in West Bengal are of acidic to alkaline in character, with a *p*H range of 4.1-9.3; predominantly sandy in texture (74-87%) with a conductivity range of 42-1,100 mmhos. Organic carbon range is 0.1-7.9% of C:N ratio is 8-18.6. They are low in total nitrogen and high in phosphorus. Soil *p*H of wetlands in Asom is acidic to near neutral in nature (*p*H 4.6-7.4) with conductivity ranging between 54.6 and 335 mmhos. Organic carbon ranges from 0.05 to 2.28%. In Bihar wetlands, the soil is generally alkaline in nature with a *p*H range of 7.2-8.0. In wetlands of Uttar Pradesh the soil *p*H ranged from 6.5 to 8.2, organic carbon range was 1.09-2.57%. Soils of wetlands of Manipur are generally acidic in nature with a *p*H of 4.3-5.1. Organic carbon range is 3.3-3.9% and C : N ratio of 6.5-8.3%, indicating poor nutrient release from soil to aquatic medium. The available phosphorus is also poor.

Pollution load

Most of the wetlands are affected by anthropogenic activities. Presence of high chloride levels, pesticide residues and heavy metals in water, sediment, flora and fauna were recorded. Heavy metals found in soil and water in wetlands of West Bengal, Bihar and Manipur are given in Table 12.7.

Table 12.7. Heavy metal traces found in soil and water phases of wetlands in West Bengal, Bihar and Manipur

Heavy metal	West Bengal (ppb)	Bihar (mg/kg)	Manipur (mg/kg)
Zinc	14-64	76.1-363.8	170-180
Copper	0.8-14.3	13.7-26.3	48-52
Mercury	0.018-0.37	-	-
Lead	-	12.4-63.1	Tr-1.9
Cadmium	-	3.3-5.6	Tr-0.7
Manganese	-	-	180-190
Iron	-	-	4,720-6,560

Source: Annual Progress Reports, CIFRI.

Isomers of most frequently used pesticides and their metabolites were detected in water samples. In West Bengal, the Haripur wetland exhibited high level of these in water phase; pesticides were detected from the bed soils of Ghurnamani, Haripur and Sarasankha wetlands.

Flora and fauna

Floodplain wetlands are highly productive ecosystems supporting rich diversity of biotic communities like macrophytes, plankton and benthic organisms. The relative abundance of these groups varies depending on the hydrodynamics and morpho-ecological conditions of the wetlands. There are seasonal and temporal variations within wetlands. However, one common characteristic feature in majority of the wetlands is the infestation of aquatic macrophytes.

Macrophytes: The biomass of macrophytes in wetlands of West Bengal varied

from 1.4 to 35.5 kg/m^2 (wet weight). The floodplain wetlands in Gandak basin in Bihar are also macrophyte infested (4.0 to 25.0 kg/m^2 (wet weight). The macrophyte cover usually varies from 15 to 90% of the water surface in most of the wetlands in West Bengal, while it is 50-100% in wetlands of Bihar. The weed infestation in wetlands of Asom ranged from 20 to 90% of the water spread. The macrophyte biomass in wetlands of Manipur ranged from 1.67 to 11.32 kg/m^2 (wet weight), covering 75-95% of the water spread of individual wetlands. The macrophytes cover of floodplain wetlands in Uttar Pradesh ranged from 20 to 90%. More than 46 species have been recorded within wetlands of these two basins. A list of macrophytes species recorded from floodplain wetlands is given in Table 12.8. These plants cause auto shading and prevent light to reach the bottom strata. A large fraction of the solar energy received by these wetlands is trapped in the macrophytes, making it less available to the next trophic level; hinter fishing operation and renders navigation difficult. They however, promote growth of a large number of associated fauna, by providing them with food and shelter; forms feeding and breeding ground for several organisms including fishes. In wetlands of West Bengal, abundance of the weed-associated fauna ranged from 53 nos./m^2 to as high as 2,832 nos./m^2. Insects and mollusks formed the bulk of this community, followed by annelids. Closed wetlands in general facilitate dense growth of macrophytes due to high nutrient load and lentic water.

Table 12.8. Macrophyte species recorded from floodplain wetlands

Type	Species
Floating	*Eichhornia crassipes, Pistia stratiotis, Azolla pinnata, Lemna perpusilla, Spirodela polyrrhiza*
Rooted/submerged	*Nymphaea nouchali, N. pubescens, Nelumbo nucifera, Nymphoides cristatum, N. indica, Myriophyllum tetrandum, M. tuberculatum, Limnophila indica, Potamogeton nodosus, P. crispus, Aponogeton natans, Hydrilla verticillata, Ceratophyllum demersum, Najas indica, N. minor, Vallisneria spiralis, Ottelia alismoides, Blyxa ochlandra, Nechamandra alternifolia, Caldesia pernassiflora*
Erect/prostrate	*Monochoria hastata, Cyperus procerus, C. exaltatus, Eleocharis dulcis, Scirpus squamosus, S. articulatus, Typha angustata, Polygonum barbatum, Aeschynomene indica, A. aspera, Ludwigia adscendens, Alternanthera sessilis, A. philoxeroides, Ipomoea aquatica, Commelina longifolia, Paspalum paspaloides, Leersia hexandra*

Plankton

Plankton populations of most of the floodplain wetlands are sparse and the densities are generally low. In wetlands of West Bengal, the phytoplankton populations varied from 396 to 14,987unit/litre. Generally, plankton populations are lower in weed-choked wetlands than that of weed-free type. A total of 74 species of phytoplankton have been recorded from wetlands of West Bengal. The zooplankton count ranges between 104 and 2,317unit/litre, with representation of 27 species, the dominant forms being rotifers, followed by cladocerans and copepods.

Benthic macro fauna: The mean population of benthic macro fauna in wetlands of Asom is 1,763 nos/m^2, while those of the wetlands of Bihar is 220-5,414 nos/m^2. The dominant forms are molluscs (94-96%). The species commonly encountered are *Bellamya bengalensis, B. variatus, Lymnaea accuminata, Indoplanorbis exustus, Digoniotoma cerameopoma, Brotia costula, Gyraulus convexiusculus, Lamellidens marginalis, Parreysia corrugate, Piscidium* sp., etc.

Primary productivity

Solar energy is fixed both by phytoplankton and macrophyte communities in wetlands. In most of the wetlands, especially those of the weed-choked nature; the carbon-fixation takes place predominantly through the macrophyte chain. The net primary productivity through macrophyte phase in wetlands of West Bengal is 883.2 mg C/m^3/day while that through the phytoplankton phase is 501.6 mg C/m^3/day. In the wetlands of Asom, the net primary productivity through macrophytes ranged from 667 to 4,612 mg C/m^2/day against 110 to 1,750 mg C/m^2/day through phytoplankton. Thus, in these wetlands, most of the primary production comes from macrophytes. The phytoplankton productivity in wetlands of north Bihar ranged from 2,220 to 2,919 mg C/m^2/day. The net primary productivity through phytoplankton in Loktak and Takmu wetlands of Manipur are 150 and 137 mg C/m^3/day.

Fish germplasm diversity

Floodplain wetlands in India harbour large number of fish species. The faunistic composition of the floodplain wetlands generally reflects that of the parent river. In open-wetlands, the catch is dominated by the riverine fauna. A total of 85 fish species belonging to 33 families have been reported from the floodplain wetlands. Five species of prawns of food value have also been reported. The major fish species can be divided broadly into major carp, minor carp, cat fishes, snakeheads, feather back, herring, gobbles, loaches, perches, needle fish, mud eel, spiny eel, puffer fish and small-size prawns and therefore the resource base is a valuable source of rich and varied endemic stock of many food, forage, larvicidal, aquarium and therapeutically important fishes. The fish fauna generally include *Puntius* spp., *Colisa* spp., *Chanda* spp., *Mystus* spp., *Ambassis* sp., *Amblypharyngodon mola, Nandus nandus, Macrognathus pancalus, M. aral, Botia* spp., *Wallago attu, Sperata aor, Ailia coila, Ompok bimaculatus, Heteropneustes fossilis, Channa* spp., *Anabas testudineus, Notopterus notopterus*, prawns, etc., bedsides Indian major carps (*Catla catla, Labeo rohita, L. bata, L. calbasu, Cirrhinus mrigala*). Many of these wetlands are being stocked under culture-based fisheries by co-operative societies. Indian major carps and exotic carps are commonly being used for stocking. Exotic carps being stocked are *Hypophthalmichthys molitrix, Ctenopharyngodon idella* and *Cyprinus carpio*. Nine species of exotic fishes including *Oreochromis mossambicus* and *O. niloticus niloticus* are reported from the wetlands. Table 12.9 shows some of the important indigenous fish species, exotic fishes and prawns from floodplain wetlands. Presently, the ichthyodiversity of these wetlands are losing their identity due to massive change in the physiographic, hydrological, ecological and climatic conditions as well as exploitation pattern.

Table 12.9. Fish germplasm resources of floodplain wetlands

Family	Species
Ambassidae	*Chanda nama, Parambassis lala, Parambassis ranga, Pseudambassis baculis*
Anabantidae	*Anabas testudineus*
Aplocheilidae	*Aplocheilus panchax*
Badidae	*Badis badis*
Bagridae	*Bagarius bagarius, Mystus vittatus, Mystus tengara, Mystus bleekeri, Mystus gulio, Rita rita, Sperata aor*
Belonidae	*Xenentodon cancila*
Osphronemidae	*Colisa lalia, Colisa chuna, Colisa fasciata*
Channidae	*Channa punctata, Channa striatus, Channa marulius, Channa orientalis*
Chacidae	*Chaca chaca*
Cichlidae	*Oreochromis niloticus niloticus**, *O. mossambicus**
Clariidae	*Clarias batrachus, Clarias gariepinus**
Clupeidae	*Gudusia chapra*
Cobitidae	*Lepidocephalus guntea, Botia* sp.
Cyprinidae	*Amblypharyngodon mola, Aspidoparia morar, Barbonemus gonionotus**, *Catla catla, Cirrhinus mrigala, Ctenopharyngodon idella**, *Cyprinus carpio**, *Danio devario, Esomus danricus, Hypophthalmichthys molitrix**, *Labeo bata, Labeo calbasu, Labeo rohita, Osteobrama cotio cotio, Puntius sophore, Puntius terio, Puntius conchonius, Puntius phutunio, Puntius ticto, Puntius chola, Puntius gelius, Salmophasis bacaila, Salmostoma phulo, Salmostoma* sp., *Securicula gora*
Eleotrididae	*Butis butis*
Engraulidae	*Setipinna phasa*
Gobiidae	*Glossogobius giuris. Glossogobius* sp., *Taenioides cirratus*
Heteropneustidae	*Heteropneustes fossilis*
Latidae	*Lates calcarifer*
Loricariidae	*Pterygoplichthys disjunctivus**
Mastacembelidae	*Macrognathus pancalus, Macrognathus aral, Mastacembelus armatus*
Moringuidae	*Moringua arundinacea, Moringua raitaborua*
Mugilidae	*Sicamugil cascasia, Rhinomugil corsula*
Muraenidae	*Lycodontis tile*
Nandidae	*Nandus nandus*
Notopteridae	*Notopterus notopterus, Chitala chitala*
Ophichthidae	*Pisodonophis boro*
Pangasiidae	*Pangasianodon hypophthalmus**, *Pangasius pangasius*
Schilbeidae	*Pseudeutropius atherinoides, Eutropiichthys vacha, Clupisoma garua*
Siluridae	*Gogangra viridescens*
Soleidae	*Brachirus pan*
Siluridae	*Ompok pabda, Wallago attu*
Tetraodontidae	*Tetraodon cutcutia*
Prawns	*Macrobrachium dayanum, Macrobrachium scabriculum, Macrobrachium rosenbergii, Macrobrachium malcolmsoni, Macrobrachium lamari*

*Exotic species.

Fisheries of floodplain wetlands

The floodplain wetlands are the major potential capture fisheries resources of Uttar Pradesh, Bihar, West Bengal and North-eastern states. In floodplain wetlands, intensive fishing is carried out by the fishers with the help of various gears such as fine mesh nets, cast nets, surface gill nets, bottom gill nets, scoop nets, long lines, dip nets, pole and lines and various traps like *Ghana, Kapacha, Kurail, Bishar, Shahat* and *Kaniyar.* Fishing is carried out, year round. The fish yields from these wetlands varied considerably with wide range of 36 to 1,100 kg/ha/year. The annual fish yield from some of the floodplain wetlands along the Ganga, Brahmaputra and Barak basins located in Uttar Pradesh, Bihar, West Bengal and Asom are presented in the Table 12.10.

Table 12.10. Fish yield of some floodplain wetlands along the Ganga, Brahamputra and Barak basins

Basin	State	District	Associated river	Wetland	Area (ha)	Yield (kg/ha/year)
Ganga	Uttar Pradesh	Ballia	Ghaghra	Surha *Tal*	2,000.0	240.0
		Mau	Ghaghra	Ratoital	800.0	142.0
		Azamgarh	Tons	Salontal	200.0	245.0
		Basti	Ghaghra	Chandutal	230.0	150.0
		Allahabad	Yamuna	Alwer *Jheel*	250.0	150.0
	Bihar	Muzaffarpur	Burhi Gandak	Sikenderpur	45.5	230.0
		Muzaffarpur	Burhi Gandak	Manika	105.8	190.0
		Samastipur	Burhi Gandak	Muktapur	60.0	120.0
		Champaran	Burhi Gandak	Moti *Jheel*	100.0	185.0
		Samastipur	Burhi Gandak	Muktapur	60.0	120.0
	West Bengal	Hooghly	Hooghly	Kol	81.6	147.0
		Nadia	Bhagirathi	Boror	9.2	240.0
		Murshidabad	Bhagirathi	Bhandardaha	437.0	150.0
		Cooch Behar	Dharub	Khoardo	50.0	204.0
		Bardhman	Bhagirathi	Bansdaha	26.0	1,100.0
		24, Parganas	Ichhmati	Garapota	122.0	330.0
		Malda	Ghurnamani	Pagla	40.0	137.0
Brahma-putra	Asom	Kamrup	Brahmaputra	Dora	160.0	116.0
		Sonitpur	Brahmaputra	Dighali	40.0	36.0
		Barpeta	Brahmaputra	Kapla	75.0	126.0
		Dibrugarh	Brahmaputra	Mer	30.0	71.0
		Naogaon	Brahmaputra	Samaguri	60.0	96.0
Barak	Asom	Cachar	Barak	Ramnagar	15	215.0
		Karimganj	Longai	Sone	3,458.0	97.0

Fish yield potential: Fish yield potential is generally estimated as a function of the rate of primary productivity. Even at the modest rate of 1% of the primary production, the fish yield potential accounts for 1,250 kg/ha/year in floodplain wetlands of Asom. On an average, macrophyte chain contributes 74% of the total yield potential.

Table 12.11. Estimated fish production potential in wetlands of Asom

Wetland	Production potential (kg/ha/year)		Total (kg/ha/year)
	Macrophyte chain	Plankton chain	
Upper Asom	883	362	1,245
Central Asom	692	368	1,060
Lower Asom	1,051	170	1,221
Barak valley	782	311	1,093

Source: Sugunan and Bhattacharjya (2000).

The fish yield potential of wetlands in Asom through macrophyte and plankton food chain is depicted in Table 12.11. The average fish yield in the wetlands of Asom is about 172.9 kg/ha/year. Similarly, fish yield potential of 18 wetlands of West Bengal, representing various categories, has been estimated. In general, the fish yield potential of North Bengal wetlands is lower than those of the South Bengal wetlands. The closed, weed choked wetlands showed a yield potential of 84.4-264.6 kg/ha/year. In closed and moderately weed infested wetlands the yield potential ranged from 43.8-256 kg/ha/year. In closed and weed-free wetlands, the yield potential was 270-320 kg/ha/year. The fish yield potential and actual fish yields of some wetlands in West Bengal are shown in Table 12.12. On an average, the actual yield was higher from closed and weed-free wetlands (2,316 kg/ha/year), followed by moderately weed infested wetlands (818 kg/ha/year). The fish yield, on an average, in the floodplain wetlands of Bihar is reported to be 40-200 kg/ha/year. The fish yield potential of the wetlands in Uttar

Table 12.12. Estimation of fish production potential and actual production in some floodplain wetlands in West Bengal

Wetland	Area (ha)	Production potential (kg/ha/year)		Total potential (kg/ha/year)	Actual yield (kg/ha/year)
		Detritus chain	Plankton chain		
Closed weed choked					
Bhomra	83	190.75	47.63-73.91	238.0-264.6	690.00
Beloon	200	96.88	13.84	110.72	875.00
Bansdaha	41	123.15	38.0-061.50	161.1-184.6	1,100.00
Mogra	60	123.9-139.12	23.6-95.88	147-235	345.80
Ghurnamani	40	51.18	33.28-208.05	84.4-259.2	650.00
Nehali	30	22.67	6.7-13.90	29.3-36.5	333.30
Dekole	43	94.50	14.5-18	109-112.5	66.18
Closed moderately weed infested					
Sarasankha	35	58.00	17-35	75-93	800.00
Berir Baor	167	3.29	192.22	199.50	507.34
Garapota	131	11.22	28-91	39-11	310.6
Haripur	30	14.89	103-158.70	117-173.50	900.00
Moranadi	35	3.42	20.1-73.50	23.5-76.90	-
Akaipur	32	1.86	42-254.30	43.8-256.10	1,921.50
Bhaluka	32	1.60	23.95-31.94	25.5-33.54	468.75
Closed weed free					
Kola	12	Negligible	207-320	270-320	4333.30
Patari	30	Negligible	12.8-49.80	12.8-49.8	298.01
Open type					
Palda	200	3.99	59-91	62.99-94.90	42.04
Bhanderdaha	400	1.34	30.23	31.57	150.00

Source: Modified from Sugunan *et al.* (2000).

Pradesh varied between 638 and 1,327 kg/ha/year, while the actual yield is 43-357 kg/ha/year The fish production from wetlands of Uttar Pradesh is depicted in Table 12.13. The floodplain wetlands of East Kameng, Lower Subansiri, East Siang, Dibang valley, Lohit, Tirap and Changlang districts of Arunachal Pradesh, produce fish at an average rate of 60 kg/ha. Wetlands in Tripura hold an annual potential for producing about 100 tonnes of fish. The fish production from the Loktak floodplain lake in Manipur is about 78 kg/ha/year, where the catch is dominated by *Ctenopharyngodon idella*, *Cyprinus carpio* and *Hypophthalmichthys molitrix* (33%), followed by Indian major carps (21%) and minnows (14%). Scientific management of fisheries of floodplain wetland has shown that their fish yields can be raised to 1,000-1,500 kg/ha from current levels. Some wetlands showed higher yields than their potential. This may be because

Table 12.13. Fish production and contribution of different groups from wetlands of Uttar Pradesh

Vetland	Fish production (kg/ha/year)	Major and minor carps (%)	Catfishes (%)	Miscellaneous species (%)
Rewati	112.7	18.5	24.0	57.4
Mundiari	49.4	14.6	28.2	57.2
Rohua *tal*	82.0	23.6	40.0	36.4
Gujartal	102.8	24.0	51.3	24.7
Narainital	58.3	19.0	35.0	46.0
Lohsar	62.0	20.7	38.4	40.9
Rainital	43.0	16.5	26.2	57.3
Chandu *tal*	150.0	27.2	32.6	40.2
Sikandarpur	175.0	37.6	28.5	33.9
Bansidah	179.0	31.2	26.4	42.4
Bhagnaiya	211.0	41.2	26.3	32.5
Gambhirban	160.0	32.5	30.2	27.3
Salontal	245.0	42.9	25.2	31.9
Devasi deval	158.3	32.2	29.8	38.0
Ratoital	142.0	24.4	28.5	47.1
Alwar *jheel*	142.0	25.2	28.2	46.4
Dahital	166.7	29.0	24.2	46.8
Gagnikhera	198.0	32.8	30.0	37.2
Mohane	220.0	38.9	26.2	34.9
ihadayal	52.5	14.4	26.4	59.2
abri	357.0	43.5	21.8	34.7
ihaghar *jheel*	190.0	32.6	29.4	38.0
angara	185.3	31.9	24.8	43.3
atanpur	126.8	22.3	39.5	38.2
onari	213.3	38.7	18.8	42.5
uthala	211.4	38.4	26.4	35.2
ahausi	218.0	36.2	32.8	31.0
heerwan	166.4	33.6	28.0	38.4
aman *jheel*	98.4	16.8	24.0	59.3
Average	160.4	33.8	27.1	39.1

Source: Pathak *et al.* (2004).

the yield potential was estimated as 1% of the primary productivity through plankton chain, the contribution of macrophyte chain was largely overlooked. This shows need for re-estimation of the fish yield potential of floodplain wetlands for more effective management.

Fish production trends: Time series data on fish production from floodplain wetlands are few and far between making it difficult for establishing clear trends in fish production The indicative information available showed that in floodplain wetlands of West Bengal, the fish production trend is upwards with 442 kg/ha/year during 1984-95 and 1,794 kg/ha/year during 1997-98. The trend in Asom is 173 kg/ha/year during1994-98 and 935 kg/ha/year during 2006-07. Fish yield trend from wetlands of Bihar is 40-200 kg/ha/year during1990s and 31-1,125 kg/ha/year during 2002-06. The composition and fish production trend of major fish groups of an open wetland (Sikenderpur) and a closed wetland (Manika) in the Burhi Gandak basin in Bihar is given in Table 12.14, showing a declining trend.

Table 12.14. Trend of fisheries from open wetland (Sikenderpur) and closed wetland (Manika) in the Burhi Gandak basin in North Bihar

Year	Estimated production (kg/ha)		Percentage contribution of fish groups in total fish production					
	Open	Closed	Indian major carps		Air-breathing fishes		Miscellaneous fishes	
			Open	Closed	Open	Closed	Open	Closed
1979	76.7	15.4	54.3	Nil	7.1	42.3	38.5	57.6
1980	43.6	4.8	22.0	8.3	18.9	43.3	59.1	48.0
1981	53.0	9.4	3.9	2.9	30.1	41.1	65.1	55.5
1982	33.0	15.4	12.0	5.3	24.0	36.2	64.0	58.4
1983	26.4	6.7	3.5	4.6	43.9	80.6	52.6	34.8
1984	19.6	4.9	1.5	Nil	31.3	73.8	67.2	26.2

The fish population structure of these wetlands has changed towards economically less important fish species. Currently the small-size fish species, especially minor carps, small catfishes and murrels are showing dominance in their population structure.

Fisheries management options

The floodplain wetlands in India exhibit ample scope for sustainable fisheries development, if managed scientifically. Technologies and management protocols are now available to bridge the gap between their current fish yield and the potential for producing fish. Technological and management options are also available for increasing the economic attributes of the wetlands and to bring additional income to fishers and other stakeholders. Being open access in nature, the wetlands have several stakeholders with varying and often conflicting interests, which becomes a major stumbling block in the way of development. Other bottlenecks include difficulty in implementing technologies at the field level; wetlands are state subject and are owned/controlled by State departments in majority of the case; policy options varies from state to state and fisheries regulations are fragmentary in nature. Sustainable development being 'ensuring a better quality of life for everyone, now and for generations to come', should aim at resolving the innate conflicts in development objectives. This requires incorporation of environmental dimensions and stakeholders into the processes of planning and development. High intensity production systems, which overexploit the resources and cause social disturbance, have higher risks and can cause collateral damage and failure. Hence, adopting lower or medium intensity technologies is better to assure sustainability and to avoid failures and risks, especially when it is impossible to take risks in open waters. This would also have the advantage of requiring moderate inputs, lessening inter-sectoral rivalry and waste accumulation, leading to no or minimum environmental and social impacts. Some such options for sustainable management of floodplain wetland fisheries in India are managed capture fisheries, enhancements and enclosure culture.

Capture fisheries: Development of capture fisheries is good in floodplain wetlands, which are connected with rivers. The management mode is similar to that followed in rivers. The main management steps are identification and protection of breeding grounds, allowing free migration of brooders and juveniles from wetland to river and vice versa, protection of broodstock and juveniles. The main strategies to achieve this are to stop or reduce over fishing, increase or decrease fishing effort as needed, observe closed seasons to protect brooders, strict adherence to minimum size at capture, diversification of gear for species and size-specific fishing and selective augmentation of stock when unavoidable.

Enhancements: FAO defines enhancements as technical interventions in existing aquatic resource systems, "which can substantially alter the environment, institutional and economic attributes of the system". Enhancement is a process by which qualitative and quantitative improvement is achieved from water-bodies through exercising specific management interventions. The common forms of enhancement which are applicable to floodplain wetlands in India are stock enhancement, species enhancement, management enhancement, culture-based fisheries and enclosure culture. Culture-based fishery is the most common mode of enhancement being followed in inland water bodies in India.

Stock enhancement: The main aspects of stock enhancement are selection of species for stocking, determination of stocking rate and size at stocking. Stock enhancement can be either to create a culture-based fishery, based predominantly on the recapture of stocked fish or to enhance/supplement the self-recruiting populations where recruitment is poor.

Species enhancement: Species enhancement is planting fast growing, economically important fish from outside, with an aim of colonizing all the diverse niches of the water body. This practice has more relevance in respect of larger water-bodies where stocking and recapture on a sustainable basis is not feasible as in large floodplain wetlands. While doing this all the possible consequences of introductions have to be taken into account.

Management enhancement: Altering the pattern of management can substantially improve the economic attributes of a water-body. This include adopting culture fishery along with capture, developing sports fishery and opening to managed tourism, declaring protected areas and natural reserves, etc. For example, the marginal areas of wetlands are cordoned-off for culture fishery and the central portion (wetland proper) is left for capture or culture-based fisheries. Under the culture and capture fisheries system, as has been widely practised around the Loktak floodplain lake in Manipur, a series of small ponds created along the periphery of the lake, which is leased out for fish farming and the wetland proper is used for capture fisheries. Some of the floodplain wetlands serve as bird sanctuaries, national parks and reserves of biodiversity or used for navigation, irrigation, jute retting and collection of edible aquatic plants, animals and birds, besides agriculture along the marginal areas. Each of these activities affects the others in some way. Therefore, action plans need to be developed to integrate the many uses of the water-bodies with a holistic approach. Agriculture, forestry, horticulture, animal husbandry and poultry can be developed along with capture fisheries depending on the nature of the water-body and its catchments. Areas can also be left intact for wild life, harbouring birds as sanctuaries, wherever needed. Managing the different sectors in a farming system mode, with recycling of resources within the farming system can augment the benefits several fold. However, the long-term effects of this type of development, on the hydrodynamics and natural biological productivity are yet to be ascertained.

Culture-based fishery: When the fish harvest in open waters depend mainly or solely on artificial recruitment through stocking from outside it is referred to as culture-based fishery. This management tool is effective in increasing fish yields when recruitment of desired species is lower than the carrying capacity of the water-body. The main focus here is stocking and recapture. As most of the floodplain wetlands in India hold fish stocks, which are unable to fully utilize the food energy present in the system and are also poor in auto-stocking, stocking of right species at right size and density, after assessing the fish production potential, and harvesting at right time at right size, can significantly augment the fish production of these wetlands. Here, the fish growth is dependent on stocking density and survival is dependent on size of stocked fish. Important parameters determining the success of culture-based fisheries are: (*i*) size at stocking, (*ii*) stocking density, (*iii*) fishing effort, (*iv*) size at capture, (*v*) selection of species, and (*vi*) selection of fishing gear. While considering a water body for culture-based fisheries mode, the existing fish production, species spectrum and production potential of the ecosystem are to be taken into account. The supplementary stocking is done only to exploit the unused food energy present in the ecosystem, after estimating the carrying capacity of the water-body. Closed wetlands are more suitable for this management mode as recapture of the stock is possible. A universal guideline however, cannot be set as there can be many intermediate situations. Species selection is a very important component in culture-based fisheries. The species option before us for stocking is perhaps the Indian major carps. Stocking of locally important fish species is to be emphasized as far as possible. But non-availability of sufficient seed materials of many of such species is a major constraint in this direction. Breeding and mass scale seed production technologies for important fish species other than major carps need development and popularization. As a general guideline, the fish species options currently being advocated for culture-based fisheries in wetlands are stocking of *Catla catla* (surface feeder), *Labeo rohita* (column feeder) and *Cirrhinus mrigala* (bottom feeder) at 100-120 mm/10-15 g size and at species ratios as shown in Table 12.15. However, this might vary according to local situations and the existing species spectrum of the water body. The fish production from floodplain wetlands of West Bengal, Asom , Uttar Pradesh, Bihar and north-eastern states are currently being augmented through culture-based fisheries norms. The projected increase in production that can be expected from the wetlands by following culture-based fisheries is given in Table 12.16. The stocking and yield pattern in some wetlands in which culture-based fisheries are being followed in West Bengal, for example, is shown in Table 12.17. The yield rates were 308-3,021 kg/ha from the normal range of 150-350 kg/ha, vindicating the effectiveness of culture-based fisheries.

It is not recommended to develop all the wetlands into Indian major carp-based fisheries, as continuous stocking of major carps has caused drastic shift in species spectrum in several wetlands, at the cost of some of the prized non-stocked native fish fauna, *Puntius* spp., *Colisa* spp., *Chanda* spp., *Mystus vittatus*, *Ambassis* spp., *Amblypharyngodon mola*, *Gudusia chapra*, *Nandus nandus*, *Macrognathus* spp, *Botia* spp., *Wallago attu*, *Ailia coila*, *Ompok bimaculatus*, *Heteropneustes fossilis*, *Channa* spp., *Anabas testudineus*, *Notopterus* spp., etc. are a few among them. The wild fish stocks that are existing in the water bodies are to be taken into account while considering for stocking, as wetlands hold stocks of a large number of wild fish species on which

Table 12.15. Species combination for stocking in floodplain wetlands

Wetland type	Species	Stocking rate (%)
Closed weed-free wetlands	Surface feeder + column feeder	70
	Bottom (detritus) feeder	30
Closed moderately weed-infested wetlands	Surface feeder + column feeder	60
	Bottom (detritus) feeder	40
Closed highly weed-infested wetlands	Surface feeder + column feeder	30
	Bottom (detritus) feeder	70

Table 12.16. Current fish production and additional production expected

State	Current production (kg/ha/year)	Additional expected (kg/ha/year)	Projected increase (%)
West Bengal	150-350	1,500-2,500	10-14
Asom	75-150	500-2,500	6-15
Uttar Pradesh	40-200	500-1,500	8-13
Bihar	40-200	500-1,500	8-13
North-eastern states	60-75	300-1,500	5-20

Table 12.17. Stocking and yield pattern of some wetlands in West Bengal

Year	Stocking (kg)	Stocking rate (kg/ha)	Harvest (kg)	Yield (kg/ha)
Bhomra wetland (83 ha)				
1994-95	9,535	115	39,158	472
1995-96	5,819	70	25,550	308
1996-97	9,677	117	56,275	678
1997-98	8,936	108	77,762	937
1998-99	9,643	116	53,688	647
Akaipur wetland (32 ha)				
1994-95	3,940	123	31,800	994
1995-96	2,892	90	23,542	733
1996-97	6,114	191	39,796	1,244
1997-98	8,108	253	38,181	1,193
1998-99	4,163	130	61,290	1,915
Kola wetland (12 ha)				
1994-95	1,199	100	6,409	534
1995-96	1,970	164	10,906	909
1996-97	1,938	165	22,569	1,881
1997-98	3,101	300	36,247	3,021
1998-99	-	258	-	2,993

Source: Sugunan *et al.* (2000).

thousands of fishers depend for their daily livelihoods. The stocking strategy is to be based on sound studies and assessment of the ecosystem properties. Although the resource size of the wild fish stocks are not known for most of the wetlands, unregulated capture and environment modifications have depleted their catch necessitating stock assessment and fixing fishable limits and regulations based on empirical data for their sustainable fisheries and conservation. Wild stocks are seldom considered while deciding stocking density in culture-based fisheries. Compared to major carps, some of the wild fish species fetch much higher price and demand in some states. Breeding and seed production technologies for these species need to be developed and scaled up to support stock augmentation of such species.

The yields from floodplain wetlands in West Bengal, Asom and Bihar have undergone considerable increase from 100-400 kg/ha/year during 1990-95 to 900-1,400 kg/ha/year during 1997-2006 after adoption of culture-based fisheries through stocking practice.

The advantages of culture-based fisheries is that it do not involve use of chemicals, artificial feeds or modification of habitat; the technology is thus environment-friendly and less capital-intensive; amenable to community-based activity involving local people; unlike aquaculture, which benefits individuals, the income and benefits generated in culture-based fishery in open waters is distributed among a larger section of people, especially the rural poor; hence considered pro-poor. It also protects the ecosystem character and the regular fishing and netting activities prevent weed proliferation and thus swampification of the water bodies.

Most of the floodplain wetlands in India, from which sizeable quantity of fish production emanates, are managed by cooperative societies. Enhancements with limited technological intervention are perhaps the only feasible proposition in these resources for environmental sensibility, economic viability and social justice.

Enclosure culture: Farming of fishes and other aquatic organisms in confinements made of suitable materials and erected in water bodies so that the stock is protected until they are harvested can be generally called enclosure culture. The two enclosure culture systems are pen and cage. A pen is a fixed enclosure made of any suitable material with the bed of the water body forming the bottom side, while a cage is an enclosure with all or all but the top sides are closed and whether floating at the surface or submerged. Enclosures are commonly made of wooden planks, bamboo, synthetic screen, etc.

Pen culture: Pens are useful in shallow floodplain wetlands for raising table size fishes and prawns or fish seeds for stocking. Pens can be erected even in derelict or weed-choked wetlands, where aquaculture is not possible and fishing is difficult and can generate additional income. The peripheries of wetlands can be utilized without disturbing its fisheries or other functions. Commercially important species of fin fishes (Indian major carps) and prawns (*Macrobrachium rosenbergii*) are reared up to table size in pens. Pens can also be used for raising seeds of Indian major carps up to the stocking size of 100-120 mm. *Labeo gonius* and *L. bata* can also be reared in pens. The stocked species are completely under human control for management and protected from predation, compared to stocking in open water. The ideal site for pen culture may be with 1.5-2.5 m water depth along the marginal areas of wetlands, where water is available for at least 4-8 months. The shoreline should be of gentle slope. The bottom should be reasonably firm, smooth and the soil sandy loam. A production of table size Indian major carps at 4,000 kg/ha in four months; giant freshwater prawn, *M. rosenbergii* at 1,300 kg/ha in four months and in mixed culture of carps and prawns a yield of 2,000-2,500 kg of carps and 500-800 kg of prawns/ha in four months are achieved. With a survival of 80%, the production of fish seed of Indian major carps expected from a pen of 0.1 ha area is 500 kg in a rearing period of three months. However, this may vary depending on the agro-climatic area and local conditions. Fish production obtained from pen culture in some floodplain wetlands are given in Table 12.18.

Table 12.18. Fish production obtained from pen culture of Indian major carps

State	Wetland	Area (ha)	Year	Production (tonnes/ha)
North Bihar*	Manika	100	1983	4.00
	Kanti	100	1986	3.17
	Muktapur	60	1990	2.54
West Bengal	Bhomra	63	1999	0.65
	Akaipur	32	1999	1.90
	Kola	12	1998	2.99
	Gopalnagar	35	1999	1.73

Source: *Chitranshi (1989).

Cage culture: Floating cages are suitable for raising stocking materials and table size fishes from wetlands, which are deep, flood-prone and where the water level fluctuates considerably. Floating cages has the added advantage of being able to be moved to suitable areas even after installation. Indian major carp seeds can be grown to 100-120 mm/,10-15 g in 60-90 days with a survival of 80% at a stocking density of 50 fry/m^2. Three crops can be achieved in the cages in a year. Indian major carps, *Labeo bata* and *L. gonius* are reared up to table size The technology is currently being refined and scaled-up.

Fishery based on ornamental fishes: Explorations in floodplain wetlands in the past revealed that apart from food fishes, they also harbour several fish species, which are smaller, attractive and can be considered ornamental for aquarium purposes. Available information suggested the existence of 45 species belonging to 16 families in the floodplain wetlands of Asom and 63 species belonging to 23 families in West Bengal, with potential for aquarium purposes. Intensive explorations in future may reveal the existence of several more species.

Sustainability and livelihood issues

Sustainable development of fisheries in floodplain wetlands of the Ganga, Brahmaputra and Barak basin, which forms 33.5% of the total geographical area of the country and support one of the most densely populated areas of the world, is an important issue. Depletion, destruction and degradation of these valuable natural assets have not only created great problems for the food security, nutrition security and health security but also have great economic consequences for the people of Uttar Pradesh, Bihar, West Bengal, Asom, Meghalaya, Manipur, Tripura and Arunachal Pradesh. It is thus imperative to conserve and develop these resources by adopting scientific management practices for development, qualitative and quantitative improvement of ecological conditions, restoration of fish stock by implementing code of conduct of responsible fishing and farming practices and mass awareness programmes to prevent unsustainable practices adversely affecting the sustainability and productivity of these water bodies. Time has come to think seriously on these issues as it has an impact on the future needs of society.

The livelihood issues of floodplain wetlands comprise all the functions undertaken by people who depend on the water-bodies in one way or the other, which influence their daily life. The livelihood issues of fishers in floodplain wetlands pinch harder than the issues affecting the resources and their management. As the floodplain wetlands in India are under the open access system, there are multiplicity of uses and stakeholders, often causing conflicts among the parties. The fishers are neither the real owners of the wetlands nor are they allowed to enjoy the complete income from fishing. The terms of income distribution is inclined towards the right holders of the wetlands, viz. lessees, controllers, co-operative societies, owners, etc. The actual fishers are at loss, both in terms of direct sharing of output and the potential loss due to frequent denial of access or fishing. Wetland leasing policy plays an important role in capture and culture-based fisheries. Large water bodies, like floodplain wetlands, need high investment in terms of lease rent and transaction cost for acquiring right. Fishers do not have the money to acquire such rights. Suitable alternative can be co-management through setting-up of cooperative societies. This has been successful, particularly in West Bengal.

Policy issues in floodplain wetland fisheries

Enumeration of all the issues related to use of floodplain wetlands, their fisheries and management is a difficult proposal. The available information indicates the following major issues, which need to be debated and crystallized.

- There are different categories of floodplain wetlands with different ecological, biological, fisheries, hydrological, geographical and social attributes. They have to be classified for management and administrative purposes. Although some categorizations have been made based on their riverine connection, origin, biological characters, etc. there still need to be clear definitions and delineation for including them under open water for the purpose of fisheries development. The existing categorization, based on >10 ha as open water, also needs to be re-looked for management purposes.
- Fisheries perspective of wetlands requires more emphasise while planning for development/conservation and the fisheries realization of wetlands needs to be looked upon from the point of fish production potential rather than the current production.
- Wetland boundaries need to be clearly delineated and there is need for revision of revenue and administrative records in this regard for the purpose of fisheries management.
- A shift in fish fauna is being noticed in floodplain wetlands which are under active stocking and culture-based fisheries. There is severe paucity of bench mark data on the resource size and germplasm and catch of wild fish stocks of the wetlands. There is need for stock assessment of wild fish stocks in wetlands to realise their value.
- Majority of the floodplain wetlands are closed and cut off from their parent rivers. The riverine connections need to be restored, where ever possible, to improve their productivity and fish recruitment to rivers.
- Wetland fisheries can effectively be managed on community basis following a co-management approach, which ensures conservation, equity in distribution of profit, providing marketing channels, gender equity, etc. Hence, a holistic approaches, wherein environment, stock, species, habitat and stakeholders' needs are to be assimilated for sustainable results.
- Adopting lower or medium intensity technologies needs be thought of in wetlands for increasing fish production and its sustainability as there are many constraints in adopting technologies in open waters.
- Wetlands need not necessarily be recommended for stocking with major carps unless the intervention is required for augmenting fish production.
- Species of local importance and those better in utilizing the dominant food pathways in the system may be encouraged for stocking. The wetland managers and State departments need to be sensitized about this.

- There are unauthorized introduction of exotics in to our floodplain wetlands as there is no effective check on the steady inflow. This could adversely affect our ecosystems.
- Wise use concepts and principles applicable to floodplain wetlands needs to be clearly spelt out based on empirical data support for more practical purposes and effectiveness. There is need for generation of sufficient empirical information for framing viable wise use concepts and practices.
- Promote research to quantify wetland values and to develop practical and sustainable users' guidelines for wetlands and their surrounding areas.
- Encourage participatory research and development programmes involving common people, fishers, researchers and other stakeholders and share the project results with the community to give a sense of ownership and participation.
- There has to be more fisher-friendly policies and programmes, involving them, empowering them, making them owners and the major beneficiaries and also providing them with opportunities for alternative source of income to cope with crisis and to reduce their dependence on wetlands for livelihood.
- Wetlands cannot be sustainably managed without advanced scientific and technical information, peoples' participation and coordination of government-research-education as well as funding agencies for their developments.
- Developments need to be linked with the preference of the communities and their participation will have to be ensured.
- Appropriate coordination with various agencies and stakeholders will have to be established and the gap in information regarding planning and use of wetland resources within State Government Departments, research institutions, social organizations and central agencies needs to be bridged appropriately for growth and sustainability.

13. Coldwater Fisheries and Aquaculture

The coldwater fishery resources in India comprise high and mid altitude lakes, rivers, streams, their tributaries and reservoirs dammed across such rivers. These resources are poorly developed, primarily due to paucity of financial resources and limited development efforts. These waters maintain relatively low temperature, which supports low production levels. However, while coldwater fishery contributes less to the total inland fish production in the country, but its importance in the larger context of comprising unique biodiversity with valuable indigenous germplasm and maintaining environmental quality in hills cannot be underestimated. In terms of species diversity, we find that apart from the members of the family Salmonidae, which are commonly known as coldwater fishes, some Cyprinids belonging to sub-family Cyprininae, which inhabit streams, lakes and reservoirs, receiving snow-melt water directly from their watersheds are also included in this definition. There are a large number of indigenous and a few exotic species of fish, that are present in rivers, brooks, lakes, ponds of uplands. Of these, trout, snow-trout, mahseer, common carp and minor carps are important as sport and food fishes. These species are widely distributed both in the Himalayas and the Peninsular hill ranges (along the Western Ghats) of the country forming an entirely different eco-geographical entity.

Distribution/categorization

The temperature tolerance of coldwater fishes lies at lower levels of the thermal scale, which is of critical significance and plays a crucial role in their dispersal in the uplands. The thermal regime limits the very existence of fish species and other aquatic life, which greatly alters composition of biotic communities in the upland streams and wetlands. On the basis of the temperature tolerance, the coldwater fishes are categorized as eurythermal (having broad temperature tolerance range) and steno-thermal (having a narrow temperature tolerance range). The *Schizothorax richardsonii, Cyprinus carpio* and *Barilius bendelisis,* which can withstand a wide spectrum of temperature, can be categorized as eurythermal. The brown trout (*Salmo trutta fario*), the eastern brook trout (*Salvelinus fontinalis*) and the Tibetian snow-trout (*Diptychus maculatus*) are examples of steno-thermal species which tolerate only a narrow range of temperature, nearly up to freezing point of water. It is the upper level of the tolerance limit that determines survival, occurrence and distribution of fish in time and space. The thermal limits of snow trout range from 5 to 25°C, while for mahseer the range is 10 to 30°C and for exotic trout the range is 4 to 20°C, and for exotic carps it varies from 7 to 32°C.

Resources

Area-wise different types of aquatic resources in our hill regions are presented in Table 13.1.

Table 13.1. Types of aquatic resources in the hill regions in India

Water resources	Length/area
Himalayan and Deccan Plateau river systems	10,000 km
Brackishwater lakes (above 3,000 m asl)	2,340 ha
Freshwater natural lakes (1,500-2,000 m asl)	18,150 ha
Kashmir high mountain lakes (above 3,000 m asl)	400 ha
Valley wetland ecosystems	3,000 ha
Shivalik Himalayan lakes	74ha
Central Himalayas (freshwater lakes in Kumaon region)	355 ha
Water area under reservoirs	265,000 ha

Ecological adaptation

The coldwater fishes are often endowed with great powers of locomotion and have stream-lined bodies, i.e. trouts, schizothoracids and loaches. Majority of the coldwater fishes possess structures, especially adapted for clinging, burrowing or otherwise to withstand fast water currents.

The variable features of the environment have induced remarkable modifications among coldwater fishes, both externally and internally. Normally, there is very little food available in hill streams for resident fish species. Coldwater fish species have acquired modifications of mouth suitable for rasping encrusted organisms and removing algal slime off the submerged or emergent rocks and boulders. The modification of the lips for removing periphytic organisms is well seen in snow-trout, mahseer and certain minor carps like *Labeo dero, L. dyocheilus, Garra* sp. and minor catfishes like *Glyptothorax* sp. The coldwater species however, are ill adapted for feeding in deep and muddy waters.

Another characteristic feature of coldwater fish is their adaptation to living in highly oxygenated water available in torrential streams of mountains. Such oxygen-rich environment has induced structural modifications in the organs of respiration also. Owing to richness of water in its oxygen content, the gill-openings have narrowed and gills themselves are greatly reduced so much so that such fishes cannot survive for long in waters poor in oxygen. The oxygen limit of snow-trout is 5-8 ppm; for mahseer it is 5-7 ppm; for exotic trouts it is 6-9 ppm; and other exotic carps, it is 3-6 ppm. Hence, the occurrence and distribution of coldwater fishes, in addition to temperature is also dependent upon the swiftness of current and nature of substratum including plant and animal communities available at the bottom.

Fish diversity

In Indian uplands 258 species of indigenous and exotic fish are spread over in Himalayas and the peninsular plateau, which belong to 21 families and 76 genera (Table 13.2). The vast and varied piscine diversity includes tiny loaches to mighty mahseers.

Table 13.2. Principal coldwater piscine groups and fish species

Snow-trouts	*Schizothorax richardsonii, S.kumaonensis, Schizothoraichthys curvifrons, S.niger, S.esocinus, S.progastus, Lepidopygopsis typus, Diptychus maculatus*
Mahseers	*Tor putitora, T. tor, T. khudree, T. malabaricus, T. mussullah, Neolissocheilus hexagonolepis, N. wynaadensis, Naziritor cheylinoides*
Minor carps	*Crossocheilus latius, Garra gotyla, G. lamta, Labeo dero, L. dyocheilus, L. pangusia, Semiplotus semiplotus, Puntius ophicephalus*
Barils	*Raiamas bola, Barilius bendelisis, B. Barila, B. vagra*
Catfishes	*Glyptothorax pectinopterus, Pseudechenesis sulcatus, Pterocryptis wynaadensis*
Loaches	*Botia almorhae, B.birdii, Nemacheilus multifasciatus, N. rupecola*
Exotics	*Oncorhynchus mykiss, Salmo trutta fario, Ctenopharyngodon idella, Hypophthalmichthys molitrix, Cyprinus carpio, Carassius carassius, Tinca tinca*

As far as commercial importance of the available species is concerned, some of the coldwater fishes are known for sports, some others as food fishes and a few for their potential ornamental value as detailed below:

Sport fishes: An important aspect of coldwater fish of the uplands is the opportunity the species provide for sport. Brown trout (*Salmo trutta fario*), rainbow trout (*Oncorhynchus mykiss*) and certain species of large-scaled barbels like golden mahseer (*Tor putitora*), deep-bodied mahseer (*Tor tor*), copper mahseer (*Tor mosal*), black mahseer (*Naziritor chelynoides*), chocolate mahseer (*Neolissocheilus hexagonolepis*) are the principal species of sport value in Kashmir, Himachal Pradesh, Uttarakhand, north-eastern states, Nilgiris, Kodai hills and Munnar ranges, where Indian and Foreign tourists annually visit in large numbers. In certain regions, sport fishery constitutes an important source of revenue. In Jammu and Kashmir, trout alone contributes to about 0-50% of the state's revenue from fisheries. Therefore, apart from increasing production of carps, the hills have also shown the potential of high value, low volume species such as trouts and mahseer for food and angling activity (Table 13.3).

Food fishes: Majority of the coldwater fishes are caught individually by local fishermen in rivers and streams and do not form fisheries of commercial importance. A few, however, such as snow-trout (*Schizothorax* spp., *Schizothoraichthys* spp. and *Lepidopygopsis typus*), large-scaled barbels (*Tor* spp.), common carp (different genotypes of *Cyprinus carpio*) and a few minor carps (*Labeo dero* and *L. dyocheilus*) are some of the commercially important food fishes, dwelling in uplands (Table 13.3). ...ly speaking, even these species do not form fisheries of appreciable magnitude. The ...sons attributed to this situation are many, but the most important ones are: (*i*) due to ...w growth and small size, most of the fishes fetch low price, (*ii*) use of cast net as the ...in gear is basically one man unit so community fishing is hardly prevalent, and (*iii*) ...terrain in uplands have meagre transport facilities causing difficulty in transporting ...ches from collection site to nearby markets to get remunerative price for the catch, ...ich under compulsion are sold by fisherman as one or two units in nearby villages. ...sently the fish farming in the hilly region is based on exotic species. But there are ...ne native species having cultivable traits, which could be classified as food fishes.

Ornamental fishes: Some colourful and fascinating species also inhabit different aquatic resources of the coldwater zones. Some of these have been already recognized as ornamental fishes. Uplands of north-east Himalaya of the country is known as repository of ornamental fish species. Some of the important ornamental species present in coldwaters are enlisted in Table 13.3.

Table 13.3. Potential fish species for diversification in hills

Food species	Sport species	Ornamental species
Indigenous		
Tor putitora, T. tor, Schizothorax richardsonii, S. esocinus, Labeo dero. L. pangusia, L. dyocheilus, Neolissocheilus hexagonolepis, N. wynaadensis, Lepidopygopsis typus, Osteobrama belangeri, Semiplotus semiplotus, Pterocryptis wynaadensis	*Tor putitora, T. tor, T. khudree, T. mussullah, T. malabaricus, Raimas bola*	*Brachydanio rerio, Danio devario, D. aequipinnatus, Botia almorhae, Barilius bendelisis, Barilius bakeri, Barilius canarensis, Shisturae sp., Hara sp., Oriecthys sp., Labeo nandina, Acanthocobitis botia, Lepidocephalus guntea*
Exotic		
Cyprinus carpio, Oncorhynchus mykiss, Hypophthalmichthys molitrix, Ctenopharyngodon idella	*Salmo trutta fario*	*Gageta cenia, Conta conta, Carassius carasius, Carassius auratus*

Coldwater aquaculture

Exotic species

The aquaculture in hills is of a very recent origin. Earlier fishery in hills was primarily a subsistence activity involving catching of fish-stocks from rivers/streams and lakes. The primitive aquaculture was restricted to government farms/hatcheries, which were used mainly to maintain some broodstocks for annual seed production of brown trout for planting in streams to maintain sport-fishing population. Efforts for trout culture in the upland region of India had been initiated since 1863. Sir Francis Day made an unsuccessful attempt in the year to introduce eyed eggs and fry of brown and lock-leven trouts in the Nilgiri hills. Later on Mr F J Mitchell succeeded in introduction of eyed eggs of brown trout in the Harwan hatchery in Jammu and Kashmir in 1900. Since then the species has been propogated at various farms both in the northern hill states and southern upland region. But the culture of Rainbow trout (*O.mykiss*) could gain momentum/or was successful since early nineties of the last centuary only, with the assistance of two foreign aided projects one each in Jammu and Kashmir and Himachal Pradesh, since then the species has been successfully bred and grown to table size in Champawat farm of Directorate of Coldwater Fisheries Research (DCFR) also, in Kumaon region.

However, the overall culture fishery in the most of the hill states is still in developing stage. The important factors responsible for its poor development could be attributed as to non-availability of natural ponds, land unsuitable for pond construction in most of the places due to high gravel-sand percentage in soil, high seepage, non-availability of quality seed, temperature linked low productivity of aquatic resources, and lack of proper support and extension facilities. But, since last two decades, Directorate of Coldwater Fisheries Research (erstwhile NRCCWF), Bhimtal, Uttarakhand and some other government agencies have initiated works on fish culture in uplands. As a result, the scenario has changed and aquaculture is gaining momentum in the coldwater regions also. Many more fishes other than trout and exotic carps like *Tor putitora, T. tor, Neolissocheilus hexagonolepis, Labeo dero, L. dyocheilus, Osteobrama belangeri, Semiplotus semiplotus* and *Schizothorax richardsonii* from indigenous stock are being exploited; amongst which *N. hexagonolepis, Osteobrama belangeri, S. semiplotus* are under evaluation as new candidate species (Table 13.3). Still maximum efforts revolve around exotic trouts and carps mainly due to slow growth rate of indigenous species.

Trouts

Hatchery management of exotic brown trouts: Suitable methodology has been developed for reduction in mortality at different stages, viz. ova, alevin, fry and fingerling, of brown trout *Salmo trutta fario* in hatcheries and farms located in hill states. The percentage survival could be raised to 80% from the earlier record of hardly 20% between green egg to early fry stage (Table 13.4). The practice of segregating spawners much before breeding commencement and feeding them on nutritive diet helped in increasing egg laying capacity of brooder by an average of 218 eggs/kg of spawner body weight.

Table 13.4. Impact of scientific hatchery management on brown trout survival

Trial	Treatment	No. of experimental green eggs	Fertilization (%)	Survival at		Cumulative survival at swim-up-fry (%)
				Eyed ova stage (%)	Alevin stage (%)	
1	Segregated	727,700	96.9 (94-98)	93.47 (91-96)	91.26 (90-92)	88.6 (87.5-88.7)
2	Non-segregated (range)	414,000	90.4 (93-96)	66.9 (64-70)	62.6 (58-66)	57.8 (53.4-60.27)

Brown trout rearing: The growth experiments have revealed that fishes grew to size range of 215-315 mm in length and 165 g in weight when fed with 28% protein diet. In comparison growth with 47% diet was better with size range of 245-330 mm in length and 325 g in weight. The estimated production with high protein diet could be around 8 tonnes/ha, while it was only 3 tonnes/ha with low protein diet. The low protein diet gave a feed conversion ratio of 3.7, feed efficiency of 28.3 and survival of 50%, while high protein diet recorded values for these indices at 1.7, 57.2 and 64%, respectively. Thus formulated feed and other management practices will help in raising

brown trout in farms, which is much sought after for improving sport fishery in hill streams.

Rainbow trout farming: Rainbow trout farming needs high investment in the form of pond construction, procurement of seed, feed, maintenance of fish health and quality water requirement. So, its expansion has limitations due to these barriers coupled with limited markets. The efforts to develop farming practices for rainbow trout (*Oncorhynchus mykiss*) were initiated quite early in the country, especially in Jammu and Kashmir and Himachal Pradesh. But these earlier attempts with the existing stock of rainbow trout, in both the states could not succeed in making its farming commercially viable. Successful collaboration with European Economic Community (EEC) and Norwegian Government in last two decades has accelerated rainbow trout (*Oncorhynchus mykiss*) farming in Jammu and Kashmir and Himachal Pradesh, respectively. This included using improved strain(s) provided by donor countries, setting up of modern raceways, hatcheries, feed mills, disease control measures and human resource development. Trout farms established at Kokernag in Jammu and Kashmir and Patlikuhal in Himachal Pradesh have state-of-art facility on rearing and breeding. Its farming in Himachal Pradesh has been extended to private entrepreneurs also. Now, the trout farming is also developing in other hill states--Uttarakhand, Sikkim and Arunachal Pradesh.

Rainbow trout has better growth and maximum cultivable traits amongst coldwater species. In a culture experiment conducted at Champawat Farm (1,620 masl) of DCFR, the fish attained maximum growth of 200 g, 1,100 g, 2,100 g and 3,000 g, respectively, during 1-4 year's life span. In subsequent efforts the trout yearlings attained maximum growth of 300-350 g in the farm. The stock fed on two formulated diets (Table 13. 5) with 47.10 and 57.68% protein level attained sexual maturity after second year in male and after third year in female. Artificial breeding was conducted by stripping during December–February. Fecundity recorded was 547-1,402 eggs/ kg body weight. Incubation period took 61 days at ambient water temperature of 4.5–7.5°C at the farm.

Table 13.5. Proximate composition of experimental diets (% dry weight)

Parameters	Diet 1	Diet 2
Crude protein	47.10	57.68
Ether extract	12.85	9.38
Crude fibre	4.65	1.35
Ash	8.90	11.93
Ntrogen-free extract	26.50	19.66
Gross energy (MJ/kg)	15.49	17.18

It is estimated that from 25 trout hatcheries in different states (Table 13. 6) about 1.5 to 2.0 million trout seed are produced annually for farm rearing and stocking in streams for angling. In this, maximum contribution is from Jammu and Kashmir and Himachal Pradesh. The current production of rainbow trout reported from hill states is estimated to be

Table 13.6. Trout culture farms/ hatcheries in India

State	Number
Jammu and Kashmir	7
Himachal Pradesh	5
Uttarakhand	4
Sikkim	3
Arunachal Pradesh	2
Meghalaya	1
Tamil Nadu	1
Kerala	2
Total	25

between 300 to 500 tonnes, which has the potential to increase many-folds, if the production loses from disease can be controlled and other financial assistance including management support, marketing facility and processing is extended to hill states.

Trout marketing, post-harvest and value-addition: Production of farmed trout is increasing year by year in our country. But, lack of proper marketing facility is the biggest hindrance in its expansion. Sale of farmed trout in fresh condition is a big problem faced in the production centres. Most of the trout farms are located in interior and remote areas, which have limited access to the domestic markets. Further being a valuable commodity, there is complete dearth of local markets. In this situation, there is need for establishment of post-harvest and value-addition units either to preserve the fish for a longer duration or to make value-added by products, so as to attract a wider market within the country and also for augmenting exports.

Carps

The three strains of exotic carps, *Cyprinus carpio* var. *communis*, *C. carpio* var. *specularis* and *C. carpio* var. *nudus*, were introduced in a few Himalayan lakes to provide faster growing fish in hills. This activity was restricted to only one-time seed stocking in open-waters and some seed production in Government controlled farms/ hatcheries. But with the efforts of the DCFR, Bhimtal, the composition of cultured species varies from monoculture of common carp to polyculture of grass, silver and common carp. Grass carp has emerged as a popular species . Small-scale carp culture is gaining popularity in the hill regions, owing to simpler farming techniques, low input requirements and possibilities of integration of available resources.

Monoculture of exotic carp: Culture of *Cyprinus carpio* in the village pond in Kashmir using kitchen refuse and other run-off from the village as source of inputs has shown production levels of 2.5-3 tonnes/ha in a grow out period of 12 months. This simple technology could be profitably utilized in Panchayat ponds in rural areas of Kashmir valley. Similar, successful monoculture trials on common carp strain have been conducted in hill regions of Uttarakhand. Average annual fish production of 1870 kg/ha had been achieved by monoculture of common carp in experiments conducted at the DCFR farm located at Champawat (1,620 masl).

Mixed culture of exotic carps: In the upland waters, Indian major carps do not grow well due to low thermal regime, therefore Chinese carps have been taken as the candidate species for mixed culture development. In the experiments conducted at Chirapani farm (DCFR) located at 1,620 masl, the stocking densities tried were 1.5, 2.0, 3.0, and 5.0 fishes/m^2 in the combination of 50 : 25: 5; 50 : 20 : 30; 25 : 25 : 50; and 20 : 20 : 60 for common , silver and grass carp respectively. The fishes were fed twice daily at 2% of their body weight with supplementary feed constituted of mustard oilcake (30%), soya flour (25%), rice polish (15%), wheat-bran (20%) and fish-meal (10%). It is reported that in a rearing period of approximately 200 days, the highest production (412 g/m^2) was achieved at the stocking density of 3 fish/m^2 with species combination of 25, 25 and 50% of common carp, grass carp and silver carp. In general, the highest growth rate of 0.27 g/day was reported at a stocking density of 2 fish/m^2, while it was 0.02 g/ day at a higher density of 5 fish/m^2.

The mixed carp farming technology has been successfully demonstrated by the DCFR, Bhimtal. The demonstrations were conducted in different ponds located at altitude ranging from 900 to 17,400 masl in Uttarakhand and North-eastern states mainly Arunachal Pradesh. At present feasible fish farming techniques for hill region have been developed by the DCFR. Polyculture involving grass, silver and common carp with an average fish production of 3,708 kg/ha, in the range of 3,400 to 6,800 kg/ha/year has been achieved from the earthen ponds of Uttarakhand located in middle Himalayan region (800-2,000 masl). In North-eastern hill region (some parts of Arunachal Pradesh and Manipur) rohu or/and chocolate mahseer are cultured along with grass, silver and common carp @ 3-4 fish/m^2 in farmers pond with provision of supplementary feed @ 2-3 % of their body weight. The production from these ponds is estimated at 0.31-0.42 kg/m^2. Paddy- cum-fish culture popularized by the DCFR, has gained popularity in the Apatani Plateau of Lower Subansiri District (Arunachal Pradesh) and adjoining areas in the agricultural field located above 1,500 masl. The fish production from the fields varied from 150 to 200 kg/ha/year.

Induced breeding of sliver carp and grass carp at high altitudes: The DCFR has also achieved success in induced breeding of silver carp and grass carp at above 1,600 masl. Both species used to take 6-7 years to mature at these altitudes, however, the experiments have been conducted to advance maturity by hormonal feeding of broodstock through diet. The fishes were bred by injecting ovaprim @1.3-1.6 ml/kg in 2-3 doses during 14-16 hr at 22-23°C. The silver carp, as per report, normally does not release eggs naturally but has to be hand stripped. The hatching process was found normal at 22-24°C, but when the eggs were reared at less than 20°C, the development got affected. The successful breeding has paved way to procure seed of these species during the suitable growing period (April to October) and will go long way in augmenting fish culture in hills

Use of polyhouse in fish farming

Low water temperature during winters is the main limiting factor in hill aquaculture, particularly in high altitudinal regions. Hence, raising the water temperature by use of polyhouse is of paramount significance. Therefore, experiments were conducted at DCFR's Champawat farm during winters (November to February) to ascertain the impacts of greenhouse effects on ambient water quality, temperature and manifestation of the raised temperature on the growth and survival of common and grass carp fry in the agro-climatic conditions of Lesser Himalayas. The ponds covered with polyhouse revealed drastic increase in temperature in the covered area. The air temperature in the polyhouse was 6.05°C higher than the control at morning (minimum range), while it was 9.24°C higher in the afternoon (maximum). Likewise, the water temperature in the pond raises 7.06°C in the morning and 10.96°C at the afternoon, than the control ponds. As a result, growth rate attained by common carp fry in the experimental ponds was 39.07 % higher than that of the control ponds. The grass carp fry also registered marginally higher (3.41 %) growth rate over the control ponds.

Indigenous fish species

Artificial breeding of different snow-trouts

Different species of snow-trouts are indigenous to Kashmir inhabiting both lacustrine and riverine systems. Most of the species are endemic in the valley and through the years of anthropogenic and environmental stresses, their fishery is on the decline. To restore this fishery, the first initiative for artificial propagation was attempted in Kashmir and success was achieved in obtaining pure and healthy seed of different species such as *Schizothoraichthys niger, S. esocinus, S. curvifrons, S. micropogon* and *Schizothorax. richardsonii* through artificial fecundation. The fecundity per kg body weight of fish was reported to range between 17,000 and 35,000 ova in different species. The size of eggs ranged between 3.0 and 4.5 mm and the rate of fertilization ranged between 70 and 90%. The fertilized eggs of *Schizothorax niger* could be incubated both under still and flowing water conditions, while in other species the larval hatching was successful only under flowing water. The reported cumulative survival from egg to swim-up fry was 80% in *Schizothorax niger* and 60% in *Schizothorax micropogon* in a specially designed incubator with flowing water facility. However, the percentage survival in *Schizothorax esocinus, S. curvifrons and S. richardsonii* ranged between 35 and 55, 25 and 30, and 30 and 35 (Table 13.7).

Table 13.7. Artificial propagation of different Schizothoracid species

Species	Per cent fertilization	Incubation period (days)	Water temp. (°C)	Cumulative survival from egg to fry (%)
Schizothoraichthys niger	70-92	8-15	9.5-20	55-80
S. micropogon	75-85	15-18	10-20	40-65
S. esocinus	80-90	15-20	13-18	35-55
S. curvifrons	70-75	8-15	14-18	25-35
Schizothorax richardsonii	75-80	8-12	14-18	30-35

Development of field incubator for snow-trout

In the absence of full-fledged hatchery at the field site, a portable incubator has been designed for production of Schizothoracid seed at the stream site. The devised incubator consists of an outer metallic circular jacket (circumference 85 cm, height 35 cm and diameter 25 cm) with an inlet (diameter 1.5 cm) at the bottom and an outlet (diameter 1.5 m) at the top. The incubator inside is zinc painted and is provided with a handle. Inside the jacket, six metallic circular hatching trays are arranged in a row one upon the other. Each tray (circumference 60 cm, height 5 cm and diameter 20 cm) has a base fitted with nylon netting (approximately 196 mesh/cm^2). The metallic walls of the trays are coated with rustproof paint. The lowermost tray rests on a small triangular stand permanently fixed to the last tray. The bottom of the incubator contains a layer of sand and gravel to check incoming silt.

The incubator can be conveniently installed on the sloppy side of a running water stream and through inlet of rubber/plastic pipe, and a continuous flow of water is maintained. The water enters through inlet at the bottom and leaves from outlet at the top. This mechanism maintains a steady current of water inside the incubator with flow ranging from 2 to 3l/minute. Incubator needs to be checked occasionly to remove dead eggs.The working of the designed incubator has been tested on the artificially stripped eggs of *Schizothorax* and those collected from nature, and in both cases encouraging results were achieved. The incubation period ranged from 8 to 15 days with 60-65% of survival. Regarding survival rates, no significant difference was recorded in hatching trays stocked at 2,000-2,500 eggs and kept at different tiers inside the main incubator. Within two weeks, this small-sized incubator can produce 10,000 hatchlings. This capacity can be increased suitably by changing incubator size. The advantages of this incubator are: (*i*) it is handy and economical, (*ii*) can be installed in the field by the side of a stream, (*iii*) there is no possibility of oxygen depletion inside the system as it can be placed near to a running water stream, and (*iv*) the size of the incubator can be changed depending upon the availability of broodstock and quantity of seed to be produced (Table 13.8).

Table 13.8. Average survival in various field trials of the designed incubator

Tray no.	No. of eggs	Hatchlings produced	Percentage survival	No. of eggs	Hatchlings produced	Percentage survival
1st tray (bottom)	2,000	1,180	59.5	2,500	1,525	61.0
2nd tray	2,000	1,264	63.2	2,500	1,507	60.3
3rd tray	2,000	1,228	61.4	2,500	1,525	61.0
4th tray	2,000	1,306	65.3	2,500	1,575	63.0
5th tray	2,000	1,240	62.0	2,500	1,527	61.1
6th tray (top)	2,000	1,262	63.1	2,500	1,502	62.0

This miniature hatchery will greatly help in seed production activity of snow-trout, thus facilitating rehabilitation of this species by production of seed at the site and ranching it at suitable sites in streams.

Seed production of snow-trout: The artificial breeding and rearing of snow-trout (*Schizothorax richardsonii*) has been achieved at DCFRs Chirapani farm from wild spawners. The experiments on artificial breeding were conducted manually by 'wet stripping method'. The rate of fertilization reported was 80.0-94 %. The incubation of fertilized eggs under two different conditions, still and continuous water flow was 96-108 hr in former at temperature range of 22.0-24.5 °C and 120-144 hr in latter at temperature range of 20.0-22.5°C. Survival at hatching stage was higher (81.0 %) in still water condition, whereas it was low (58.0%) in continuous flow. The size of alevin range from 7.5 to 9.0 mm with corresponding weight of 0.015 to 0.020 g, having a large yolk sac. The absorption of yolk sac takes place five days (Within 84-168 hr) after post-hatching and the fry is 9.5-13.5 mm in length.

The young fry starts feeding on supplementary feed just after absorption of yolk sac and complete development of digestive system. The fry were fed on a laboratory compounded wet artificial diet having 32 % crude protein @ 5-10 % of body weight. The feed composition was soyflour (38.0 %), groundnut oil-cake (20.0%), rice polish (20.0%), fishmeal (20.0%) and vitamin-mineral premix. The finely powdered dry feed was soaked in water to make small balls, which were kept in enamel coated feeding trays on pond bottom, twice a day. The starter diet was found very helpful in reducing mortality rate at this critical stage. The methodology developed has opened possibility of raising *Schizothorax richardsonii* seed on a large scale to ranch depleted waters for enhancement of fish-stocks in Himalayan region.

Golden mahseer seed production: For seed production of golden mahseer (*Tor putitora*). a hatchery unit was designed and established by DCFR at Bhimtal (Nainital), close to lake. The unit comprises series of tanks placed at a specific height with water supply and distribution systems, creating a flow-through impact on hatching trays and troughs. This design has been developed to fit in rural hatchery concept and is cost effective.

During breeding season, the ripe and mature spawners collected by gill-nets from local lakes– Bhimtal, Naukuchiatal and Garurtal. The female brooders normally are in the size range of 350-620 mm with corresponding weight of 500-2,200 g in these lakes. The ripe eggs are stripped and fertilized with oozing milt from male spawners in the size range of 290-460 mm/300-800 g by dry method. The rate of fertilization varied from 88.5 to 97.0%. The incubation period ranged between 92 and 100 hr at a water temperature of 22-24°C. The hatching rate ranged between 93 and 97% and yolk absorption was completed in 10-12 days. The cumulative survival from fertilized eggs to swim-up fry was estimated at 95%. After size grading, mahseer fry were stocked in flow-through water troughs (2 m^2 area) having flow rate of 3-4 litres/min at 2,500-4,000 m^2. The fry were fed with laboratory compounded dry diet, having crude protein level of 45.5%. The main ingredients of artificial diet were casein, soybean, silk-worm pupae, fish oil supplemented with vitamin and mineral pre-mix. The feeding was carried out at 10-15% of body weight initially (20-25°C) and reduced to 5-10% latter (10-20°C). After fingerlings rearing was over ranching programme was initiated in different lakes and streams in locality. During rearing period, water-quality parameters ranged between 10.5 and 26.5°C temperature, 7.1 and 7.9 *p*H, 8.2 and 11.5 mg/litre dissolved oxygen, 60-140 mg/litre total alkalinity, 1.4-4.5 mg/litre silicates, nil-0.02 mg/ litre phosphates and 12-15 µg/ litre nitrates. In the process, a survival of 70-90% was achieved at different developmental stages.

Flow-through hatchery for mahseer eggs: A flow-through hatchery, designed and fabricated by the DCFR, Bhimtal, in Kumaon hills, has the capacity of incubating 0.25 million eggs, rearing 0.2 million swim-up fry and production of 0.1-0.15 million advanced fry. The capacity of a flow through hatchery can be further increased with installation of more troughs/trays and nursery facilities with substantial increase in water quantity through overhead tanks. In comparison to conventional methods, in flow-through hatchery it was possible to achieve 30% higher survival from fertilized egg to advanced fry stage. This hatchery is very useful in producing stocking material of golden mahseer on a large-scale for ranching in natural waters and for raising under aquaculture programme.

Hatchery site: The site as far as possible should be at a higher elevation to ensure sufficient flow of water and should be quite safe from high flood zone of the source. The terrain and water supply for hatchery/farm site should have moderate gradient, uniform thermal regime and least human activities along its catchments. Preference should be given to a site where gravity water supply can be assured in hatchery and farm. The water source to the hatchery should be of good quality and of adequate quantity.

Water source: The source of water may be either rheocrene or limnocrene type of springs or from a brook/stream having low silt content and organic nutrients. The water supply to the hatchery must not contain pollutants or toxic substances detrimental to fish-life. Water from the spring source is the most ideal for mahseer cultivation as temperature regime does not fluctuate much. The oxygen content of water is of paramount significance and should be 7.0-9.0 mg/litre at all times and in all seasons. The water temperature between 20 and 25°C during breeding and marginally higher during rearing phase is desirable. It is always better that the water is passed through de-silting device or a deep storage chamber before it is fed to hatchery.

The distribution of water in the hatchery should be so regulated that each unit, comprising hatching troughs and nursery tanks have separate inlets to receive the required quantity of fresh oxygenated water in various components of the hatchery; overhead tanks with pumping facility can be a suitable alternative (Table 13.9).

Table 13.9. Water flow requirement in mahseer at each developmental stage

Incubation of fertilized eggs and hatchlings	1.5-2.0 litres/min for 5,000-10,000 stock at water temperature of 20-25°C
Swim-up fry and early fry	2.0-3.0 litres/min for 3,000-5,000 stock at water temperature of 25-27°C
Fry and advanced fry	3.0-5.0 litres/min for 1,000-3,000 stock at water temperature of 25-30°C

Broodstock: Unlike salmonids which are domesticated species, the availability of broodstock either from farm or from wild waters is a pre-requisite for mass-scale seed production of golden mahseer. Mahseer is said to have multiple spawning periodicity. The gravid fish in the spawning run, either from streams, lakes or reservoirs are gilled in nets and are employed for stripping operation. The species is amenable under controlled conditions for egg-taking and artificial fecundation, hatching and fry and fingerling rearing.

Hatchery unit: A hatchery, for incubation for eggs and rearing of swim-up fry, is generally sheltered with a roof having number of hatching troughs and tanks, especially designed for this purpose. The floor should be cemented with a gradient to facilitate cleaning and removal of water. The hatchery should be protected from direct sunlight and should have adequate neat and clean working space.

Troughs: The hatchery troughs may be of different shapes and sizes but each should have capacity to hold sufficient water for rearing eggs, larvae and early fry. The rectangular troughs (220 cm × 50 cm × 40 cm or 220 cm × 60 cm × 50 cm), which are generally used in the trout hatcheries, can be used for rearing mahseer eggs and raising its larvae and fry. The depth of troughs may be increased by 10-25 cm to facilitate rearing of spawn and fry of mahseer. These troughs can be made from cement, aluminum but preferably of fiberglass. The arrangement of hatching troughs may be in a series so that water source flows into the first or head trough to subsequent troughs. Additional water supply to augment the dissolved oxygen content can be provided for each trough. Each trough should have a separate inlet and outlet mechanism for water. A trough with at least five hatching trays can hold 20,000-25,000 fertilized eggs.

Trays: The hatching trays made of fiberglass/wood may be rectangular or square in shape with the size so adjusted that 4-5 trays can be placed in each trough. The bottom of each hatching trays is fitted with synthetic netting cloth (mesh 2 mm) to ensure regular water movement, and height of each tray ranges from 3 to 4 inches (7.62-10.16 cm). The outside dimensions of each tray are such that they can be accommodated in series along the length of each trough. Each tray (50 cm × 30 cm × 10 cm) has a capacity to hold 4,000-5,000 fertilized eggs.

Nursery tanks: The nursery tanks are the other important component of a hatchery, which are used for rearing early fry of mahseer during their initial feeding stage. These tanks may vary in shape and size but should not be very deep. Efficient nourishing of tiny mahseer fry can be possible in shallow tanks. The suggested size of the rectangular nursery tanks can be 2.0 m × 0.5 m × 0.6 m or 2.0 m × 0.75 m × 0.60 m, and circular tanks, preferably of fiberglass, with suitable inlet and outlet facilities can also be used.

Fry ponds/tanks: The advanced fry reared in the nursery tanks are shifted to earthen ponds (5.0 m × 1.5 m × 0.75 m or 3.0 m × 1.0 m × 0.6 m), available at the farm site for raising mahseer fingerlings. These fry ponds/tanks can also be constructed using stone pitching, cement or made of fiberglass with continuous water renewal facilities (flow rate 2-3 litres/minute). In these ponds fry at 1,000/m^2 can be stocked.

Artificial feed for mahseer and snow-trout: The DCFR in its efforts to develop a balanced formulated feed for coldwater fishes, especially for mahseer, had conducted a large number of experiments, in which six diets were formulated and compounded. The feeding experiments were carried out on the hatchery reared hatchlings, advanced fry, fingerlings and juveniles collected from nature. Artificial diets in protein range of 21.4 to 50.2% were tested, better growth and survival was recorded in 45.4% protein diet. A positive correlation was observed between dietary protein content and overall growth performance and conversion ratio. The feeding trials have been reported on different stages of golden mahseer and snow-trout also. The comparative growth rate results reported by the institute indicate that mahseer shows better performance in comparison to snow-trout at all developmental stages.

Coldwater capture fisheries and ecology

Stream ecology of North-west Himalyan streams

Kashmir streams: General creel census of important trout streams in Kashmir valley was undertaken to determine fishing pressure and productive potential. The study was to fix the bag limit for angling on a sustainable basis. This work assumes importance in view of promoting angling tourism of brown trout *Salmo trutta fario*. Similarly, in Jammu region, potential mahseer seed collection sites were identified and quantified in local streams of Jhajjarkotli, Anji, Beni, Duddar and Ujh. Based on various ecological parameters involving water quality and status of benthic population in different streams, a classification of streams was developed, which reflects productive potential of each stream type. The results of this investigation are helpful in formulating any ecological action plan for stream management with focus on fisheries development and conservation.

Ladakh streams: The investigations carried over on river Indus in Ladakh region of Jammu and Kashmir at above 3,000 masl by the DCFR in December 2007 revealed that Indus and its stream waters are alkaline having *p*H in the range of 8.1-8.8, temperature between –0.4 and 2.0°C, dissolved oxygen 9.2-12.0 ppm, alkalinity, 68-72 ppm, Silicates. nil. The fish diversity within the system was found to be composed of 17 speceies, mainly comprised of snow trouts (5 spp.), loaches (9 spp.) and 3 exotic speceies (3). The snow-trouts are represented by *Diptychus maculates, Schiopygopsis stolczkae, Schizothoraichthys labiatus, Schizothorax richardsonii, Ptychobarbus conirostris*. Amongst loaches, three belong to genus *Nemacheilus, N. arafi, N. montanus, N. fascimaculatus;* six belong to genus *Triplophysa, T. choprai, T. gracilis, T. griffithi, T. ladacensis, T. microps* and *T. tenuicauda*. Exotics are represented by *Salmo gairdneri gardneri* and by *C.c. communis* and *C.c. specularis*.

Himachal streams: The investigations carried over on the hill streams of four basins (Satluj, Beas , Yamuna and Ghaggar) by many investigators showed that these streams can be classified in four types depending on altitude and bed type. Streams (Faujal, Sarvari, Parvati, Sainj, Tirthanand, Jeuni) which are in the altitude range of 850- 1,440 m and above having temperature range of 10- 16°C. *p*H range of 7.0-9.4 and total alkalinity range of 38-90/mg have only 1-2 species , trout and *S. richardsonii* latter being dominant. Streams in the altitude range of 700 m to 1,100 m with temperature range of 18-20° C, total hardness range of 46-139/mg and alkalinity range of 112-210/mg commonly present in valleys (Ashni, Giri, Jeuni, and Jarol) support a variety of 5-8 fish speceies with mahseer being dominant. Streams (Ali, Baner, Gaj, Suketi and Dabar) in the altitude range of 400-700 masl having temperature range of 20-22°C, total hardness range of 71-162 mg/litre, have 4-15 fish species with no group being dominant. *T. putitora* and *S. richardsonii* are important fish species from commercial point of view. *Barilius bendelisis* is present in almost all streams of lower and middle reaches of Himachal Pradesh. Fishes like *Channa* spp, *Xenentodon* sp., *Sperata* sp., and *Heteropneutes* sp., *Mastacembelus* sp., have started colonizing the streams but do not form important fishery. Presence of exotic fish, *Cyprinus carpio* in nursery streams is a worrying factor.

North-east Himalyan streams

The streams within north- eastern Himalaya above 1,000 masl have usual cold water characteristics but in regions like Meghalaya and other parts where coal mining is going on, these do not show typical cold water characteristics because of the impact of Acid mine drainage (AMD, i.e removal of vegetation and soil to gain access to metal or coal deposits). The dissolved oxygen content range from 5.7-11.6 mg/litre, have presence of free carbon dioxide, 5-9 mg/litre and certain stretches are acidic. Cold water fish germplasm within these streams is represented mainly by snow trouts (*S. richardsonii, S.esocinus, Schizopygae rogastus*) mahseers (*T. tor, T.putitora, N.hexagonolepis*) and carps *L. dero* (*L. pangusia, S. semiplotus*).

Central Himalaya streams

Kumaon Himalayan streams: The investigations were carried out in Gaula, Gandaki, Ladhiya and some other lotic systems in the region. These streams have *p*H in the range of 7.3-8.2, temperature range of 13.2-22.3 mg/litre, dissolved oxygen range 8.8-11mg/litre and total alkalinity range of 54.0-120 mg/litre. The productive potential of the systems was evaluated in terms of biodiversity. The fish biodiversity of Gaula stream was represented mainly by indigenous mahseer (*Tor putitora*) and snow-trout (*Schizothorax richardsonii*) along with other species, viz. *Garra gotyla, Barilius bendelisis, Nemacheilus* sp. and *Botia birdi*. The snow-trouts of 160-250 g in weight and 150-260 mm in length were frequently encountered. The sex ratio of *T. putitora* was recorded at 1: 1.6 (175-255 mm in length). On the other hand the sex ratio of male to female of *S. richardsonii* in the stream was 0.5: 1. The males were in oozing stage in June while gravid females were encountered between July and August. The experimental fishing revealed the CPUE value to range between 107 and 500 g/man/hr. The contribution of *S. richardsonii* to total catches was nil-67.3% and that of *T. putitora* between nil and 59%. Other species also contributed significantly to total catches at specific stretches.

The rivulet Ladhiya flowing through the Middle and Lesser Himalayan belts of the Central Himalaya, in district Champawat (Uttarakhand) is a tributary of the river Kali. A total of 10 fish species have been observed from the system, in which all 10 were recorded from the lower stretch, 5 from upper and 10 from its major tributary – Kwerala.

The fishery in the rivulet is predominated by *S. richardsonii* (36.07 %), followed by *T. putitora* (34.25 %), *G. gotyla* (7.46 %), and *B. bendelisis* (6.85). The experimental fish catch per unit effort (CPUE) from the rivulet varied from 0.0 g to 42.2 g

Fishes once abundant in Kumaon Rivers and streams have now become rare. One of the principle reasons for decline in fish fauna is their mass killing by poisoning, dynamiting and using small-sized mesh nets for catching. The rapid deforestation along the catchment of the streams and rivers facilitates soil erosion, which ultimately deteriorates natural feeding and breeding grounds of fish. Apart from these activities, the habitat loss due to water abstraction for agriculture, domestic and other uses leads to an appreciable reduction in minimum water volume required for fish growth. These physical and chemical modifications of

the river result in an ecological imbalance for fish communities, which cause loss in their diversity.

Impact of exotic over indigenous fish species

The different phenototypes of the exotic carp, *Cyprinus carpio*, were introduced in Kashmir waters in late fifities. It was in eighties that impact evaluation studies were taken up by cold water fisheries centre of CIFRI. From the investigations conducted on the Dal Lake in Kashmir with regard to fish population dynamics, it was possible to identify three main impacts of species introduction. The population shift of about 70% in favour of *Cyprinus carpio* was most significant. In comparison, the indigenous species of Schizothoracids in the lake were reduced to nearly 20% in total catches. The investigations revealed competition for similar food-niche, fecundity and spawning behaviour as reasons for exotic dominance.

Food: The mirror carp (*C. carpio*) is mainly detritus eater and omnivorous with affinity towards phytoplankton and its feeding pattern is similar to *Schizothorax* in lacustrine habitat (Table 13.10).

Table 13.10. Food overlap in common carp and snow-trout in Kashmir lake

Species	Decayed organic matter (%)	Phytoplankton (%)	Zooplankton (%)	Misc. (%)
Cyprinus carpio	73.81	23.43	2.76	-
Schizothorax spp.	61.56	27.98	1.75	8.71

Fecundity: The fecundity of mirror carp was estimated at 197,403 eggs/kg of body weight. On the other hand, the average fecundity of *Schizothorax* sp. was estimated at 26,420 eggs/kg of body weight. Mirror carp produces seven times more eggs as compared to *Schizothorax* sp. giving a competitive advantage to exotic carp.

Spawning behaviour: Mirror carp breeds in lake on thick vegetation, thus facing no problem with regard to spawning ground. In comparison, members of Schizothoracids have to perform spawning migration to adjoining snow-fed streams. Thus eggs/spawns of Schizothoracids have to face many hazards like impact of heavy silt load in streams due to snow-melt water during summers and virtual drying up of these streams in autumn when the fry are ready to migrate to lakes. In this process, the fry perish and natural recruitment of this indigenous species is significantly hampered. Thus, food overlap, higher fecundity, better spawning facilities in the lake itself, higher rate of fertilization and shorter incubation period to produce larvae in *Cyprinus carpio* have all contributed to decline of indigenous Schizothoracids in the lake ecosystem. The stocking of this exotic variety has pushed up fish yield from the system, but negative ecological impacts are also apparent.

Fish biology and ecology

Different workers have generated valuable database on the general and breeding biology of snow-trouts from different aquatic biotopes such as river systems, lakes

Table 13.11. Comparative biological features of Schizothoracids in Himalayas

Species	Feeding habit	Growth attainment (mm)	Fecundity/ kg body weight	Peak breeding season	GSI (Range)	Remarks	Distribution
Schizothoraichthys niger	Illiophagic, herbivore	1+ (100) 4+ (292)	8,000-23,000	March-April	1.53-10.85	Mainly lacustrine habitat	Restricted to Kashmir Valley in J and K
S. esocinus	Herbivore, omnivore, bottom feeder	1+ (220) 4+ (412)	35,000-40,000	May-June	1-7	Inhabits upper zones in streams	Endemic to Kashmir Valley in J and K
S. curvifrons	Illiophagic, herbivore, occasional column feeder	1+ (130) 4+ (306)	25,000-40,000	May-June	0.9-12.1	Inhabits middle zones in streams	Endemic to Kashmir Valley in J and K
S. longipinnis	Herbivore, Detritophagus	1+ (115) 4+ (288)	25,000-32,000	May-June	1.0-13.0	Inhabits middle zones in streams	Endemic to Kashmir Valley in J and K
S. micropogon	Herbivore, bottom feeder	1+ (80) 4+ (215)	20,000-25,000	May-June	1.2-11.56	Inhabits middle zones in streams	Endemic to Kashmir Valley in J and K
Schizothorax richardsonii	Herbivore, typical bottom feeder on rocks and stones	1+ (175) 4+ (330)	18,000-35,000	April-June (in Kashmir Himalayas) September-November (in rest of Himalayan regions)	0.4-10.4 (in Kashmir) 1.93-14.79 (in Uttara-khand) 2.2-14.2 (in Nepal)	Inhabits upper reaches of large streams, undertakes migration	Widely distributed in the entire Himalayan and sub-Himalayan region

and streams in Kashmir valley (Table 13.11). For the first time breeding ground of *Schizothoraichthys niger* were located in the Dal lake, implying that this species of Schizothoracid group does not require breeding migration. The destruction of natural snow-trout seed in local streams was also estimated and quantified. The investigations carried out to assess the natural recruitment potential of Schizothoracid in Kashmir waters have revealed that majority of species migrate to the tributaries of the river Jhelum and other snow-fed streams and lay eggs in shallow pools under sand and

stones. However, in case of *Schizothorax niger* there is a significant deviation. Apart from migrating upstream of the Dal lake for breeding it also lays eggs in shallower regions of the lake. Spawn is usually available during June to August. Studies have shown that the densities of mixed spawn of *Schizothoraichthys esocinus. S. planifrons, S. plagiostomus, S. micropogon, S. curvifrons* from the Isthal, the Veshov, the Nirhama, the Erin and the Arah streams ranged between 50 and 245 fry/m^2. Since the spawn usually remain under boulders it is difficult to collect from streams. However, under favourable conditions, approximately 2,000-3,000 fry can be collected per day (assuming 6 hr working) by employing two persons. This makes the artificial propagation of this group all the more important. Similar fish biology and ecological data have been generated on *T. putitora* and *S. richardsonii* in the Central Himalayan waters in Uttarakhand. This basic bio-ecological data on different fish species from different ecosystems in the region are valuable in developing technology for their artificial breeding and culture.

Lake fishery management

Ecology and energy flow in typical wetlands of Kashmir valley

The detailed water chemistry of typical wetlands has indicated that they are suitable for fish growth and their well being. The biological spectrum of these lakes revealed that fish food in the system was quite good and favourable for fishery to sustain and develop. The estimated fish production of the systems ranged between 10 and 30 kg/ha/yr, which was quite favourable in unmanaged ecosystems. But it gives an indication of further improvement if management norms are applied. The lakes fixes on an average 2,463 g C/m^2/year at primary level, out of which only 6% is contributed by phytoplankton and 94% by macrophytes. On the other hand zooplankton fixed about 16.7 g C/m^2/year, and on an average fish harvest was estimated at 0.250 g C/m^2/year. Indicating low conversion efficiency at each succeeding trophic level, the conversion efficiency between primary producers and zooplankton was 0.055%, and between former and fish it was only 0.002%. In such wetlands, most of the energy fixed by macrophytes remains unutilized as no vegetation feeder fish species were available in the system. Similarly, the energy fixed by phytoplankton and zooplankton in the system was not efficiently utilized towards fish production. Combination of different fish species will help in optimal utilization of energy fixed from different sources and promote fish yield. Four species combinations could be tested in these ecosystems with Schizothoracids, common carp (coldwater strain), grass carp and silver carp, as possible candidate species. However, stocking density of grass carp can be kept low to have sustainable growth of aquatic weeds in the systems.

Eutrophication problem and energy transfer in natural flood-plain lakes/wetlands of Kashmir were investigated. Based on the data generated judicious fishery exploitation strategy was developed for these ecosystems. Similarly, bio-indicator species for eutrophication were identified, which would help in pollution and general health

Table 13.12. Main characteristics of different lake types in Himalayan region

Characteristics	Zone I (32-36°N)			Zone II (28-32°N)	
Altitude (masl)	1,587	2,200	>3,000	600-850	1,300-2,200
Water spread (ha)	10-6,000	15-50	2-160	25-75	40-100
Max. depth (m)	3-12	6-8	6-85	5-50	20-30
Mean depth (m)	1.5-2.5	2-3.5	8-20	20	10
Surface temp. (°C)					
Maximum	28-29	23-25	7-15	31-33	23-27
Minimum	5-6	sub-zero	sub-zero	12-15	9-12
Bottom temp. (°C)					
Maximum	13-28	15-16	6-8	26	20
Minimum	5.5-6.5	4-5	3-4	13	10
Thermocline depth	3-6 (m) (weak and stable)	1-3 (m) (stable)	3-6 (m) (stable)	3-9 (m) (stable)	3-5 (m) (short-lived/ stable)
Thermal type	wm and pm	dm	dm and cm	wm	wm
Dissolved oxygen	7-11 ppm	5-10 ppm	8-9.6 ppm	4-12 ppm	7-14 ppm
*p*H	7.2-9.2	7.8-8.4	6.8-7.1	7.2-8.9	6.8-9.5
Macrophytes	P	P	nil	P	P
Fish	*Cyprinus carpio, Schizothorax* spp. and minor carps	*Cyprinus carpio, Schizothorax,* minor carps	*Salmo trutta fario Diptychus maculatus*	*Cyprinus carpio, Tor* spp., Indian major carps Chinese carps	*Cyprinus carpio, Tor putitora,* Indian major carps, Chinese carps

wm, Warm monomictic; dw, dimictic; pm, polymictic; cm, cold monomictic.

monitoring of lakes in the valley. These indicator species were very stable and reliable. The energy transfer investigations resulted in developing a fish stocking action plan for temperate systems. For the first time in the country high altitude (>3,000 masl) glacial lakes were investigated in detail in order to develop a strategy for fishery development at those inhospitable areas of Kashmir Himalayas (Table 13.12).

Kumaon lake ecology

Apart from other lakes in the region, as a case study, investigation was conducted on Khurpatal located at 1,600 masl. It is typical warm-monomictic and closed type lake with underground and catchments as the source of water. The lake supports massive growth of phytoplankton population, which ranged from 1.27 to 15.84 × 10^4 units/litre. The populations were mainly dominated by Dinophyceae (55-100%), followed by Bacillariophycae (nil-35%) and Chlorophyceae (nil-10%). On yearly basis, the dominant forms in the lake were *Peridinium palatinum, Glenodinium quadridens* and *Ceratium hirundinella*. The diversity of zooplankton population in the lake was low. The density in the littoral zone varied from 18 to 313 units/litre with Copepoda (41.2-100%), rotifera (nil-48%) and Cladocera (nil-37%) as major groups. The macrobenthic populations in the system ranged from 267 to 1,422 units/m^2, recording a wet biomass of 4.43-86.56 g/m^2. Among major groups Odonata (nil-68%), Ephemeroptera (nil-38%), Diptera (nil-68%), Coleptera (nil-49%), Mollusca (nil-77.7%) and Oligocheta

(nil-46%) were most dominant. The gross primary productivity at the littoral zone ranged between 67.5 and 112.72 mgC/m^3/hr while at pelagic site, it ranged from 35.5 to 97.25 mgC/m^3/hr.

The biological characteristics of mahseer population in the lake revealed sex ratio 1:1 and fecundity to range between 8,615 and 9,120 eggs/kg body weight. Aquatic insects and zooplankton were found the main food items for mahseer. The ripe specimens of either sex of mahseer to the tune of 83% were recorded from lake between July to August. The experimental fishing carried out in the lake revealed *T. putitora* to be dominant, followed by *Cyprinus carpio*. The size frequencies of mahseer ranged between 305 and 425 mm in total length and 250 and 625 g in total weight. The catch per unit effort was estimated at 3.5 kg/net/day. To enhance mahseer fishery in the lake, advanced fry of mahseer produced in the hatchery are being stocked at regular intervals to adjust balance between angling pressure and recruitment and main limnological parameters of Kumaon lakes are indicated in Table 13.13.

Table 13.13. Comparative physical and water quality parameters in Kumaon lakes

Parameters	Nainital	Bhimtal	Sattal	Naukuchiatal
Altitude (masl)	1,938	1,370	1,390	1,220
Length (m)	1,433	1,901	920	951
Width (m)	463	451	270	692
Max. depth (m)	24.2	18.8	22.0	38.5
Mean depth(m)	14.2	11.5	8.0	22.5
Area (ha)	48.78	63.25	50.25	50.07
Transparency (m)	0.30-2.43	2.10-3.70	1.40-5.50	2.56-4.68
Water temperature (°C)	9-22	10.5-26.5	12.5-27.0	15-27
*p*H	7.2-8.4	7.2-8.3	7.2-8.3	7.3-8.2
Dissolved oxygen (mg/litre)	1.7-12.8	6.2-12.6	5.6-10.0	6.8-12.0
CO_2 (mg/litre)	Nil-7.0	Nil-2.1	Nil-5.1	Nil-3.0
CO_3 (mg/litre)	Nil-160	Nil-32	Nil-20.0	Nil-30.0
HCO_3 (mg/litre)	136-250	80-182	46-110	60-142
Total alkalinity (mg/litre)	140-470	80-182	46-124	60-142
Chlorides(mg/litre)	24-32	13-22	8-18	8-18
Total hardness(mg/litre)	220-376	64-140	48-112	60-128
Phosphates (mg/litre)	Nil-0.45	Nil-0.05	Nil-0.25	Nil-0.05
Silicates (mg/litre)	1-8	4-15	2-10	4-15
TDS (mg/litre)	330-550	80-200	50-250	100-250

The successful introduction of golden mahseer in Shymlatal lake in Kumaon region has been reported, wherein the natural riverine mahseer fingerlings upon being stocked in the lake in a phased manner grew to a size range of 240-400 mm in length and weight range of 240-680 g with a re-capture recovery of 55%. The mahseer stocks have got established in the lake, and will eventually develop into auto-recruiting population if stock management is carried out scientifically. It is a success story of mahseer conservation in a central Himalayan lake.

Sikkim lakes

The freshwater lakes situated in the high altitudinal north-eastern region of

Sikkim are known for their religious and tourists importance. The Tsomgo, Memencho, Kupup Tso and Manju lakes, situated above 3,500 masl are oligotrophic in nature and remain snow-covered for 4-5 months in a year. The plankton availability in the lakes varied from 510 to 750 unit/litre with dominance of zooplankton over phytoplankton. The dominating forms among the phytoplankton are *Tabellaria fenestrata, Synedra ulna, Diatoma vulgaris, Fragilaria capucina* etc. Zooplankton mainly comprises copepods (75%) and cladocerans (20%). These lakes have been stocked with brown trout (*Salmo trutta fario*) and Memenco lake reportedly has self-sustaining population of the fish. Indigenous fishes were not reported from these lakes.

Development issues

Most of the hill states are at different levels of development with regard to their fishery progress. Jammu and Kashmir and Himachal Pradesh, during the last two decades have made significant progress in capture fisheries, such as sport fishery and aquaculture, especially of trout, fishermen welfare and support services to the sector. In spite of these efforts, the production in hills is still very low as compared to all-India average and fish farming is still in developing stage. On the other hand, the newly created Uttarakhand where hill fishery did not receive adequate attention in the past is now being addressed. In North-eastern states too, in spite of the existence of potential coldwater fishery resources, the development is at a very low level although the activity has gained momentum in some states like Arunachal Pradesh and Sikkim. Further, in West Bengal though the hill fishery resources are significantly low, it can also contribute to hill economy to a great extent. But of late it is being realized and demonstrated that coldwater fishery can contribute to food and nutrition security in hills and remote regions. Therefore, in the planning process the fishery in hills needs to be provided due importance in terms of financial, infrastructure and modern institutional back-up facilities. In hills, the fishery development through aquaculture, sport and conservation should be promoted and supported to introduce crop-fish diversification in hills, so that natural resource management becomes economically sustainable activity. This will result in profitable utilization of small resource-base available in hills for any farming activity.

Possible measures for fisheries development

Horizontal and vertical expansion of fish culture activities: As per varied micro-climatic conditions, such suitable patches of land/water-bodies should be identified and be brought under any one of the three-pronged fish farming practices: (*i*) trout farming, the suitable areas above 1,500 masl having temperature range of 4-20°C should be identified and brought under trout culture, (*ii*) polyculture, hill regions between 700 and 1,500 masl with suitable land and water resources could be utilized for Chinese carp culture, (*iii*) the eco-climatic conditions of the foothills and river valleys located below 500 masl are suitable for composite culture of Indian major carps and Chinese carps. Such sites are available in the catchments of the Himalayan and peninsular rivers, streams and their tributaries. The carp farming could be successful in the valleys and peripheral regions located in the temperature range between 15° and 25°C. The ecosystem of north-east hills regions need to be exploited for polyculture of indigenous sp along with exotics. The same is possible due to the successful rearing of *Neolissochilus hexagonolepis* in captivity at the DCFR, Bhimtal farm to 14.6 g within a culture period of one year and growth performance of pengba *Osteobrama belangeri* to 500 g in monoculture and 274 g in poly culture in Manipur. Paddy-cum-fish culture which has been initiated in Manipur and Arunachal Pradesh need to be expanded to other hill states also. The practice can give additional income to farmers, especially in such states where only one cash crop is being harvested.

Production enhancement in lentic systems: The present level of fish production from the lakes and reservoirs could be enhanced up to some extent by means of sustainable intensive culture practices, i.e. rational stocking and harvesting, cage and pen culture based on autochthonous productivity of the water-body.

Development of ornamental fishery: The aquatic resources of NE Hills region are home for a number of endemic ornamental fish species. There is need to harness the resource in sustainable basis. Collection, rearing, breeding and marketing of ornamental fishes (indigenous as well as exotic) could provide a lucrative profession to the progressive farmers, unemployed youths and others in the region.

Development of sport fishery

Sport fishery within India has been taken care of mostly in Jammu and Kashmir and Himachal Pradesh but the same can be developed along other hill states and upper stretches of rivers along Satpura and Aravalis also where ever the two main sport fishes trout and mahseer exist. To develop this fishery, propogation of these two fishes needs to be strengthened and its seed (fingerling/yearling) ranched where ever waters are conducive. The former in snow-fed streams of high altitudes and latter in streams of lesser or outer Himalayas and head waters of peninsular rivers. In addition, rest camp facilities in the form of tents, indigenous huts with all basic amenities along fishing sites need be developed. Sustainable development of sport fishery will go long way in uplifting the socio-economic status of the far-flung/remote areas of country.

Protection and conservation of the fishery resources

The fishery resources in the varied aquatic systems of the region in general and sport, food, typical hill stream fishes in particular are under severe stress from habitat degradation, over-exploitation and wanton destruction. Therefore eco-restoration, proper implementation of the existing legislations for protection of the species, artificial propagation and ranching for stock augmentation and mitigation, creation of protected areas/sanctuaries and massive mass awareness campaign among the target groups are the measures for effective conservation and management of the critical fish species.

Policy issues

The aquatic resources in hills are quite valuable for development of fishery, both for food and sport, but scientific management of these resources is necessary to achieve objectives. To manage these ecosystems so that they contribute to fishery development in remote hilly regions on a sustainable basis, the following issues need attention: Ownership of resources; Infrastructure development; Lake fisheries; Hill fisheries conservation; Development of sport fishery; Development of ornamental fishery; Conservation of native and exotics.

Future perspective

The Hill Area Development is now being focussed as priority in the country. But up till now economic upliftment of hill states, due to various climatic, geomorphologic and resource constraints has been very insignificant. The hill regions of our country are bestowed with valuable indigenous fish germplasm and pristine water resources with tremendous range in their thermal regime. The fish can play a vital role in supplementing protein requirement to the poor people located in remote Himalayan region and to provide source of income to a section of people who because of resource constraints in terms of cultivable lands in hills overexploit natural resources. At high altitudes we have tremendous scope for development of low-volume, high-value species such as trout, especially rainbow variety. At 4% growth in farming of rainbow trout, a production of 150 tonnes is possible, which can be enhanced to 200 tonnes at growth rate of 8%. As per the study, our domestic demand has been assessed at 800 tonnes, therefore, steps must be taken to achieve this target. This can further promote feed industry and preservation units at high altitudes. Similarly, sport fishing ancillary units including short and long distance transportation of trout will come into operation. All these will generate avenues for establishment of self-help groups in hill regions. But it will be possible if the seed production centres and table fish production units for trout are de-linked and private sector is involved in fish production while quality seed and feed supply is to be insured through state channels. All the private units should be registered to maintain hygienic standards.

Depending upon the natural aquatic resources in the hills, the fishery, if developed on scientific lines will go a long way in contributing to rural economy in remote hilly zones. It is suggested that fishery development should be initiated based on the available resources involving both exotic and indigenous fishes. There is an immediate need to replenish depleting stock of some of the most important commercial as well as sport fishes. The indiscriminate use of chemicals in orchards/tea gardens may affect catchment's water quality of regional river/stream systems.

The training in coldwater fishery and hill resource management is also an issue to be addressed. Confluence of rivers in north-east and central Himalayas was reported one of the best mahseer angling spots of the world once upon a time. Thus, creation of adequate facilities for anglers for sport fishing is of paramount importance. Similarly, streams in Kashmir and Himachal Pradesh are world famous for brown trout angling/fishing. Coupled with sport fishery development, the commercial farming through bhora fishery in sub-Himalayan West Bengal has a good potential of generating rural income and will contribute towards upliftment of socio-economic conditions of local population in this hill region. Establishment of carp hatcheries and farms at lower

altitudes is another pre-requisite for hill states to meet demand of local farmers who are engaged in small-scale fish farming. There is tremendous potential for running-water fish culture based on exotic carp. This should be encouraged by providing know-how and seed to the farmers to supplement their income. Though some effective efforts have been initiated for development and popularization of fisheries in the hill region of our country, still there is lot to be done. Besides conservation of valuable fish species, a holistic approach required for overall fisheries development includes expansion of fish culture activities in all potential areas, integrated aquaculture, stock diversification, implementation of the sustainable production, enhancement measures in lakes and reservoirs, development of ornamental fish and promotion of fishery-based eco-tourism at the suitable sites.

14. Sport Fisheries

Fishing is an age-old practice and the man hunted for aquatic animals in rivers, lakes, estuaries and the seas around him for food. With growth of civilization, besides food, fishing turned out to be a sport too as it provided considerable recreation. Sport or Recreational Fishing was well known in India as references are available in the Vedas, Ramayana and Mahabharata. It appears that the brilliant economist, Chanakya was the first to frame laws for regulating fishing and conservation a, early as the 3rd century BC during the reign of Emperor Ashoka. In the 12th century AD, King Somesvara gave a detailed account of fishes, their habits and habitat, techniques of rearing, besides the tackle meant to catch them in his book *Manasollasa* and aptly described the pleasure and enjoyment that angling provided in the chapter on '*Matsyavinod*'.

Angling is an art that provides rewarding pastime to millions of people from all walks of life. It is fun with many and the doctors recommend it to relieve tension and stress. Most people find it interesting and worthwhile as it enables a healthy appreciation of nature. Truly speaking, an angler's pursuit of game fish is a passion and the feeling of accomplishment is his reward. India is gifted with some very good game fishes such as the mighty mahseers that, were made known to the world by H S Thomas through his book on '*Tank Angling in India*'. Later, in his second book '*The Rod in India*', he included some other indigenous game fishes too. It needs a special mention that though the British introduced the trout, both brown and rainbow, in Jammu and Kashmir, Tamil Nadu (Nilgiri Hills) and Kerala (Munnar) in the first quarter of the twentieth century and popularized angling or recreational fishing as sport fishing, the indigenous sport fishes remained a great attraction with the British anglers too who considered them tremendous fighters both in terms of their size as well as tenacity. The mahseers, especially, were so popular that Sir H Ramsay stocked these fish in the lakes in Kumaon Hills around 1858. While Skene Dhu (1923) highlighted the fighting quality of the mahseers in '*The Anglers in India or the Mighty Mahseer*', McDonald (1948) too focused on this valuable fighter in '*Circumventing the Mahseer and other Sporting Fish in India and Burma*'. Dr S L Hora (1937-43), the well-known ichthyologist, did yeoman service to fisheries science through his contributions on the taxonomy of mahseers, besides identifying and popularizing a number of indigenous sport fishes through a series of articles published in *Journal of the Bombay Natural History Society*.

Sport fisheries constitute an important social and economic activity in the West but have not received the attention that they deserve despite the great potential that exists in our country. It is a romantic sport that provides entertainment and generates employment, enables nutritious food and earns foreign exchange, besides giving birth and support to the development of several ancillary activities including tourism. Of late, an increasing interest being evinced by the conservationists, research institutions,

angling associations and the governments both at the Centre and the States in conserving the biodiversity and popularizing the sport should be seen as an effort in the right direction for promoting tourism through development of sport fisheries. In this context, the contributions of the Tata Electric Supply Co. Ltd, Lonavla (Maharashtra), by way of organizing a series of workshops on mahseer propagation and those of Angling Associations through seminars and angling competitions in different parts of the country coupled with the publicity being given by the Governments of various states to sport fishing deserves a special mention.

Sport fishing or 'Angling' draws its origin from the invention of angled fish hook. The word 'angling' has been derived from the Greek '*ankos glen*' (barbed hook) or the old English, '*anga hook*' (angled hook).

Big game fishing

The big game fishing or sea fishing started as a sport after the invention of motor boat in 1898 and developed mostly along the locations where large number of this fishery was present relatively close to shores within range of the boats of that era mostly Florida, California (USA); Cairns (Australia), New Zealand and Hawaii. Sea game fishery grew as the vessels used for sport fishery became larger, faster, longer ranged and more sea-worthy. Big game fishery is now pursued on grounds ranging from 60 to 70 miles (96.56 to 112.65 km) distance from ports all over the world. Nonetheless sea fishing is a high-value leisure activity mainly indulged as a sport in well developed western countries and by foreigners in foreign offshores. A study based on annual expenditure interpreted as use value of marine recreational fishing from 18 countries indicated 75% of the overall value of commercial landing ranging from 7% in Norway to 22.2% in United States, where it is a very high-value leisure activity involving use of sophisticated and expensive equipment thereby giving fillip to other ancillary industry. The sport has not taken in a big way in India because of non-availability of good indigenous fishing vessels and its high operational cost although there is a good variety of game fish off the coast of India.

Sport fishes

A large number of species, big and small, from both fresh- and brackishwaters as well as the seas that provide wonderful sport to the rich and poor alike in India are listed in Table 14.1.

Fishing tackle and fishing techniques

There are four basic categories of fishing tackle, viz. bait-casting, spin-casting, spinning and fly-casting. These differ from each other in popularity, ease of use, fishing styles, spool type and strength but the differences are not great except in case of fly-casting where the weight of the line delivers a near-weightless fly. Spin-casting is easy and hence the most popular with children and the beginners and so is spinning which is also equally popular amongst the beginners but is widely used by anglers at all levels of experience.

Table 14.1. Sport or game fishes of India

Species	Distribution	Remarks
Family. Notopteridae Scientific name: *Chitala chitala* (*Notopterus chitala*) Common name: Featherback, Cheetal	Rivers of the Indo-Gangetic system; also tanks and reservoirs	Small head, compressed body; cleft of mouth extends to the middle of the eye; dorsal fin very small; anal long and confluent with the caudal; dorsal side semi-circular with a notch above the eye. Silver-grey on the back with dark bands descending towards the middle of the body. Size: over 1 m; weight: 30 kg. Tasty and in great demand.
Family: Megalopidae Scientific name: *Megalops cyprinoides* Common name: Tarpon	Freshwaters and estuaries of Kerala, Tamil Nadu, Chilka and West Bengal	Body laterally compressed; eyes big, maxilla reaching up to the eye; lower jaw with a narrow symphyseal gular plate; last ray of the dorsal prolonged. Head dark olive, abdomen silvery with bluish markings; size about 45 cm.
Family: Cyprinidae Scientific name: *Catla catla* Common name: Catla; Katla (Bengali), Bhakur (Hindi), Thaila (Punjabi)	Indo-Gangetic system; transplanted in major rivers of the south and in ponds, tanks, and reservoirs	Head big with no scales; body deep and slightly compressed laterally; scales large. Mouth wide, upturned and with a longer lower jaw. Highly valued and fastest growing freshwater fish, cultivated throughout the country; weight 35 kg.
Scientific name: *Cirrhinus mrigala* Common name: Mrigal; Mirgal, Nain Naren (North India)	Major rivers of the north and south; ponds, tanks and reservoirs	Body cylindrical, head small; mouth terminal with thin lips; back silvery with copper tinge, eyes golden. Good eating and smart game, size 90 cm
Scientific name: *Gonoproktopterus curmuca* Common name: Curmuca barb; Kural (Kannad); Kooral (Malayalam)	Cauvery and rivers of Kerala	Highly priced; band of pores on cheeks; caudal fin with blackish tips. Good game fish; size 1.2 m.
Scientific name: *G. dubius* Common name: Nilgiri barb; Kozhimeen (Tamil)	Cauvery system	Migratory in nature; also found in ponds and tanks; size 25 cm

(Contd...)

Species	Distribution	Remarks
Scientific name: *G. kolus* Common name: Kariyan (Malayalam), Nilusu (Telugu), Kholus (Marathi)	Godavari, Krishna and Cauvery; rivers of Kerala	Horny tubercles on sides of snout, more in males than females; size > 60 cm
Scientific name: *G. micropogon* Common name: Kariyan (Malayalam)	Bhawani and head waters of Cauvery; Periyar river	Highly prized as food and sport; introduced in reservoirs and lakes; 60 cm, though 90 cm is also reported. Good game fish
Scientific name: *Labeo calbasu* Common name: Kalbasu; Kalbons (North India)	Major rivers of the north and the Peninsula	Body deep, mouth small and inferior; lips thick and fringed, each with a distinct inner fold; two pairs of black barbels; blackish or greyish; bottom feeder, grows well in ponds rich in molluscs; slow-growing but popular food and game fish; size 90 cm
Scientific name: *L.dero* Kursha *(Bengali)*, *Gid* (Punjabi)	In shallow waters all along the Himalayas	Used as food fish; also as bait for *R. bola* and *T. putitora*
Scientific name: *L. rohita* Common name: Rohu; Rohu or Rui (North India)	Rivers of the Indo-Gangetic system; transplanted in east coast rivers; ponds, tanks and reservoirs	Head scaleless, body deep; lips thick and fringed with a distinct inner fold above and below; a single pair of short maxillary barbels; base of each scale dotted with a red tinge. Excellent food fish, cultivated all over the country. A good game fish
Scientific name: *Neolissochilus hexagonolepis* Common name: Chocolate or Red or Snub-nosed Mahseer; Bokar (Assamese)	Asom and North Bengal	Deep bodied; lips thin, cheeks covered with tubercles; dorsal spine strong and smooth; body olive-green above, silvery white below; golden yellow lateral band in the middle. Grows to 60 cm
Scientific name: *Osteobrama belangeri* Common name: Pengha (Manipuri)	Manipur	Body trapezoidal and compressed; entire abdominal edge keeled; size 38 cm
Scientific name: *Tor khudree* Common name: Khudree or Deccan Mahseer;	Odisha and south of Tapti river in the entire Peninsula	Head almost equal to depth of body; upper jaw slightly longer than lower one; lips thick, lower one with a median fold; scales 24-26; fins bluish-grey; barbels 4. Maximum length 40 cm

(Contd...)

Species	Distribution	Remarks
Khadasi, *Barsa* or *Baras* (Marathi) Scientific name: *T. mosal* Mosal or Copper Mahseer; Lobura (Assamese)		
Scientific name: *T. mussullah* Common name: Mussulah or high-backed Mahseer; Katti (Malayalam)	Ramganga (Uttarakhand), Himalayan rivers (Asom), Mahanadi, Krishna and Godavari rivers	Head small but equal to the depth of body; cheek and snout devoid of tubercles. Colour, olivaceous yellow in front, burnt amber posteriorly; dorsal fin, reddish orange
Scientific name: *T. putitora* Common name: Putitor or Golden or Himalayan Mahseer	Throughout Himalayan foothills; Punjab, Haryana, Uttarakhand, West Bengal and Asom	Snout and cheeks with a patch of indistinct tubercles; size 120 cm, recorded to attain over 50 kg. Body oblong and stream-lined; head broad and pointed anteriorly; lips fleshy and continuous; barbels 4; greenish above, light pink on sides with a broad light greyish-blue lateral band, abdomen white. Feeds on algal encrustations on rocks, insects and small fish. Maximum recorded length 270 cm. One of the world's best game fish
Scientific name: *Tor tor* Common name: Deep-bodied Mahseer; mahasol (Bengali), Badas, Turia, Masal (Hindi), Barse masla (Marathi), Peruval, Poo-meen (Telugu); Hallamin (Kannad)	Indo-Gangetic river system; Brahmaputra, Narmada, Tapti, Mahi, Mahanadi; and associated tanks and reservoirs	Deep-bodied; head shorter than depth of body; large scales, 22-28; lips thick and fleshy with continuous labial fold across the lower jaw; barbels 4; greenish gold above and light olive green below in adult; fins red. Juveniles feed mainly on insects while adults on macrovegetation. Maximum size 152 cm
Scientific name: *Raiamas bola* Common name: Hill trout or Indian trout	Foothills of the Indo-Gangetic system; Madhya Pradesh, Maharashtra and Odisha	Known as Indian trout owing its resemblance. Head and body highly compressed; mouth wide and directed upwards; lower jaw with a knob that fits into the notch in the upper jaw; no barbels. Back greenish-grey with irregularly arranged bluish-grey spots on the sides. Good game fish

(Contd...)

Species	Distribution	Remarks
Scientific name: *Schizothoraichthys esocinus* Common name: Snow trout; Chiroo (Kashmir)	Indus in Ladakh; Jhelum and its tributaries	Body sub-cylindrical, upper jaw slightly longer than lower; gape of mouth extending to middle part of eye; labial fold interrupted in the middle; dorsal spine serrated. Silvery with a number of black spots. Good game, local delicacy; grows to 42.5 cm
Scientific name: *S. planifrons* Common name: Chush (Kashmir)	Rivers and lakes in Kashmir valley	Narrow-bodied with elongated flat head; mouth anterior, jaws equal, lips thick with the lower one interrupted in the middle. Dark above and dotted with black pigments on the ventral side. Maximum length, 25 cm
Scientific name: *S. progastus* Common name: Dinnawah (Uttarakhand); Lohone (Assamese)	Jammu and Kashmir; Ganga in Uttarakhand; Brahmaputra (Asom)	Migrates for breeding; silvery with few fine spots; dorsal inserted nearer tip of snout; tasty flesh; good game, comes on paste and also fly
Scientific name: *Schizothorax richardsonii* Common name: Alwan, Jis (Kashmir)	Inhabits Himalayan rivers with rocks	Scales very small; dorsal inserted midway between snout tip and base of caudal, bottom feeder, valuable game and food fish; comes on bait and also fly; 60 cm
Family Bagridae Scientific name: *Sperata aor* Common name: Aar (Bengali), Tengra (North India)	Rivers of Indo-Gangetic system; Mahanadi	Body elongate and compressed; upper jaw longer, snout rounded, mouth width less than half head length; barbels 4 pairs, maxillary reaching caudal; base of adipose as long as the rayed dorsal. Bluish back, abdomen white with black spots on the adipose. Attains a large size 182 cm
Scientific name: *Sperata seenghala* Common name: Singhala (North India)	Rivers, ponds, tanks, reservoirs, throughout India	Body elongate and compressed; snout spatulate, mouth width 1/3 of head length; barbels 4 pairs, maxillary short reaching pelvics. Back brownish-grey, sides and abdomen silvery; black spot on the hind end of the adipose dorsal. Size, 1 m
Scientific name: *Mystus cavasius* Common name: Gangetic mystus (English); Khirkhirya (Marathi)	Freshwaters, tidal rivers and lakes, beels, ponds, ditches and flooded fields	Barbels four pairs, maxillary extending beyond the base of caudal fins; adipose long and almost continuous with the rayed dorsal; mid-lateral longitudinal stripe; dark humeral spot. size 40 cm

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Species	Distribution	Remarks
Scientific name: *M. gulio* Common name: Nona-tengra (Bengali), Kontia (Oriya), Singati (Marathi)	Inhabits estuaries and tidal rivers; common in Gangetic estuary, Chilka and Kerala backwaters	Barbels four pairs, maxillary extending to end of pelvic fins; bluish brown on head, dull white below; maxillary barbels black, outer half of fins black
Scientific name: *Rita pavimentata* Common name: Gegra (Hindi), Ghoghrya (Marathi), Banki-yeddu (Telugu)	Narmada and Krishna rivers	Barbels three pairs, maxillary reaching up to operculum, mandibular the base of pectoral; dorsal serrated on its posterior border and strong; size 26 cm
Scientific name: *R. rita* Common name: Reeta (North India)	Most rivers of north India, also tidal	Head depressed; barbels three pairs, mandibular reaching pre-operculum; 150 cm
Family: Siluridae Scientific name: *Ompok bimaculatus* Common name: Butter catfish; Puffta (Bengali), Goongwari (Marathi and Gujarati)	Rivers, tanks and ponds	Barbels two pairs, maxillary barbel reaches beyond anal fin base; A large dusky spot on shoulder on lateral line and a small black spot on caudal peduncle; carnivorous, feeds mainly on insects and can be raised in ponds to provide good sport
Scientific name: *Ompok pabda* Common name: Butter catfish; Pubda (Bengali)	Rivers, tanks and ponds	Barbels two pairs, maxillary short reaching only middle or tip of pectoral fin; two dark lateral bands on body; a dark oval shoulder spot; size 17 cm
Scientific name: *Wallago attu* Common name: Freshwater shark; Parin/ Lonch (Hindi), Mallee (Punjabi), Aattu vaala (Malayalam)	Throughout India	Head large, snout spatulate, laterally compressed body; eyes small located over the mouth opening; jaws with strong pointed teeth; Maxillary barbels long and reach up to the anal but mandibulars short; highly predatory; considered good eating in Manipur and in the north-west. Silvery sheen, dark above and light below. Grows to 1 m and above
Family: Schilbeidae Scientific name: *Clupisoma garua*	Throughout India in large rivers	Body elongated and compressed with an adipose dorsal in the young; upper jaw longer; four pairs of barbels of which maxillary

(Contd...)

Species	Distribution	Remarks
Common name: Garua (Bengali), Buchua (Hindi), Gajri (Oriya)		is the longest reaching middle of the pelvic; Silvery grey above, lighter below; attains a weight of 900 g; bottom feeder, takes a worm/mole cricket put on a light tackle
Scientific name: *Eutropiichthys vacha* Common name: Buchwa (North India)	Major rivers of the Indo-Gangetic system	Snout compressed and pointed; upper jaw slightly longer; gape of mouth reaching beyond the eye; four pairs of barbels, maxillary reaching the operculum while nasal beyond the head; dorsal spine thin and serrated. Greyish silvery with dark back and black edges in the pectorals and caudal
Scientific name: *Silonia silondia* Common name: Siland (North India)	Major rivers of the Indo-Gangetic system	Compressed and elongated body; mouth with rows of large and sharp teeth; Maxillary barbels reaching the eye, mandibulars very short; adipose dorsal present; dorsal spine serrated. Good sport that grows to a large size weighing as much as 45 kg
Family: Pangasiidae Scientific name: *Pangasius pangasius* Common name: Pangas (North India)	Throughout India	Mouth wide with upper jaw longer than the lower; barbels 4, maxillary reaching the base of pectorals; dorsal spine serrated and strong. Silvery with dark back and purple sides, cheeks and under surface of head golden. Attains about 1 m; good sport
Family: Sisoridae Scientific name: *Bagarius bagarius* Common name: Goonch (North India)	Major rivers of the Indo-Gangetic system, Mahanadi and the Deccan plateau	Body elongate and compressed, head rounded, eyes small, wide mouth; strong pectoral spine; base of adipose and rayed dorsal equal. Greyish-yellow with large irregular brown and black markings and cross bands, fins with a black base and a dark band. Attains a rather huge size of 1.6 m weighing 112 kg (Pong reservoir) with ugly looks. Good sport that gives a tough fight but poor in taste
Family: Salmonidae Scientific name: *Oncorhynchus mykiss* (*Salmo gairdnerii gairdnerii*) Common name: Rainbow trout.	Arunachal Pradesh, Himachal Pradesh, Jammu and Kashmir, Kerala, Sikkim, Tamil Nadu and Uttarakhand	Colour variable depending on size/age and also on water quality, silvery on sides with irregularly located dark blotches and a red band; no spots below lateral line; rises to fly and fights well

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Species	Distribution	Remarks
Scientific name: *S.trutta fario* Common name: Brown trout.	Himachal Pradesh and Jammu and Kashmir First introduced in Kashmir in India from UK in 1900	Red and orange spots on the body both above and below the lateral line; edge of the adipose fin tipped with red; fishing with small spoon and wet flies; size 40 cm
Family: Channidae Scientific name: *Channa marulius* Common name: Snakehead/murrel; Sanwal (Hindi)	Almost in all rivers, reservoirs and tanks	Body sub-cylindrical, tapering from the head to the tail; dorsal and anal long, caudal round; head snake-like with scales; maxilla extending beyond the eye; accessory respiratory organs enable it to stay in dirty waters as well as out of water. Greyish green on the back, pale white below; adult with 5-6 faint bands below the lateral line and a large black ocellus at upper end of the base of caudal. Attains a large size of 120 cm.
Family: Centropomidae Scientific name: *Lates calcarifer* Common name: Cock-up/Asian seabass; Bhetki/bekti (Bengali); Jitada (Marathi), Narimeen (Malayalam), Koduva (Tamil)	Seas and estuaries of Maharashtra, Kerala, Odisha and West Bengal	Euryhaline, grows well in freshwaters; body hump-backed; maxilla extending beyond the large eyes, mouth with sharp teeth; opercles serrated; two dorsals united at their bases, anal with three spines, caudal rounded. Back grey-green, silvery below. Highly priced food fish, equally good game. Grows to about 1 m.
Family: Serranidae Scientific name: *Epinephelus tauvina* Common name: Greasy grouper	All along the Indian coasts inhabiting rocky grounds and coral reef areas	Operculum with three spines; scales 67-74; cycloid except at the end of pectoral fin; pale greyish covered with dull orange reddish brown spots; a large blackish blotch at the base of last four dorsal spines; attains over 75 cm in length and over 12 kg in weight
Scientific name: *E. malabaricus* Common name: Malabar rockcod or Malabar grouper	Seas and estuaries	Scales 56-67, ctenoid except on the belly; body pale grey covered with small well defined blackish brown spots and scattered large, pale spots and blotches; five irregular slightly oblique broad dark bars that tend to bifurcate ventrally

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Species	Distribution	Remarks
Family: Sillaginidae Scientific name: *Sillaginopsis panijus* Common name: Tool machh (Bengali), Yerra-soring (Telugu)	Southwest coast, east coast, Gangetic delta	Snout and head greatly depressed; two dorsals, second spine of the first dorsal very elongate; size 44 cm
Scientific name: *Scomberomorus commerson* Common name: King seer (Surmai/surmi in Karnataka, Maharashtra and Gujarat), Neymeen/Aikkura (Malayalam)	Coasts of Gujarat to West Bengal	Body mackerel-shaped, laterally flattened, snout pointed; cleft of mouth deep, jaws with teeth; two dorsals, the first with weak spines, the second with finlets; anal with three weak spines and 9-10 finlets; caudal peduncle slightly keeled. Bluish above, silvery below, narrow grayish vertical bars on the body. Moves with tremendous speed. Attains 120 cm. Hook and line fishing
Scientific name: *S. guttatus* Common name: Spotted seer, Vijram (Tamil)	North-east and north-west coasts	Body torpedo-shaped; two dorsals, the first with weak spines and the second followed by finlets; anal with three weak spines and 7-9 finlets; caudal peduncle keeled. Dark above and silvery below with three horizontal rows of elongated spots; front part of spinous dorsal blackish, other fins bluish grey. As good in speed but grows to 180 cm being much larger than *S. commerson*; hook and line fishing
Family: Scombridae Scientific name : *Thunnus albacares* Common name: Yellow fish tuna.	East and west coast of India, Lakshadweep, Andaman and Nicobar Islands	Body fusiform; Scales relatively large. Eyes with well developed adipose lid: two slight ridges on each side at tail but no wide keel.
Scientific name : *T. obesus* Common name: Big eye tuna	South-west and east coast. Lakshadweep islands. Vizhinjam. Ratnagiri coast.	
Scientific name : *Katsuwonus pelamis* Common name: Skipjack tuna, Choora (Malayalam)	Andaman and Lakshadweep Islands. Off Andhra Pradesh coast.	

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Species	Distribution	Remarks
Family: Lutjanidae Scientific name: *Lutjanus argentimaculatus* Common name: Mangrove Red Snapper; Blue-spotted rock perch	Fairly common in estuaries from Gujarat to West Bengal	Maxilla reaching the eye; anal with three strong spines; caudal lunate. Cherry-red in colour, with 6-9 vertical silvery white bands when young. A tough fighter, grows to 60 cm
Family: Sciaenidae Scientific name: *Protonibea diacanthus* Common name: Spotted croaker (Ghol, Marathi and Gujarati)	N-W Coast; Hooghly	Scales cycloid on snout and below the eyes, ctenoid elsewhere; small black spots on top of head; 120 cm
Scientific name: *Otolithoides biauritus* Common name: Koth (Marathi); Goyani (Gujarati)	N-W Coast; Hooghly	Small scales, cycloid on head and upper part of the anterior portion of body, ctenoid elsewhere; 150 cm
Family: Polynemidae Scientific name: *Eleutheronema tetradactylum* Common name: Four finger threadfin; (Rawas) Marathi	Seas and estuaries along Gujarat, Maharashtra, Kerala, Odisha and West Bengal	Eyes large and prominent; lower lip absent; mouth large, teeth extend on jaws; maxilla reaching beyond the eye, mouth with minute teeth; two dorsals; pectorals with four free rays extending to the pelvics. Silvery-green on the back and yellowish-white below; dorsal and caudal greyish, pelvics and anal pale orange on the outer side. A dark spot on the shoulder.
Scientific name: *Polynemus indicus* Common name: Indian threadfin	Shallow coastal waters with muddy and sandy bottoms	Pectorals with two parts, lower with five free rays of which the upper is the longest reaching the anal also enters estuaries
Scientific name: *Polynemus paradiseus* Common name: Mango-fish; Dodywa-rawas (Marathi); Topse (Bengali)	Enters estuaries and freshwaters during spawning season	Pectoral in two parts, lower with seven free filamentous rays, upper three reaching beyond caudal; caught on lines in May-June. Highly valued as food fish
Scientific name: *Channa punctatus* Common name: Spotted snakehead, murrel; Bhunda (Hindi), Lata (Bengali)	Freshwater ponds and tanks all over the country	Scales on head, snout resembling that of a snake; numerous black spots on body and dorsal, anal and caudal fins; dark blotches on flanks; size 31 cm

(Contd...)

(Table 14.1 concluded)

Species	Distribution	Remarks
Scientific name: *Channa striatus* Common name: Snakehead/murrel; Shol (Bengali), Varaal (Malayalam)	Throughout India in rivers, reservoirs, tanks and ponds	Body cylindrical and tapering resembling *C. marulius* but smaller in size. Back dark brown, abdomen yellow. Breeds throughout the year, also found in brackish waters. Migrates on wet soil and can stay out of water owing presence of accessory respiratory organs. Grows to about 90 cm
Family: Mastacembelidae Scientific name: *Mastacembelus armatus* Common name: Spiny eels; Bam, Bami or Vam (North India)	Fresh and brackishwaters of the Plains	Body elongate and cylindrical; snout trilobed with fleshy appendages at the anterior end; dorsal with free spines, anal with three spines; dorsal and anal confluent with caudal; body, pattern of zigzag lines

While bait-casting is similar to other casting techniques, it is a distinct and unique style of fishing. It is generally used for freshwater fishing but the tackle is well suited for saltwater species too. It is more difficult to learn than other types of casting and requires a higher level of skill to achieve the desired results that makes the angler a complete fisherman. Bait-casting gear is considered the standard equipment for a freshwater fisherman due to its tremendous versatility with lures such as crank baits (plugs), large spinners and spinner baits, heavy jigs, large soft plastics, and a few others. Expert anglers prefer bait-casting because it offers the combination of high line capacity, cranking power and greater casting accuracy from both short and long distances. The mechanics of a bait-cast reel are strong, durable and less prone to failure than spinning or spin-cast reels.

While spinning, tackle definitely serves a valuable purpose, especially when using small lures, light line and/or live bait, bait-casting gear gives the angler unmatched versatility for a variety of lures and fishing methods. Most experienced anglers have at least one, if not more, of both spinning and bait-casting outfits.

Bait-casting

Bait fishing involves rigging and presenting the bait in a variety of ways and techniques to attract and catch the fresh or saltwater quarry. Bait may be live or dead, entire or cut into bits and presented alone on a hook or in tandem with an artificial lure to make it more appealing to the quarry. There are many different types of organisms used as bait, the majority being small fish though shrimps and crabs are also popular. Used live or dead, the bait is usually more effective when fresh.

Bait rigs are the various combinations of terminal tackle-hooks, leaders, swivels, beads, sinkers, etc. that an angler uses to present natural bait in a given fishing situation. A single hook attached to the main fishing line is the simplest rig of all and is normally quite effective. However, with experience bait rigs have been refined over the years and several varieties are now available. Today, there are rigs designed to present bait throughout the water column from surface to the bottom, or anywhere in between. Certain rigs exist for presenting a specific type of bait and for catching specific species of game fish. Individual anglers create new bait rigs all the time, and their innovations often become standard in local or regional waters, sometimes throughout the world.

Bait fishing is used for mahseers, *Pangasius pangasius*, *Bagarius bagarius*, *Sperata seenghala*, *Silonia silondia*, *Wallago attu* and *Raimas bola*. Live-bait (not exceeding 20 g in weight) fishing is an effective method for landing the mahseers even from muddy waters. *Garra gotyla*, *Channa gachua* and *Oxygaster* spp. are preferred as bait, besides insects and earthworms.

Spin-casting

It is a method of fishing with artificial tackle where a weighed lure is cast with a line that unwinds from a spool which does not turn. The line is rewound by a 'finger' that turns around the stationary spool as one cranks the wheel. Spinning bridges the gap between fly fishing and bait casting. With spinning tackle, one can cast a fly, a lure, or live bait at a distance of three or four times farther away than with a fly rod without losing the live bait off the hook. Spin casting is different from spin fishing in that the spin-casting reel is mounted on top of the rod, and the spin-casting rod is essentially the same as the casting rod. The line on this type of reel is controlled with a thumb device. However, the main disadvantage is that it is not possible to land a big fish from waters that are full of trees, stumps, or bushes. The average freshwater spinning line ranges between 1.8 and 3.6 kg breaking test. There is a brake on the rod which is adjusted to prevent snapping the line. Therefore, a big fish may pull off line while one is frantically cranking the reel to bring him in, but this light-test line is an advantage because one can cast it more accurately and farther than heavy-test lines.

Spinning rod is 2.3-2.5 m long and has two types of reels, open-face and closed-face. On the open-face reel, the line and spool are in full view. But the closed-face reel has a cone covering the spool and line; the line feeds through a small hole in the centre of the cone. Probably the advantage of the open-face reel is that you can see and correct line troubles quickly. Monofilament or braided lines are especially made for use in spin fishing.

There are several ways to cast, but the over-head cast is the most popular and the safest of all. To cast a lure low over the water, side switch cast technique is adopted which means simply switching the rod tip slightly downward and a little to the right or left. Catapult cast is used to cast beneath low tree limbs.

Spinning

Spinning tackle differs, both in design and function, from the other three types of tackle but can be used for fishing both in fresh and salt waters. While it is based on an entirely different concept than fly-fishing, it can be interchanged with bait-casting or spin-casting in certain situations. Spinning rods are typically longer and lighter – about 2.0-2.5 m for use in freshwaters and 5 m for surf casting than casting rods and come in a wide variety of actions (strength), from ultra-light to heavy. The spinning tackle can be used relatively easily than bait-casting or fly-fishing tackle. Spinning reels also handle very light line better than any other reel type, which enable them to be matched with light and ultra-light action rods. In addition to these qualities, spinning reels on an average, are less expensive than bait-casting reels but more than most spin-casting reels. However, many spinning reels cannot handle heavy lines and as such it often limits their use on large fish or in areas with heavy cover.

Unlike bait-casting reels, spinning reels are mounted below the rod handle and utilize a stationary spool. The design of the spinning reel and spool promotes the free flow of line on the cast, allowing friction-free flight as it glides off the spool. Prior to the cast, a curved bar, or 'bail,' is opened to allow the weight of the lure or bait to pull the line from the stationary spool on the cast. After the cast, the bail snaps closed, capturing the line at the start of the retrieve. When the reel handle is turned, the bail turns accordingly, winding the line evenly onto the spool. Drag adjustment systems are situated either at the front of the spool (front drag) or the rear of the reel (rear drag).

Spinning tackle is ideally suited for presenting most varieties of bait and rigging it in many ways with a hook, sinker and a bobber. Since most of the baits are lightly secured to the hook, using spinning tackle allows the angler to cast these baits farther than with bait-casting gear. The superior casting distance from spinning gear also enables the angler to reach schooling fish from a distance in open water casting. Further, small jigs, spinners, crank baits, spoons and minnow imitations are more easily cast with light line and spinning gear.

Floats, known as bobbers or corks, come in all shapes and sizes and are used for strike indication and depth control. Round bobbers made of plastic and available in two-tone colours are by far the most popular and widely used for fish that are commonly caught from the bank. Pencil bobbers are long and narrow and poorly visible to the fish than rounded floats. They also provide less resistance when a fish pulls down the line and are preferred for more subtle-striking fish like the trout. Slip bobbers have a small hole through the length of the bobber through which the line can pass. A bobber stop is attached to the line at whatever depth the angler desires to fish and this enables it to be used in much deeper waters than either round or pencil bobbers.

The method is suitable for fishing the mahseer, *Chitala chitala, W. attu, R. bola, Schizothorax esocinus* and murrels. Spoon fishing has been found to be quite effective in river Beas with rich returns.

Fly-casting

One of the oldest fishing methods that has changed over time, fly-fishing involves the presentation of small 'flies' to the game fish and differs significantly from other styles of fishing discussed above. The most fundamental difference between fly-fishing and other styles of fishing is that a heavy line is used to cast a near weightless fly as opposed to a heavy lure or bait that carries a near weightless line. Fly-fishing is generally confined to fish that dwell in shallow waters or fish that can be reached in shallower areas of deeper waters. Most fly-fishing in freshwater is focused on trout though other species are also fished in a large variety of waters. The equipment for fly-fishing is specific and consists of a variety of rods, reels, lines and other gear.

Originally, the rods were made of bamboo strips that were available exclusively in China but later replaced by fibreglass. Though highly expensive, these are now made of graphite and are, on an average, 3 m in length. The strength (action), power and flexing qualities of the rod are referred to as its 'weight' that ranges from 1 to 14. In general, weights from 1 to 4 are used for small fish, 5 to 8 for medium-size fish, and 9 and above for large fish.

Since fly-casting is a function of the rod and line, fly reels generally serve the purpose of storing the fly line. Fly reels are mounted on the rod below the handle, giving the rod-and-reel combination a natural, balanced, feel in the hand of the angler. Most fly reels have an adjustable drag system that allows the angler to put added pressure on fish when fighting from the reel. Fly-lines have much thicker diameters than conventional fishing lines as thickness is needed to give weight to the line, an essential requirement for casting. Fly-lines vary in length, but are commonly 30 m long. The strength and density of a fly-line is referred to as its 'weight.' The weight

ratings are the same as for fly rods, because equivalent line and rod weights are required for balance and proper performance. Usually, the fly-lines are not consistent from end to end, varying in actual weight or density at certain portions of the line depending on what type of method the angler is using. Some fly-lines will float on or just below the surface while others will sink deep below the surface. Another factor in fly-line is its taper or density at the tip, usually the last 3 m or so that allows for easier long-distance casts. Lines that concentrate the weight more towards the end of the line make it easier to cast smoothly and are the most popular. The more forward the weight is placed, the more casting power it has.

Leader is the section of line between the fly-line and the fly and is made primarily of colourless monofilament nylon that provides a nearly invisible connection between the thick fly-line and the fly so that the fly appears natural to fish. The wide end of the leader, called the 'butt,' is attached to the fly-line. The narrow end, known as the tippet, is tied to the fly. Tapered leaders make it easier to land the fly delicately because the heavier weight (wider diameter) is behind the lighter-weight section. The leader is as long as the rod but 2.5-3.5 m long is the most common.

Flies are the artificial lures used in fly-fishing. They have a hook and body and are so designed that they closely imitate a specific food of the fish, mainly insects, their larvae and nymphs, or other organisms such as baitfish, frogs, crustaceans, or even small terrestrial creatures. While hooks are the foundation of all flies – the size of the fly being determined by the size of the hook – the bodies comprise the middle sections of flies and are tied to the hook shank with yarn. Choosing the right fly is often the most challenging decision that a fly angler faces. As such, a well-prepared angler carries a wide variety of flies and fly sizes that can be used at all water levels from the surface to the bottom.

Dry flies that are almost weightless and virtually wind resistant are the most common types of surface flies. They are mostly designed to imitate the adult stage of insects found floating on the water surface. Poppers are popular surface flies that imitate anything from a frog to a baitfish. Wet flies are subsurface flies designed to imitate the juvenile stage of aquatic insects or other creatures that inhabit areas between surface and bottom. Nymphs are sinking flies that are designed to imitate larval stages of aquatic insects as they emerge from the bottom as well as shrimp or other small invertebrates. Streamers are subsurface flies imitating a baitfish that descend at moderate to fast speeds when in the water.

Fly-fishing encompasses several methods, especially the casts that are unique only to this type of fishing. Fly-casting can take some practice to master, but it is basically the upward and backward motion of the rod, followed by a rapid, downward follow-through motion. The pulling and releasing of line with the non-rod hand accompany this rod action. Both rod and hand work in tandem to produce line speed, which helps produce accuracy and a subtle presentation. It is often necessary to move the fly-line through the air repeatedly in order to get the fly correctly placed on follow-through. This process is referred to as false casting, a process where many casting motions are made before allowing the line and fly to land on the water.

Casting methods include 'back casting' or 'overhead' casting, the most common cast in fly fishing is 'roll casting', the easiest to accomplish when used with floating and slow-sinking lines and 'side-arm casting', primarily used only by the most experienced anglers and hence the least commonly used technique.

Once the cast is complete, the angler needs to concentrate on catching and landing the fish as it is a big challenge on fly tackle than on any other tackle. The angler should allow the fish to run instead of trying to overpower it. Proper netting technique is essential in fly-fishing. Fly-fishing is suitable for fishing the mahseer and trout, the latter preferring dry over wet flies. It can well take mahseers smaller than 2.0 kg in weight and could also be used for *R. bola* and *Puntius* spp.

Jigging

Jigging is a fundamental fishing technique used for almost any fish in any season, in fresh or saltwater and in warm or coldwater. A jig is an artificial lure but unlike other artificial lures such as plugs, spinners, surface lures or flies, it has little or no 'action' on its own and it depends entirely on the angler to produce the right action and fish-attracting movement that will result in a strike. A jig can be fished effectively with spinning, bait-casting or spin-casting tackle.

Though jigs do not appear to represent any particular shape of a water-borne object but, when presented properly, the fish considers them as live, wriggling, swimming creatures that make for an easy meal. Jigs come in all shapes and sizes and are made up of three parts, the head, the hook and the body. The head is made from a heavy substance, usually lead, that forces the lure to sink once it hits the water. Jig heads can be ball-shaped, oval-shaped, bullet-shaped or coin-shaped. The shape and weight of the head helps distinguish one jig from another. The hook is moulded inside the head, forming one balanced piece. The body is made up of soft plastic, feathers, rubber or nylon.

The jig should be easily seen underwater, hence colour selection is important. A bright coloured jig is most effective on sunny days while darker jigs are the best when the skies are overcast. In clearer waters, lighter colours work well and the darker in murkier waters. Matching the jig with the correct line, rod and reel is crucial to effective jigging. The rod should be stiff enough to deliver action to the jig, sensitive enough to detect light bites, and heavy enough to ensure solid hook sets. A reel with a fast retrieve speed should be used as it allows the angler to reel in slack line while the jig is falling, an important factor in detecting strikes. The lightest weight line is the best as it balances well with the rod and reel. Further, it neither interferes with the jig's action nor the angler's ability to detect a strike.

The basic method used for jig fishing involves casting the jig beyond the intended target and allowing it to flutter down toward the target, and 'hopping' the jig and swimming it in and around where the fish are likely to be. Fish generally strikes a jig as it falls, though many strikes occur even when it is motionless or resting at the bottom. To be successful at jigging, anglers need to concentrate on their line and know where their lure is or they will miss many strikes. Many beginners tend to give up on jigs after several casts. Jigging, like any other method, requires patience and practice.

Fishing equipment and accessories

The equipment include a whole lot of items such as fishing rods, reels, spoons, baits and lures, waterproof clothing and shoes, preferably sandals which can be easily slipped off to drain out sand and water, tents, boats, life jackets, vehicle, medicines, sunscreen, light hat and dark glasses, besides sufficient woollens and a mackintosh during the winter. While some of these could be hired but it is always better to be fully equipped and self-sufficient if one has to enjoy his fishing trip. Such facilities are rather limited at the moment in India but perhaps the situation would soon change with growing interest and tourist influx. In Mumbai, Kata Bazaar in Masjid is the place where rods are available from ₹3,000. Baits for freshwater angling involve mixing a special *masala* with flour, mud, etc. They have interesting names like *jaldi aao*. The recipe is secret and anglers usually source this from Kolkata. One can also source equipment from places like Singapore or Australia.

There are Trade Fairs in India and in the neighbouring countries but sport items appear to be the last attraction and draw. However, an exclusive Angling Equipment Trade Fair (NA RYBY) is a regular feature and an important angling event in Poland.

Of late, development in the design and material of baits and lures has brought a great cheer to the angler whose catches have now doubled, if not trebled. These are electronic lures hard baits that blink a blood-red light simulating an injury, that bring about fast and fierce strikes. These are available in sets of three: top (Floater, for surface to 1 m depth), middle (Diver, for depths from 1-2 m) and deep water (Sinker, > 2 m). In addition, there are 'walking worms' that constantly curl like a real worm, automatically, exciting a predatory response in fish.

To top it all, there are artificial wooden lures from willow wood, hand-carved and hand-painted, and completely sealed to prevent waterlogging for a life time. These could be used both in salt water as well as freshwater. Its buoyancy provides a more realistic action than the artificial jerky motion of conventional plastic lures and has been found to give higher catch rates.

Then there is the 'mini-rod' or 'The Pen Fisherman' – unique telescoping rod that turns from a 17.5-cm pen into a 105-cm fishing rod just in seconds. It is a travel rod, compact and durable, that easily fits into a back-pack.

As for boats, the inflatable ones are becoming obsolete owing less of available interior space, time taken to inflate/deflate and frequent problem of punctures. Instead portable boats for small lakes are getting popular as these do away with all the disadvantages of the inflatable boats and can be operated on gas outboard or electric or both. These are quite stable, durable and can fit easily on top of a vehicle and fold to 11 cm flat.

It would be good if some entrepreneurs in India import these different equipment and accessories for trials and manufacture it indigenously as otherwise it would be unaffordable for local fishermen and also a majority of tourists.

Fishing sites, seasons and facilities

To be a successful angler, it is imperative to know where and when to fish. India has rich aquatic resources both in terms of cold and warm waters as well as fresh-, brackish- and salt waters. About 10,000 km of rivers and streams, 20,000 ha of natural lakes, 50,000 ha of man-made reservoirs in the Himalayan belt and 8,000 km of conducive coastline are home to some of the world's finest sport fishes and offers ample scope for sport fishery/Angling. The main river stretches suitable for Angling are in lower Himalayas, Satpuras, Aravallis and high ranges of Nilgiris and Munnar along the Western Ghats in peninsular India; and the main areas suitable for big game fishing are seas around Andaman and Lakshadweep Islands, offshore area of the whole west coast of Indian mainland and offshore area of Tamil Nadu and Andhra Pradesh.

The major rivers of the north, viz. Ganga, Yamuna, Sutlej, Brahmaputra, and their tributaries harbour a wide variety of fish, including the mahseers – the 'King of Indian Sportfish' – considered to be almost as good game as the Atlantic salmon. The largest mahseer on rod and reel has been recorded from Brahmaputra and found to weigh 63.50 kg. The time taken to pull a mahseer, in general, has been estimated in ratio to its weight as 2 min. for every 1 kg. Other game fish found in the rivers of northern India include the trout and scizothoracids in cold waters and Indian major carps, murrels and catfish in the warm waters of the plains. Catfish are a particularly popular choice with Indian anglers, as they are easy to bait, are good fighters, and are prized for their tasty, rather boneless flesh.

The rivers of Peninsular India – Mahanadi, Godavari, Krishna and Cauvery – are open to angling and sport fishing almost throughout the year barring a short spell during the monsoon being the breeding season for the fish. The species prominent in the peninsular rivers include the mahseers, white carp (*Cirrhinus cirrhosa*), carnatic carp (*Barbodes carnaticus*), besides *Gonoproktopterus* spp.

India's long coastline also offers abundant opportunities for angling, and port towns like Mumbai, Kandla, Nhava Sheva, Marmagao, Kochi, Kolkata/Haldia, Paradip, Vishakhapatnam, Chennai and Tuticorin have facilities for coastal fishing where snappers, perches, sea bass, sharks, jacks, mackerel, marlin, tuna, and sailfish provide good sport. One could catch fish off the Land's end in Bandra and Mahim Creek in Mumbai but there are several places along the Konkan coast such as Alibaug, Harihareshwar, Kankavli and Vijaydurg in Maharashtra where one could go angling. Fishing is also possible in estuaries and the Chilka Lake in Odisha. Though rich in marine life that anglers enjoy most in Andaman and Nicobar and the Lakshadweep Islands, conservation laws in these areas have put a large portion of the waters off-limits for anglers. The status of sport fisheries in various states of the country is discussed below.

Himachal Pradesh

Of the 3,000 km of rivers and streams in Himachal Pradesh, 600 km provide for trout fishing while the rest are available for mahseer, schizothoracids and other species. The main rivers are Beas, Sutlej, Ravi, Tirthan, Sainj, Uhl, Baspa, Pabar, Lambadug, Giri, Rana, Nugal Gai, Baner and Bata for which licenses are issued. Fishing with only rod and line is permitted and regulated according to the Himachal Pradesh Fisheries

Act. The Department has identified potential fishing sites for trout fishing in stretches measuring from 5-20 km totaling about 80 km on Beas, Tirthan, Sainj, Uhl, Ravi and Lambadug and for mahseer fishing in 5-10 km stretches, mainly on Beas, totaling over 50 km. Some of the well-known beats are listed below:

Trout fishing: Upstream of Rohru in the Pabbar valley: Seema, Mandil, Sandasu, Tikri and Dhamvari (all within 5 to 25 km of Rohru); Uhl river near Barot: Luhandi, Tikkar and Kamand; Upper reaches of river Beas (Kullu valley) and its tributary streams: Sarvari, Parbati, Sainj, Hurla and Tirthan (areas around Aut, Patlikuhl, Katrain, Raison and Largi) – upstream of Pandoh reservoir on Mandi-Manali highway.

Mahseer fishing: Kangra valley has several spots: Pong Dam right up to the town of Dehra; Around Nadaun along river Beas; Chamba Pattan near Garli (accessible from Nadaun or Jawalamukhi), Amtar (2 km from Nadaun), Harsi Pattan (30 km from Tira Sujanpur) and Lambagaon (15 km from Tira Sujanpur); On the river Giri, Gaura (30 km from Solan): near Dadahu (5 km from Renuka Lake); river Yamuna, downstream of Paonta Sahib.

The Directorate of Fisheries, Himachal Pradesh, provides information on licence issuing authorities and the fee for mahseer and trout fishing, rest houses and the officers to be approached for reservation, besides useful tips to the anglers, do's and don'ts, and the provisions of the Fisheries Act that call for deterrent punishment to the defaulters. Fishing is completely banned in all general waters including lakes and reservoirs during the spawning season from 1 June to 31 July and in trout waters from 1 November to 28 February of the following year to enable the fishes to spawn unhindered. Use of dynamite or any other explosive substance or any poison (bleaching powder or any noxious material) in any water and killing or catching fish with a net during the close season are considered cognizable, non-bailable, offences punishable with imprisonment or fine or both.

Himachal Pradesh has acquired the status of a prime fishing locale, especially the Kullu Manali region, with Larji valley which is crisscrossed by a number of streams that are tributaries of the Beas. Most of these streams have good brown trout. Kullu is linked by air with major cities and is also accessible by road from almost anywhere in northern India. Kullu has ample accommodation, and is a convenient base for angling tours around the valley.

Further north, the Baspa too is replete with trout, and there are a number of good beats along the Sangla valley where prime specimens can be caught. Kasol, Bathad and Banjar are more known for mahseer. The best period for mahseer fishing are those months that have an 'r' in their spelling - January, February, March, April, September, October, November and December.

Jammu and Kashmir

In Jammu and Kashmir, about 1,050 km of rivers are potential trout streams that include Bringhi, Sindh, Aru, Kishanganga, Lidder, Boniyar, Dagwan and Erin. In addition, Vishansar, Kishansar, Gangabal and other lakes that are located over 3,500 m above the msl are also potential fishing areas where brown trout are available and fished. Permits for trout fishing are issued by Department of Fisheries at Srinagar Best season to fish are April to October.

Snow-trout fishing can be done in any part of valley, especially along river Jhelum and its tributaries, but good catch can be along Arh stream feeding Dal Lake. Madhumati feeding Wular Lake and Mirhuma feeding river Jhelum. Woosan feeding river Sind. Mahseer as a fishery is not present in valley but exists in Jammu region in river Chennab and Tawi. Fishing sites are Ikhnee nalla and Anji.

Uttarakhand

The rivers and streams as well as the lakes in Uttarakhand offer good fishing. The Ramganga and Sharda rivers and the lakes, Dodital in particular, are known for trout and mahseer fishing. The stretches around Beas Ghat and Gangalehri on the Ganga and Yamuna and its tributaries in Dhoon valley are good for mahseer

Brown trout are available only in small numbers in Bhagirathi, Birehi and Pinder rivers but the Directorate of Coldwater Fisheries Research (DCFR, Bhimtal) is now rearing the rainbow trout to table size at its Chirapani Farm (Champawat district) in Uttarakhand.

There are four hatcheries in the state – those at Bairanga Trout Farm (Chamoli district) under the Department of Fisheries and at Chirapani Farm (Champawat district) owned by the DCFR have been producing the fingerlings of both brown and rainbow trout while the hatcheries at Talwari (Chamoli district) and Kaldyani (Uttarkashi district), both under the control of the State Department, are respectively producing the fingerlings of rainbow and brown trout. These old hatcheries of the State Department have been facing the problems of water quality, disease and feed. While feed mills are being established at Bairanga and Chirapani, it is proposed to develop trout aquaculture in a big way which may also help provide fingerlings for stocking the rivers, lakes and raceways for sport fishing.

A mahseer hatchery has also been established by the DCFR at Bhimtal where golden mahseer seed is being produced since 1990 and used for stocking the various lakes of Kumaon Himalayas, besides the Kosi river and supply to other agencies.

Delhi

Though there is no scope for good sport in the Yamuna at Delhi due to pollution and muddy waters but about eight species including catfish, murrels and feather-backs are available in Yamuna at Okhla, the best beat in Delhi which are most enjoyed by the local anglers.

Asom

Angling is one of the favourite sports of Asom with the Brahamputra, its tributaries and a number of smaller streams offering a series of fishing sites, Jia Bhoroli, Kapili and Manas being categorized as excellent for mahseers (*Tor* spp.) and the katli (*N. hexagonolepis*) or bokar as it is locally called.

An annual competition in November brings hundreds of anglers from within and outside the country to participate for fishing at Jia Bharali river to net the golden

mahseer. The record catch of golden mahseer at Jia Bharali on rod and line weighed 24.5 kg. In view of the rapid decline in the population of golden mahseer in the river as a result of poaching, the Asom (Bhorelli) Angling and Conservation Association has stocked the river with fingerlings and also launched a programme on scientific breeding so that the game does not get lost.

Northern West Bengal

The Teesta with its tributaries Jaldhaka, Torsa, Rangit, Gadadhar and Sankosh joining the Brahmaputra and Mahananda, Balason and Mechi draining into the Ganga are home to the katli (or bokar), Indian trout (*Oreinus moleswörthii*), the Goonch (*Bagarius bagarius*) and the mahseers, both the red-finned (*Tor tor*) and the golden (*T. putitora*). The Teesta, in particular, is known for its excellent mahseer.

Sikkim

Sikkim is fast developing as a recreational place for sport fishery. Anglers can fish mahseer, katli, goonch and snow trout in rivers Teesta and Rangit.

Arunachal Pradesh

Arunachal Pradesh is the best to go for recreational fishing in the east. The Brahamputra (known as Siang in Arunachal), along with Subansiri, Kameng, Lohit and Tirap are the major rivers of the State and are the site for white water rafting in India which provides a thrilling experience along with a number of fishing sites at Tezu on the Lohit, Tipi and Bhalukpong on the Bhoroli river, and Pashighat, Panging, Boleng and Yembung on the Siang.

Tamil Nadu

With the Avalanche hatchery being now active, the seed of rainbow trout is available for stocking the Mukurthi Lake and the reservoirs created by the Avalanche and Emerald rivers. A number of streams, rivers and pools in the Nilgiris are now providing good trout fishing, Peermund, Kalkundi, Portimund and Chembar streams and Mekod river being the best among trout streams.

Kerala

In Kerala, the High Range Angling Association has been actively managing the Rajamallay Hatchery and stocking the streams (Kadallar, Pettimudi and Rajamallay) and lakes (Elephant and Devicolam) in Munnar High Ranges. Good angling is possible in the streams around Munnar which is 4-hour drive from Kochi by road and is well connected with other cities and towns in southern India.

Karnataka

The Cauvery is the prime angling or sport fishing river with Bheemeshwari (located 100 km from Bengaluru), Doddamakati (46 km from Bheemeshwari) and Galibore (16 km from Doddamakati) being the perfect destinations for mahseer anglers in the

Cauvery. Like in many places abroad, in Bheemeshwari too, where the Government of Karnataka is actively involved in promoting angling, one is not allowed to take the fish back home and it has to be released back in the water.

Mysore is located conveniently close to the Cauvery. The anglers can stay either in the city or at the Kaveri Fishing Lodge, slightly outside Mysore. The waters around the lodge, which is on the bank of the river, are a good place to fish for mahseer.

Maharashtra

Powai, an artificial Lake created in 1891 for drinking water supply to the city of Mumbai though no longer serving its original objective owing pollution has been a haunt of anglers for over 100 years and considered an angler's paradise for the city of Mumbai. It was initially leased to the Western India Fishing Association, when only minnows and olive barb (*Puntius sarana*) were available. Later the Bombay Presidency Angling Association was formed and registered in 1936. In 1955, its name was changed to 'The Maharashtra State Angling Association (MSAA)' with the objective of angling as a sport but its constitution was revised in 1991 to include preservation of Powai in view of its fast deteriorating environment. The Association stocked the lake with catla, rohu, mrigal, calbasu, khudree mahseer and a few other species too. Calbasu was once established in the lake but pollution and poaching coupled with heavy infestation of water hyacinth and silting have adversely affected the lake's water quality. The average rainfall at Powai is about 2,540 mm, and the lake overflows for about 60 days each year. Today, MSAA has covered boats, a proper club house and a nursery where fishes are reared and released into the lake each year thus replenishing the losses due to poaching. The Association is also responsible for inclusion of Powai Lake in The National Lake Conservation Programme of the Government of India.

While in most cases, it is the Department of Fisheries and its officers who are responsible for issuing fishing licenses and provision of lodging facilities, besides monitoring the maintenance of rules and regulations. On some rare cases, Associations provide equipment and lodging facilities and maintaining and conserving the fisheries of the lakes or rivers as the case may be. Some of the well-known Associations in different states are listed below:

Asom	Bhorelli Angling Association, Tezpur
Delhi	Assistant Warden of Fisheries, Delhi Administration (Okhla Barrage, Okhla)
Haryana	Angling and Aquatic Conservation Society of India, Faridabad
Himachal Pradesh	Himachal Pradesh Angling Association, Palampur
	District Fisheries Officer, Dharamshala
	Himachal Fisheries Department (Katrain/Barot/Sangla/Rohru)
Jammu and Kashmir	J & K Department of Fisheries, Srinagar
Karnataka	Wildlife Association of South India, Bengaluru
	Coorg Wildlife Association, Madikeri
Kerala	High Range Angling Association, Munnar
Maharashtra	Maharashtra State Angling Association, Powai Lake, Mumbai
Tamil Nadu	Palni Hills Game Association, Kodaikanal
	Assistant Director of Fisheries, Udhagamandalam
Uttarakhand	Dehradun Fishing Association, Dehra Dun
	Forest Department, Corbett National Park
	Municipal Corporation, Naini Tal (for fishing in Naini Tal)
West Bengal	Fisheries Department, Mirik

Open sea fishing destinations in India

There are four principal coasts where open sea fishing can be indulged and exists to some extent, Odisha, Lakshadweep Islands, Andaman Islands, Goa and the Kerala coast. Besides this, port towns like Mumbai (Bandra and Mahim creek), Kandla, Navasheva, Marmagao, Kochi, Kolkata/Haldia, Paradip, Viskhapatnam , Chennai and Tuticorin have facilities for coastal fishing

Odisha: On India's east coast, Odisha offers unique game fishing in its largest brackish water lake called Chilka. It is rich in Tiger Prawn, Tuna and other varieties of fish. Chilka Lake is also known for migratory bird life.

Lakshadweep: Lakshadweep Islands in the Arabian Sea are rich in game fish including sharks, Kulvel, Barracuda, blue marlin and groupers. Out of 36 Islands sport fishing is allowed only on two islands – Agatti and Bangaram. Angling is allowed by Pole and line method only so that only big fish can be caught. Fishing season is between October to May.

Andaman Islands: Andaman Islands, some 293 in number, stretch across 25 km from the north to the south of the Bay of Bengal. As home to numerous game fish species and adjudged as the best game fish destination in the world. Commercial fishing by long-lines, trawlers are banned around this island, only traditional fishing by local inhabitants practising hand line is allowed. Sea sport fishing allowed around south Andaman Islands only. Fishing allowed between October to April, and Game Fish Charters allowed between February to April. Catch and release policy for anglers adopted.

Goa and Kerala: The sea fishing region of Goa and the Kerala coast extends from the beach resort of Goa to Thiruvananthapuram along the long southwest coast. The main ports in the area are Goa, Mangalore, Cochin and Thiruvananthapuram. Best fishing sites along Konkan coast are, Alibag, Harihareshwar, Kankavli and Vijaydurg. Most suitable time for fishing is before and just on the top of high tide. Bait used for fishing is the sardine or shrimp.

An idea about the ecology of rivers and streams is a prerequisite for successful fishing. Both trout and mahseer migrate upstream for breeding looking for suitable sites - redds - for egg laying and also for feeding and so do the carps and catfishes and some other species too. It is therefore necessary that the breeding behaviour and season are kept in mind while selecting the angling spots. The best season for fishing for the mahseers is spring (February to April) in large rivers of the north and autumn (October-November) for small rivers. Cloudless and clear sky provides an ideal fishing condition as one needs calm and still waters. Hot weather in the beginning of the season is by far the best. In Karnataka, Madhya Pradesh and Maharashtra, the season for spinning-bait and fly-fishing begins once the turbidity in the rivers clears after the monsoon floods from November/ December to February/March.

Carps and catfishes are best fished using fermented or scented dough balls and worms/insects, respectively, as baits almost throughout the year but especially during the monsoon floods while the murrels in clear weedy waters during any season with frogs as bait.

Sport fishing/angling and the tourism industry

It is necessary to prepare a Fish Species Directory with special reference to the game fishes of each state. To begin with, some of the best fishing sites having easy accessibility and facilities for camping or lodging and boarding should be included in the Directory which could later be improved to cover all the fishing spots in the state. Taxonomists and biologists from the universities and research institutions in collaboration with the officers of the State Department of Fisheries and the fishermen of the area would need to work together to compile the actual and hitherto unknown information on bionomics with particular reference to habitat (specific areas of availability) and the tackle and bait to be used for each species of fish. (These need to contain information on shops and stores or such other agencies where the required fishing implements and gadgets could also be procured, if necessary).

However, an angler should not be wanting in what he requires and be fully prepared. In such a case, a checklist could be provided to him that would be helpful in organizing the outing without much ado. High quality angling equipment for angling is not widely available for hire in India, although some outfits in popular areas like Garhwal and the Nilgiris do provide equipment on hire.

It would perhaps be desirable to establish a website that could give detailed information separately in respect of each state. This would work out cheaper, faster , better and would be especially helpful to foreigners. Though the Department of Fisheries, Himachal Pradesh, and the Indian Fisheries Conservancy (IFC) have put up their websites, these need to be updated regularly and elaborated. However, the importance of brochures and leaflets should not be ruled out as net facility is neither available to everyone nor everywhere.

Feasibility studies and surveys conducted by Air India to develop the angling tourism industry employing foreign anglers are now three decades old and a part of history. A 50 kg mahseer or a 5 kg trout may be a rarity now but we still have some good streams where 5-10 kg mahseers and 1 kg trout could be found that need to be managed properly if continued flow of foreign angler-tourists has to be maintained. Several other countries, more so India's neighbours, have developed their tourist industry so well that we need to think twice and plan it in the most modern way. The trout streams in Kashmir that were once known to offer some of the best fishing sites in the world need to be reassessed and then projected in a big way employing all the available media and through our Embassies and High Commissions. Articles and ads need to be published not only in the In-flight magazines of Indian Airlines or Air India but in all other domestic and international flights.

With a view to encourage game fishing in India, the national and state tourism departments have started providing leaflets and brochures on areas where fishing is possible, where to go, what are the facilities available in the area, where angling equipment can be hired, and additional information can be obtained from the State Tourism Departments. Major cities and those close to angling and sport fishing grounds have some travel agents and tour operators who also cater to the anglers and provide everything from equipment and experienced guides to boarding, lodging and

transportation. However, further information and assistance can always be obtained from the local Wildlife, Forests or Fisheries Departments.

While the tourists from foreign countries would enjoy mahseer and trout fishing, the Indian angler would as much love to fish for the indigenous species that are a galore in fresh and brackish waters and the seas around us, more so as he cannot undertake long journeys and stay out which only a few rich can afford. An outing in a group or with the family is one of the best means of enjoying a holiday and get fresh fish for eating at not much expense. This is best achieved by organizing Anglers' Clubs and developing the ponds and tanks through aquaculture.

Besides being a sport, angling also serves the purpose of commercial fishing in ponds where the fishermen charge rather heavily for netting to the extent of 25-40% of the catch incurring a great loss to the farmer. The indigenous catla, rohu and mrigal are not only tasty and highly relished but a good game too. In Banstola (Purulia District, West Bengal), the village group organizes an angling competition in the month of *Shravan* (July/August) each year when it throws open the 0.6-ha community pond for angling on all Sundays charging a small fee and earns a huge amount in just four days at almost no expense. The fish taken out by the anglers are weighed and sold to them at a fixed cost on par with the market. Under a collaborative Project on aquaculture in Jalpaiguri (West Bengal), experimental angling for rohu and mrigal was organized in three *dighis* (0.44-0.60 ha) as fishing with dragnets was difficult owing uneven bottom and presence of *ghats* and pillars/temples in the centre of the ponds. On an average, 10.85 to 20.75 fish were caught/rod/day in 5-day period, mrigal falling an easier prey than rohu with morning catches being better than afternoon. In addition to saving the labour costs on fishing that adds to the profit margin of the farmer, the other advantages are that removal of big fish reduces the risk of poaching and gives the smaller ones more space to grow faster with lesser feed for consumption. It is also an avenue for employment to some rural folks with necessary angling expertise.

In the USA, minnows and shrimps are bred in hatcheries and cultured in ponds and a big industry exists that is involved in their transport and marketing as bait for the anglers. We do not have any parallel of this kind of trade but it would certainly develop one day with emphasis on eco-tourism or sport fishing-based tourism and a fillip to the development of a breed of local sports fishermen.

Management, development and conservation

Sport fishery is a form of outdoor recreation which can be undertaken only along certain specific sites and locations as envisaged, locations in India, especially within inland system are far flung and in such areas which need economic development and conservation simultaneously because of their ecological status. As such sport fishery needs to be developed on the concept of ecotourism. Development of Sport fishing in inshore and offshore waters need different strategies because of nature of activity, difference in support system and economics involved.

In Inland system, it is now time that the sport fisheries of the streams, rivers, lakes and reservoirs in the country is managed on scientific lines. This calls for detailed studies of the entire ecosystem, its carrying capacity, recruitment rate of the game fish as also others that compete with it so as to plan stocking/ranching to build-up its population for the angler and also to fix the bag limits. Data on creel census collected some years ago had indicated that the catches were declining and ranged between 200 and 1,000 g/rod/hr/day in a kilometer length of fishable stretch, the average weight of brown trout being 265 g and 415 g, respectively, in Himachal Pradesh and Kashmir. Further, small-sized rainbow trout ranging between 100 and 200 g in the streams is clearly indicative of an ominous situation. Yet no bag limits have been fixed till date either for trout or for mahseer which is also declining in many areas. While this study needs to be conducted by researchers, it is at the same time equally unfortunate that the Indian angler and the Associations, in general, have not been maintaining a proper creel census data that is so essential for managing the natural populations. It should be incumbent on the licensee to honestly file the required data in the prescribed proformae, which need to be developed in collaboration with the research institutes, and for the Associations to provide it to the Departments of Fisheries or Research Institutions for proper analysis and recommendations on necessary management measures to regulate recreational fishing.

Truly speaking, we have no idea about the number of anglers – local, national and international – and the number of days spent by them on fishing, type of fishing and beats/place(s) covered, species/size/quantity and value of the fish caught by them. Detailed information on the expenditure incurred on transport, lodging, food, license fee, equipment, etc. will help economic evaluation of the recreational fisheries and outline its importance as an essential ingredient for developing the tourism industry. It would be worthwhile maintaining a registry of all anglers. It is necessary that the rules regulating the game fisheries are properly impressed upon the anglers and implemented strictly. What is needed is that the State Departments should help organize Angling Clubs and register it as is being done in case of Cooperative Societies or Self Help Groups (SHGs) and help them organize awareness programmes on 'responsible fishing' and angling competitions besides organizing opinion surveys to monitor the preferences of the public regarding the management of recreational fisheries.

A decline in the population of golden mahseer has been reported from almost all the rivers and also the large reservoirs such as Govind Sagar, Rana Pratap Sagar and Gandhi Sagar. The populations of *T. putitora* and *T. tor* in Kali, Gauri, Saryu and Ramganga rivers in the Kumaon region are on a continuous decline due to dynamiting, poisoning, use of small-meshed nets, water abstraction, deforestation, landslides, erosion and pollution resulting in poor water quality in the Yamuna. The *tor* mahseer has declined in the Narmada from 30% to 15% in the last four decades because of construction of dams that have obstructed its migration and submerged the breeding grounds. The seed collection centre at Bandrabhan at the confluence of Narmada and Tawa has ceased to exist owing the construction of Tawa Dam near the confluence of Tawa and Denwa – the breeding ground of mahseer. Pollution has reduced its population from 90% to almost nil in Bilaoli reservoir at Indore and also in Chandpatha in Shivpuri in Madhya Pradesh. Despite the fact that the lives of two boys were lost in early 2004, illegal fishing using electricity in Denwa river in Pachmari Biosphere Reserve in Madhya Pradesh, is still practised. The *khudree* and *mussullah* mahseers have disappeared almost totally from Bhima, Krishna and Koyna rivers in Maharashtra and also from the Cauvery except from some stretches in Karnataka that are leased to angling associations.

There are two ways to rehabilitate the fisheries, either restore the habitat which appears difficult, if not impossible, or else make good the declining stocks in the rivers, streams, lakes, reservoirs and ponds and tanks through fingerling transplantation to replenish the losses or provide recruitment support, wherever required.

Habitat restoration is expensive and time taking as afforestation to check landslides and soil erosion and improvement of water quality adversely affected by discharge of pollutants is not an easy task. Construction of dams for irrigation or power production is imperative in the larger good of the people but its adverse effects on river ecology, submergence of breeding grounds or barrier to their migration for spawning or feeding have to be made good by other means. Reverting to the old situation is well nigh impossible. The Tata Power Co. Ltd. (TPCL) has since 1970 undertaken the work on ecological improvement and conservation of fish and other aquatic life including stocking mahseer seed in all the five lakes under their control.

Stocking the streams or lakes requires the seed to be collected from nature or produced artificially. Since the techniques of breeding and rearing were known in case of the trout, it was possible to produce their seed for ranching and stocking the lakes and streams to maintain and strengthen their populations though not on a large scale till now. With the renovation of about 30 hatcheries and farms in the Jammu and Kashmir and the establishment of a modern hatchery at Kukarnag, it is expected that the trout streams will now be adequately stocked. The construction of a modern trout farm at Patlikuhl in Himachal Pradesh in 1991 and a hatchery at Batahar in 1995 has created considerable interest amongst the local population. A feed mill has also been established to meet the requirements of larval, grow-out and broodstock stages. Though there are another 11 hatcheries – four in Uttarakhand, two each in Arunachal Pradesh and Kerala, and one each in Sikkim, Meghalaya and Tamil Nadu – these do not appear adequate to meet the growing requirements. The problem is not just the number – it is its size and capacity, availability of quality broodstock, water supply and its quality, expertise of the staff and its availability, budget and overall management that counts. It is absolutely essential either to provide trained manpower or organize their training at established hatcheries/research institutes within the country or abroad. Diseases in trout and other coldwater fishes are quite rampant resulting in low survival rates in hatcheries or even in rearing ponds and there is no gainsaying the fact that there is a glowing shortage of expertise in this discipline. This needs to be made up through training abroad. The Himalayan states have a great stake in tourism development and timely action is imperative.

However, owing to non-availability of the breeding and rearing technology for mahseers and other indigenous game fishes, ranching and stocking of rivers, reservoirs and lakes with indigenous game fishes could not be taken up till recently though seed of *tor* mahseer was collected at some centres in Madhya Pradesh and stocked in ponds and reservoirs. It is to the credit of the two hobbyists, S. Moolgaokar of TELCO and S P Manaktala of Tata Electric Companies (TEC), who were instrumental in providing infrastructure facilities and support to Dr C V Kulkarni, who with the help of Shri S N Ogale, achieved remarkable success in artificial propagation of mahseer when *T. khudree* collected from Walwhan Lake was first spawned on 8 August 1970 through stripping and 14,000 eggs artificially fertilized at Lonavla. The interest of the TEC in pioneering the cause of sport fisheries through conservation and rehabilitation of mahseer needs to be given due recognition. The TEC has been sharing its experiences with others by organizing workshops for scientists, development officers and policy makers to transfer the technology along with hands-on training and demonstrations on artificial fecundation of the mahseers.

Artificial propagation of mahseers has made further progress at Lonavla where both *T. putitora* and *T. tor* were also procured and are being bred regularly along with *T. khudree* and the seed supplied to various State Departments and Angling Associations. However, the enthusiasm that accompanied the success in seed production of *khudree* and other species of mahseers led to production of hybrids between *Tor khudree* and *T. tor, T. putitora* and *T. mussullah* and their release in the Walwhan lake. Even F_1 hybrids were back-crossed and F_2 generation produced. It would be nice if a scientific approach is adopted and production and stocking of hybrids as well as transplantation of other species of mahseers in Walwhan Lake is avoided.

With the establishment of the Directorate of Coldwater Fisheries Research (DCFR, erstwhile National Research Centre on Coldwater Fisheries at Bhimtal, District Nainital) in 1988, special attention was paid to restore the declining populations of mahseers and other coldwater species. The Centre installed a temporary mahseer hatchery at Bhimtal in 1990 with a capacity to hatch 2.5 lakh eggs and maintain 2 lakh fry and 1.5 lakh fingerlings at a time. However, there are no ponds for broodstock and it needs to be collected from Bhimtal and other lakes in the region. Seed production of snow trout and mahseer is also undertaken at Chirapani – an outreach centre of DCFR. A portable, flow-through, hatchery having a production capacity of 2 lakh seed of chocolate mahseer has recently been set up in Arunachal Pradesh at Iduli Fish Farm, Roing Dibang Valley District while another two hatcheries for golden mahseer, one each at Bagua Fish Farm in Southern Sikkim and Eco Camp Nameri at Tejpur in Asom, have also started functioning.

However, these few hatcheries are just not enough if all the suitable streams and reservoirs and tanks have to be stocked and angling developed on a large-scale. Replenishment or supplementation of stocks by artificial propagation is an essential requisite to meet the increasing numbers and growing demands of anglers and development of tourism industry. Establishment of hatcheries in all those locales where the environment is still suitable for the fish is the need of the hour to stock them. Where construction of hatcheries is not possible, transportation of mahseer eggs that take 80 hr to hatch should be considered. These could now be easily transported in moist cotton over long distances where they can be hatched, reared and grown. Success in cryo-preservation of mahseer milt will go a long way in their propagation and rehabilitation. The Tata Electric Company is on an average stocking 200,000 fingerlings annually in its hydel reservoirs where their population has increased considerably. While the anglers and many others have expressed serious doubts regarding the fighting qualities of the hatchery-produced mahseers as compared to those of the wild ones, it should not be forgotten that both trout and salmon – so well known game fishes are also hatchery-produced. Maybe a programme on selective breeding of mahseers would be taken up some day to select the best breeds for stocking the streams and lakes for angling and also for culture in ponds and raceways.

Any number of measures could be taken depending on the requirements and the suitability of such measures to conserve the natural populations of sport fishes. While enforcement of rules to prevent illegal methods of fishing and killing of brood fish and juveniles are necessary in all cases, declaration of closed-season and reserving certain areas as sanctuaries are other measures. Sanctuaries exit in various parts of the country, of these the temple sanctuaries on the banks of the Ganga in Uttarakhand, Narmada in Madhya Pradesh, Bhima in Maharashtra, Bhadra, Cauvery and Sharavathi in Karnataka are well known. The entire stretch of Denwa, a tributary of Narmada, falling in Pachmari Biosphere Reserve (PBR) is a safe habitat for mahseer. Declaring the stretch of Yamuna from Kelasar to Hathnikund, forming a common boundary between Haryana and Uttar Pradesh, as a sanctuary is needed to protect the mahseer fishery. Being open waters, the riverine sanctuaries are not safe during the monsoons as the fish move away from their usual haunt. They are killed *en masse* during the spawning migration and even if they get a chance to spawn, the eggs, larvae and the fry suffer natural constraints or are finally fished as juveniles and the young by fine-meshed nets affecting their recruitment as adults.

It is necessary to undertake Mass Awareness programmes involving the local leaders, associations and clubs to impress upon the advantages of conservation measures. Recently, Indian Fisheries Conservancy (IFC), an NGO has started actively canvassing for conservation of mahseers and has been drawing support from administrators as well as the scientists. It plans to seek control of potential river stretches on lease for developing conservation projects with the help of local communities who would act as guides and provide accommodation. Habitat restoration and ranching will also be a part of the programme, besides developing angling rules and maintenance of data on catches. This appears to be a good beginning and needs to be kept up and also followed in by all others in different parts of the country.

As regards Sea game fishing, some basic information is necessary for developing the sport.

(i) **Current status of recreational fishery around Indian coast/sea:** The Indian Government allowed 'Sea Game Fishing' especially along Andaman Islands since 1993 under joint venture scheme between Indian and foreign companies, but the activity is mostly undertaken by 'Game fish charters' operating from Phuket (Thailand). Before such game fish charters invade the Indian waters, government should place proper development and management policy for this activity. There should be some mechanism in place indicating permissible capacity of outboard engine, GPS, VHF and sounder fitted in these charters and permission to utilize sonar system providing 3D images so that an equal opportunity exists for exploitation of the resource and no conflict arises between local or foreign operators and above all the resources get exploited in a manner that it won't lead to depletion.

(ii) **Economic assessment of the activity:** Economic assessment of the activity needs to be done, based on which indigenous infrastructure to undertake the activity can be developed /encouraged. To know about the status of this sport, a survey programme has been initiated ay CIFT, Kochi and the observations are, that around Andaman and Nicobar Islands, twelve sport fishing companies are registered with Department of Fisheries, Andamans. Altogether 26 vessels are registered as sport fishing vessels under these 12 companies The vessels range in size from 5.18 to 19.45 mL_{OA} fitted with on board motor (OBM) of 10 to 250 hp. The vessel has to be registered to get a license, viz. ₹ 2,500 as license fee/boat/year. Different types of steel, plastic, rubber and feather jigs and lures are used for angling. Around Lakshadweep Islands, Sports fishing is not very well developed. The Society for Promotion of Nature and Tourism and Sports 'SPORTS' which is a society under Lakshadweep Administration looks after the tourism in the islands. They do not have any package for recreational fishing. Most of the resorts at Agatti cater to recreational fishing but is mostly restricted to lagoon fishing to the tourists. Few interested tourists carry out recreational fishing activities at sea on their own by contacting local fishermen. But there is very good scope of recreational fishing in the islands as there is plenty of game fishes like tunas, seer fishes barracudas, carangids etc.

(iii) **Interaction between recreational fishery and other user groups:** Evaluation is needed where resource (fish) is shared (exploited) by commercial as well as recreational fisherman.

(iv) Interaction between fisheries and outside influences, evaluation in areas where it has to compete with non-fishing use of water like Scuba diving /surfing etc.

Economics and efficiency of recreational fishing

As for the economics and efficiency of recreational fishing, a very interesting study based on data on expenditure interpreted as use value of recreational fishing from 18 countries indicated that, on an average, the annual expenditure on marine recreational fishing was 75% of the overall value of commercial landings ranging from 7% in Norway and Iceland to as high as 222% in the United States, where it is an exceptionally high value leisure activity involving the use of sophisticated and expensive equipment. While the share of marine recreational fishing lies between 3 and 4% of the total fin-fish landings in the United States, it makes an additional contribution of 26-73% of annual commercial cod landings from the Baltic Sea in Germany and the once abundant cod fisheries is now at the risk of stock collapse.

Sea game fishery as a means of tourism has a great potential currently under utilized

by India. Nonetheless we cannot ignore its importance as it is the fastest growing market in the Tourism Industry with an annual growth rate of 5% worldwide, representing 6% of the world gross domestic product, 11.4% of all consumers spending as per World Tourism Industry.

Finally, it is imperative to create a Division on Sport Fisheries at the Directorate of Coldwater Fisheries Research Institute, Bhimtal with a division at CIFT, Kochi to undertake research on equipment suitable for fishing for different species in different waters, development of specific baits/lures, development of Data base regarding sport fishery in the country and organization of training programmes in Sport Fishing. This will go a long way in developing recreational fishing as a big tourist industry.

15. Carp Breeding and Seed Production

Cultivable major carps generally do not breed in confined waters except common carp. Seed is the critical input for carp culture in the pond. Indian major carps breed spontaneously in natural waters, viz. rivers and bundh type tanks, where fluviatile conditions prevail. Natural breeding of Indian major carps was recorded in 1924. Carps breed in riverine conditions only during monsoon and no single factor can be held responsible for the spawning. The spawning act demands fulfillment of a chain and inter-related condition as pre-requisite. It is opined that heavy monsoon flood capable of inundating vast shallow area that form the breeding grounds of the fish and believed to be the primary factor to stimulate spawning. Further, the shallow spawning ground acts as a deciding factor for spawning of Indian major carps in most of the riverine systems.

Reports on the influence of some physical parameters like water depth, water current, temperature and turbidity on the spawning grounds are also fragmentary. Dissolved oxygen and *p*H also play key role for fish breeding in nature. However, increased *p*H value and high O_2 tension of the breeding ground are a deterrent for carp spawning. Highly turbid water with distinct reddish colour, low *p*H (6.2 -7.6), moderate dissolved oxygen (6 ppm), low total alkalinity (80-90 ppm) and temperature range between 27° and 29°C are favourable for carp spawning. Fish seed in the shape of fertilized eggs, spawn, fry and fingerlings were collected from the natural resources of different states during the season. From the breeding grounds, eggs were scooped by angular mosquito net of varying sizes. In flowing water, the eggs were also collected by *benchijal* (Conical bag net). Captured eggs were placed in a compartment of the collecting boat for some time but that practice resulted in high mortality due to congestion and inadequate aeration. Better method of handling of eggs and incubation of eggs involving nets, which were suspended from bamboo frames, was also attempted. Bamboo baskets which were lined with fine cloth and suspended in the hatching pit were used for egg incubation. Hatching rate in this device was usually 25-50%. The earthen pit is the earliest device for hatching the carp eggs. There were specially devised earthen pit of 90 cm × 60 cm × 30 cm dimension and called as *chabba* in west Bengal. Pits are dug in several rows and their inner walls are plastered with mud. The fertilized eggs were collected from the natural spawning ground and incubated here for 24 hr or till hatching. The newly hatched larvae were transferred to a new pit of 120 cm × 90 cm × 45 cm dimension, termed hammar hatching pits in West Bengal. The Chittagong types of hatching pits are similar in construction to ordinary pits but additionally a piece of muslin cloth is kept below the mosquito net piece in the pit. The newly hatched larva passes through the net and gets collected on the muslin cloth, which is operated for three days. Carp larvae which emerge out from the eggs in 18-24 hr and measure 5-7 mm length are called hatchlings. Hatchlings of 72 hr are called spawn. They could also be collected by *benchijal* directly from the natural sources.

Indian major carps slowly tend to breed in big confined water. The first attempt to breed major carps in confined water was by bundh breeding technique. Though Indian major carps normally do not breed in ponds and tanks, there were some favourable conditions in certain confined water where they breed during monsoon months when the riverine conditions were simulated. These water-bodies were known as 'bundhs'. The concept of bundh breeding of major carps was originated after a fish farmer named Manu Teli observed breeding of carps in Sorabati Bundh of Bankura district of West Bengal in 1882. Subsequently, spawn collection from bundh in West Bengal became a regular practice for carp culture.

The reclamation of water-bodies for inland aquaculture and increasing trend of intensification in carp culture claimed huge quantity of quality seed. Water pollution, formation of hydro-projects across the river and indiscriminate hunting of brood from natural seed collection. At this juncture, induced breeding of Indian major carps in 1957 by Hiralal Chaudhuri and K H Alikunhi made an epoch for carp seed production in confined waters.

In1930, the first experiment on a viviparous species for induced breeding was performed. This concept was successfully applied for oviparous fish breeding in Brazil during 1934. In India, ovulation in *C. mrigala* was induced by administration of mammalian pituitary hormone in 1938, but the eggs were not fertilized. In 1955, the first successful breeding of *Esomus danricus* by intraperitoneal injection of carp (*Catla catla*) pituitary gland extract was recorded. *Pseudotropius atherinoides* was bred by administering pituitary gland extract from *Cirrhinus reba*. It was in1957, *Cirrhinus reba*, a medium carp was induced bred by administration of aqueous carp pituitary extract at Angul (Odisha) by scientists of pond culture sub-station of the Central Inland Fisheries Research Institute, Barrackpore (West Bengal). Soon after the first success, Indian major carps could be bred both at Angul and Cuttack (Odisha) within 15 days. Ever since 1957, carp breeding by hypophysation is an established technology for seed production.

In continuation with the induced breeding of carps by carp pituitary extract (CPE), attempts were made to explore suitable substitute of the carp pituitary extract as inducing agent. Drugs like winstrol, clomiphene, progesterone and synthetic hormones were tried for induced maturation and spawning of carps. The Indian major carps were also bred successfully with the fractionated pituitary extract and partially purified Salmon gonadotropin in 1971 and 1977 respectively. Recent investigations revealed that FSH (follicle stimulating hormone) unlike LH (luteinizing hormone) of mammals, fish possess GtH I (gonadotrpin 1) and GtH II (gonadatropin 2). GtH-I acts on the gonads as its target organ and help formation of 17 β- estradiol, which takes major role in oocyte growth and vitellogenesis. Synthesis and release of 17α-20β dihydroxypregnane-3- one (17α, 20β- DHP) is regulated by GTH II. The 17α, 20β-DHP acts on oocyte for final maturation and leading to spawning.

Induced breeding in confined water was initiated as hapa-breeding during 1960s. Breeding hapa is a six-sided cloth compartment stitched and closed from all sides except a portion at upper horizontal wall. The breeding hapa is fixed in confined pond water by four bamboo poles where the hormone induced male and female brood are introduced for breeding.

Exotic major carps, viz. grass carp, silver carp and common carp are also equally important for composite culture as early as 475 BC. Successful induced breeding of silver carp and grass carp was reported during 1955 and 1958 respectively.

The problem in the commercial carp seed production was no longer continued as non-spawning of carp brood in confined water. Rather the major problem was lack of knowledge in egg collection and their effective incubation. Hatching hapas are commonly known as conventional double-walled cloth hapa, the inner hapa is the smaller unit and fitted inside the outer hapa. The standard size of outer and inner hatching hapa is 2 m × 1 m × 1 m and 1.75 m × 0.75 m × 0.75 m respectively. These hapas are fixed in a series to incubate the fertilized eggs. Hapa system was the most popular incubation device in our country. The floating hatching hapa has an improvisation over conventional double-walled cloth hatching hapa. This hapa had been designed to cope with the rise and fall in the water layer in reservoirs and bundh. Here the conventional hapa as such is mounted to a plastic or aluminum pipe framework supported by many floats. However, the hapa hatching system entails heavy loss of fish eggs and spawn due to fluctuation in water level and temperature, presence of minnows, common carp and crabs. Glass jar incubators are further improvised system consisting of a battery of cylindrical glass jars of 6.35- litre capacity which are cone-shaped at the bottom. It is better to say that it is a flow-up system because water flows from bottom of the jar and escapes at top. As technology developed, the glass jars are replaced by the transparent polythene jars. These jars are comparatively bigger in size, i.e. 18-21 litres capacity. Galvanized iron jar hatchery is also comparable to the glass jar or polythene jar hatchery but made of galvanized iron sheet. It is strong and suitable for use for many years. Bean hatchery and hanging dip-net hatchery are also some of the devices of carp egg incubation. At the Central Institute of Fisheries Education, Mumbai, some improved version of commercial carp hatcheries during 1980-86. These models comprise plastic portable units for breeding and hatching.

In Peoples Republic of China, the first success of artificial propagation of Chinese carp was achieved during 1958 by simulating the favourable ecological conditions with gonadotropin hormone injection. Models of hatcheries, viz. circular, elliptical, rectangular and hexagonal spawning pools, were formulated for experimental fish breeding simulating the riverine conditions to the breeders. The circular model of hatchery was developed in China during 1960 which could provide suitable environment for induced breeding and egg incubation operations. The circular type of Chinese hatchery is presently known as eco-carp hatchery in India and became more popular due to several advantages over the other types of spawning and incubation pools.

Bundh breeding

Bundh breeding system of seed production virtually contributes a large quantity of quality carp seed for freshwater aquaculture. When riverine seed collection was not adequate and the collection was rather an admixture of very many uneconomical

species, there was a search of new technique of carp breeding. Since then, bundh breeding and captive induced breeding were two parallel attempts to achieve the seed production target. The bundh breeding concept was originated as wet bundh, which was nothing but a perennial large water-body, situated in the slope of a big catchments area of undulating terrain with proper embankment. Water flow rushes from the elevated catchment over an extensive shallow area, which stimulates the brood carp to spwan. Wet bundhs are mostly natural water-bodies with little or no human manipulation. Though the well-designed reservoirs of the irrigation and hydro-electric projects fulfill the requirement of bundh breeding and well in many states, such bundhs are not under the control of any Fishery Departments for exploitation of seed production.

Dry bundh is completely man-made and well designed. It is a seasonal shallow pond ranging from 0.5 to 4 acres (1 acre= 0.404 hectare) bounded by embankments on three sides and gets filled during the monsoon season. As soon as sufficient water was accumulated in the deeper portion of the bundh, the males and females from the neighbouring areas were introduced for acclimatization and eventual spawning. Smaller unit of the dry bundh made of cement brick masonary are also constructed in the name of Bangla bundh.

Now bundhs are being considered as hatcheries, close to nature nicely bridging the natural breeding with the modern trend of induced breeding technology. Initially, the bundh breeding was completely dependent on favourable conditions. Usually broods were transferred from any perennial source to the bundh after the accumulation of sufficient rainwater for breeding. Nothing was scientifically monitored like stocking density of the brood, male : female ratio and their maturity status. Later, breeding strategy followed more scientific approach considering the brood density and sex ratio to reduce the cost of spawn production. Next improvement was sympathetic breeding based on the physiological thrust and environmental influence. In this method few pairs of brood are released into the bundh after injecting with pituitary extract along with several other non-injected pairs. If 10% of the broodstock is injected with a single resolving dose of pituitary extract, mass spawning of carps occurs. The latest bundh breeding system known as Bangla bundh is having the optimum efficiency. Here all the brood are injected with low dose of carp pituitary extract in a single dose, and are released in the bundh. This system is more organized and promising for mass-scale production of carp seed.

Induced breeding of carps

Induced breeding technique is responsible for augmenting the carp seed production in our country. There are more than 700 distinct commercial hatcheries in the country producing the carp seed through this technique. These hatcheries adopt both traditional hypophysation and the recent GnRH-based induced breeding method for seed production.

Hypophysation

Pituitary glands of the same species (homoplastic) or closely-related species (hetroplastic) are preferred. Carps that donate the pituitary gland is called the donors and while those receiving the pituitary extract are known as recipients. Since gonadotropin (GtH) in the pituitary gland is found abundantly during breeding phase, the carp pituitary glands collected during summer are found more potent. In this context, the pituitary gland of common carp is found suitable round-the-year as they breed many times during this period. It is appropriate to collect the pituitary gland from freshly harvested fish. Gland can also be collected from the fish in ice. Absolute alcohol (ethanol) is a good preservative for pituitary gland. It also acts as dehydrating agent. The alcohol can be replaced with the new alcohol after 24 hr of collection and then stored. In place of alcohol, acetone can also be used. The preserved glands are safely used for induced breeding for 2-3 successive breeding seasons. While using, some preserved glands are brought out of the vial and dried to remove the preservative, i.e. alcohol or acetone. A known quantity of glands is put in a glass homogenizer with a known volume of distilled water and macerated. The homogenized content is centrifuged and the supernatant is decanted as carp pituitary extract (CPE). The CPE can also be preserved in glycerin for better shelf-life, where glycerin and water are 2 : 1 ratio. Generally, female carp receives pituitary extract in two split doses at an interval of 6 hr. Male receives single dose at the time of second dose to the female. Intra-peritoneal injection is found better than the intra-muscular injection. However, the quantity of pituitary hormone to be injected depends on the maturity status of brood fish and the quality of pituitary glands. Indian major carps usually spawn 4-6 hr after second dose injection, which continues up to 3-5 hr after the initiation of spawning.

GnRH-based inducing agents

Based on the concept of hypothalamic peptide (GnRH) mechanism on GtH-II release, several inducing drugs cotaining GnRH-analoge (GnRAa) and dopamine antagonist have been formulated. These drugs are administered to the brood in a single dose. Usually female broods receive @ 0.3 ml-0.5 ml/kg body weight and male brood receive half of the dose of that female, i.e. 0.15 ml-0.25 ml. The synthetic hormone-induced broods are released in the breeding hapa or in the eco-hatchery breeding pool for breeding pool. These drugs are gaining popularity day-by-day owing to their promising results. These drugs have advantages over the conventional carp pituitary extract because of single dose administration, long shelf-life, less latency period (time between hormone administration and initiation of spawning), reduced effective spawning period (time between the initiation of spawning and end of the spawning), higher breeding response and higher spawning fecundity. However, it is premature to comment upon the cumulative physiological effect(s) of such drugs on the brood fish in the long run.

The induced breeding techniques have enormously increased the seed production of major carps during last three decades, making the country self-sufficient in this sector. The key of the success for induced breeding is the good inducing agents and also good brood fish. The difference between good table fish and good brood is being increasingly understood which is discussed here.

Carp brood husbandry

Carp brood farming is an essential activity in a commercial breeding complex. The farming includes raising and rearing of the brood. Raising programme of stock starts with the recruitment of healthy juveniles or yearlings, which are to be collected from natural breeding grounds or from the farm reared stock of different hatcheries. This is to prevent inbreeding depression and genetic drift in the offspring, which is often encountered in commercial carp hatcheries. Care is also taken to avoid the collection of stocking materials from wastewater or industrial effluents fed culture system. The stock is initially kept under quarantine condition for 2-3 months to avoid the entry of unhealthy or diseased fish in the seed farm.

Brood raising

Rectangular ponds having an area of 0.2 to 0.5 ha, with water average waters depth 1.5 m is preferred for brood raising. Such ponds should be free from aquatic weeds, predators and weed fishes. Aquatic weed is to be removed manually as far as practicable. Methods adopted for eradication of predatory and weed fishes are by repeated netting, dewatering and application of suitable piscicides before stocking. Fresh mahua oil-cake @ 2,500 kg / ha or bleaching powder (30% chlorine level) @ 300 kg/ha acts as effective piscicides. Quantity of bleaching powder can be reduced to half, if it is combined with urea at 100 kg/ha. Urea can be applied 24 hr prior to bleaching application. Density of the brood in raising pond is kept at 1,500 kg/ha. Ratios of different species are maintained as 2 : 3 : 2 : 2 : 1 of catla : rohu : mrigal : grass carp : silver carp respectively. The carp brood is raised here up to two years plus age group with standard pond management practices. Conventional supplementary feed such as groundnut oil-cake and rice bran (1:1) may be given @ 2% of the fish stock. Drainable pond with the scope for water replenishment facilitates brood rearing programme.

Selected prospective spawners are again reared for few months in different ponds at a stocking density of 1,000 kg/ha. Brood may be reared in a pond with principal brood system. In this system, a species contributes 60% of the population out of five species combination and other four species contribute 10% each. In catla principal brood system, catla only contributes 60% of the population and rest of the species, viz. rohu, mrigal, grasscarp and silvercarp, contribute 10% each. The broods can be fed on a farm made formulated diet containing crude protein 33%, crude lipid 10%, and gross energy 4,000 Kcal/kg. The formulated feed was superior than the traditional ones, which contains low protein (15-20%) consisting of GOC and RB (1:1 by weight) (Table 15.1). Besides the

Table 15.1. Formulated feed for Indian major carp (IMC) broodstock

Groundnut oil-cake	70.0 kg
Rice bran	28.4 kg
Common salt	1.5 kg
Trace elements	0.1 kg
Vitamin C	10.0 g
Vitamin E	3.0 g

(Trace elements: ferrous sulphate 50 g, copper sulphate 8 g, zinc oxide 6.7 g, manganese sulphate 15.4 g, potassium iodide 4.2 g, cobalt chloride 2 g, calcium carbonate 13.7g).

Source: Gupta *et al.* (1995). *Veterinary Archives* **65**(5): 143-48.

formulated diet, ponds should be fertilized at regular intervals to increase natural pond production.

A carp brood diet in the name of 'CIFABROOD' is developed for intensive brood rearing programme. The ingredients of this feed are groundnut oil-cake, rice bran, fish meal, soyabean meal, vegetable oil and vitamin mineral premix. Nutrient level of the feed is given in Table 15.2.

Table 15.2. Nutrient level of CIFABROOD on dry matter basis

Crude protein (%)	31.3
Crude lipid	11.7
Gross energy (kcal/g)	3.9

Feed for grass carp dominated pond is discussed elsewhere in this chapter. Although there is a common supplementary feed for all the three species of IMC and are fed @ 1% of their body weight, there is difference in the feed disbursal system in different ponds. In catla-dominated pond, the powdered feed is broadcast. Semi-soaked feed is suspended in the column water for rohu, whereas soaked feed ball is preferred for the mrigal pond. In a principal species of brood system, daily ration for 60% of the population (i.e. only for the dominated species) is given, whereas rest of the population depends on the natural productivity of the pond and the leftover feed of the dominate species. The principal brood species system is further a step ahead towards commercial seed production. In this system desirable number of brood of a species can be obtained in single haul from the pond. Moreover, the feed cost of the brood rearing programme is reduced 40%.

Brood health care

Argulus sp. is a major ecto-parasite affecting the seed production significantly unless it is controlled. Several mechanical practices and chemical applications are available to control the parasite in grow-out culture ponds. However, any chemical application to control the parasite during brood rearing has adverse effect on gonadal development so also the breeding performance. Hence, brood infested with *Argulus* sp. may be isolated in separate pond to control the parasite by mechanical methods only. Similarly, epizootic ulcerative syndrome (EUS) also affects brood survival and seed production. No adverse effect on seed production is reported due to treatment of CIFAX. Lack of immune competence in the early stages of life leads to severe mortality in larval stages due to many pathogens. Study indicated that the maternally derived antibody helps to protect hatchlings of IMC against specific pathogens. Hence, researches are focused to immunize the brood against those pathogens.

Stress management

Stress and stress management in carp brood husbandry is less understood. The stress may be of environmental or physical but it has serious impact on the breeding performance. Stress in brood may lead to non-spawning or partial spawning in the hatchery. Stress is also the main cause of the poor survival of spent brood in the pond after induced breeding. The environmental stress may be due to low oxygen tension, malnutrition, accumulation of pollutants like heavy metals and pesticides in the pond.

Some of the symptoms, which are observed in brood pond, may be described as:

- Prolonged non-acceptance of supplementary feed
- Mass surfacing of the fish of a single species or all the species
- Isolated random surfacing and trailing movement of the fish
- Poor growth, reduced smartness, shedding of scales and white ring mark around the mouth
- Late appearance of secondary sexual characteristic in the brood fish.
- Poor recovery of spent brood during post-spawning rearing phase. Physical stress in brood is mainly caused during transportation of brood from pond to hatchery or vice versa. Besides, hormone administration, weighing operation etc., also causes stress to the broodstock. Some of these points are further elaborated with examples.
- When the workers transport gravid brood from pond to hatchery in a hapa or in a container, they hurriedly keep too many numbers brood with very little water or even without water. The fish which remain at the bottom of the container, take the entire load of the stock. This may cause the internal hemorrhage to the ovary in case of the female brood. Transportation of limited number of brood in sufficient water in a hammock in free-floating condition caused negligible stress to the brood.
- Hand nets or scoop nets are often used in hatchery to handle the brood. In an under-sized hand net and over-sized mesh the brood remains in bent position projecting the paired and unpaired fins outside through the mesh. This causes injury to the fins and stress to the fish. Bigger hand net than the brood and smaller mesh size than the fin is always preferred for handling the brood.
- Intra-muscular hormone administration is the common practice of induced breeding. In this operation, one person holds the fish tightly and other injects the hormone content intramuscularly below the scale at the caudal peduncle. Intra-peritoneal administration on the thin scaleless skin below the pectoral fin reduces the chance of stress, makes the administration process much quicker and easy.
- In a breeding operation, the post-spawning sex play and chasing cause the physical injury to the spent brood. Timely separation of both the sexes improves the situation.

Sexuality

All the cultivable major carps are heterosexual in nature. Both male and female are equally responsible for successful breeding result. Sex can be easily identified during breeding season. Morphological features to identify the sex are related to the shape, size and texture of the pectoral fins, condition of the genital aperture and size of the belly.

Male brood

Usually in tropical ponds, the secondary sexual characteristics appear from March and retain up to September. Roughness on the dorsal surface of the pectoral fin is one of the males identifying characters. In *Cirrhinus mrigala*, the pectoral fins when extended touch the 10th and 11th scale on lateral line, whereas in *Labeo rohita* and *Catla catla* the same is extended to 6^{th} and 7^{th} and 8^{th} and 9^{th} respectively. The total spread area of the pectoral fin in a male is considerably more than that of the female of same age group reared in the same pond environment. Besides, the first fin ray of the male pectoral fin is thick and stout. The body mass of the male is less than that of female of same age group. Such body mass ratio is recorded approximately as 40: 60 of male and female respectively. However, the experienced eyes can identify the male carp even without touching the fish during breeding season and non-breeding seasons.

Milters proficiency

The male brood in ripe condition is termed as milter and the fish semen is known as milt. The profundity of the milter can be assessed by evaluating the quantity and quality of the milt. Such evaluation parameters are–milt yield by volume, viscosity by spermatocrit value, sperm density by total sperm count/unit volume and motility by activation. Milter in peak breeding season yields 1-2 ml/kg body mass when pressed gently on its abdomen. Prospective milter can yield about 6-10 ml milt on hormonal induction with any standard inducing agent. The colour of the milt is creamy-white to milk-white depending on the viscosity. Viscosity of the milt implies the total sperm packed cell found per unit volume and can be expressed as spermatocrit percentage. Spermatocrit value is ascertained by haematocrit capillary and heamatocrit centrifuge instrument. Non-induced milter produces little milt but of very high spermatocrit value ranging from 90 to 95%. On induction, milt volume increases but spermatocrit value comes down to 70-90%. The number of spermatozoa is estimated per unit volume by a simple haemocytometer in *catla, rohu* and *mrigal* as $2.0\text{-}2.5 \times 10^7$, $3.0\text{-}3.5 \times 10^7$ and $2.0\text{-}2.5 \times 10^7/mm^3$ respectively. The carp spermatozoa do not bear any acrosome. Motile spermatozoa fertilize the egg on spawning. Carp spermatozoa are found inactive in testis or in seminal fluid, which are activated when they come in contact with a hypotonic solution to their own seminal plasma. Water is a very good activator of carp spermatozoa. Thus the milt gets activated when it is released to the water environment on spawning. Activated carp spermatozoa remain viable for a few seconds and fertilize an egg if found within their reach. The motility of a milt sample can be tested on a five- point eye estimation assessment scale (Table 15.3).

Table 15.3. Five-point eye estimation assessment scale for carp spermatozoa

Spermatozoa activity	Symptom under microscope	Assessment scores
All died	Still spot	0 (zero)
Slightly active	Colloidal movement	+
1-30 % (mild)	Head oscillating and spinning	+ +
30-50 % (moderate)	Swarming movement	+ + +
50-70 % (good)	Jumping movement	+ + + +
70-100 % (excellent)	Vigorous jumping movement	+ + + + +

Male brood carps need less inducing agent for effective spawning than that of corresponding females. In case of carp pituitary induction, males need approximately 1/3 of the requirement of the females. The requirement of the synthetic inducing agent like Ovaprim is the half of the dose of females. In both the cases of induction, male brood starts spawning (milting) within 4-6 hr of hormone administration. The posterior pituitary extract exclusively can also induce male carp brood and economize carp pituitary-based induced breeding. Over-dose of the inducing agent causes early milting resulting poor fertilization. Under-dose may cause late sex extrusion in male. One carp brood set in a hapa induced breeding implies two males with one female in standard practice. The present day induced breeding in eco-hatchery needs the ratio of male and female 1:1 by number and 40:60 by body mass to economize the seed production. In a mass breeding programme of eco-hatchery system, this ratio can be further reduced to 8:10 without any adverse impact on the rate of fertilization. The rationale behind the use of the reduced proportion of male is that a good milter can produce milt much more than the oocytes, which are produced by a female of same age group under the same environment conditions. Thus the judicious use of males give better scope to rear and breed more female within same investment and same infrastructure of the carp hatchery complex.

The milter can be reused effectively in the induced breeding programme within a time gap of 30-45 days between the two successive breeding during the same season. As much as four spawning of milters have been reported from March to September in Indian major carps. Here the time lapse is not the parameter to decide about reuse of milter. The milters that show milt yield at least 5-6 ml/kg body mass, spermatocrit value > 60%, and motility at least ++++ are suitable for subsequent use. Certain pre-spawning and post-spawning care helps the spent male brood to recover and remature soon. Some of the measures are recorded as: (*i*) minimization of physical and physiological stress during the transport of brood from the pond to hatchery and back to pond from the hatchery, (*ii*) intraperitonial administration of hormone reduces the physical stress, and (*iii*) segregation of male broods from females in the spawning pool soon after spawning is over. This avoids pseudo-chasing and conserves energy. Intermittent dip treatment of spent male brood in 5 ppm potassium permanganate ($KMnO_4$) solution reduces the chances of post- spawning secondary dermal infection and helps them to recover fast.

Female brood

Generally, females of major carps attain the first maturity later than the male of same age group. During breeding season, the female can be very well identified by their soft belly, reddish vent and smooth surface of the pectoral fins. When the pectoral fin of the female catla and mrigal are intended towards the back dorsal side of the body, it reaches 8^{th} and 9^{th} lateral line scales. Similarly, the pectoral fin of rohu touches 6^{th} or 7^{th} lateral line scale. The ovarian maturity status and the prime condition of the brood can be ascertained by means of a catheter. The catheter is a smooth rubber or plastic pipe smaller than the diameter of the vent, which brings the ova sample out from the ovary when it is inserted into the ovary through the vent and sucked. Application of the catheter 60° to the mid-ventral position on the either side (left or right) brings out the eggs without any mechanical injury to the ovarian wall. The sample of eggs which are collected by the catheter is treated in a fluid containing 70% of glacial acetic acid and 30% of absolute alcohol. In the above treatment, if most of the oocytes show eccentric position of the germinal vesicle (nuclear material), it indicates the readiness of the fish for breeding. In carp, pituitary extract administration induced breeding females require one priming dose of 4-6 mg/kg body weight and a decisive dose of 10-12 mg/kg body weight. The recommended dose of GnRH-based drug is about 0.5 ml/kg body weight in a single dose. The gametes (spermatozoa and oocytes) are expelled to the water after six hours of GnRH-based inducing agent or 12 hr in carp pituitary extract administration. The fertilization is external, sperm penetrate into the oocyte at a specific point known as micropyle. In monospermy, the micropyle is closed soon after the penetration of first sperm. The newly spawned eggs are not buoyant so settle down immediately. Slowly the eggs imbibe water, which is known as the water hardened eggs. The first parthenogenetic cleavage starts within 15-20 min. of spawning. Some times unfertilized eggs also under go cleavage but regress soon. The embryos are hatched out with in 14-18 hr after fertilization. The average spawning fecundity of the Indian major carps during induced breeding is recorded to the tune of 1-1.5 lakh/kg body weight of the female brood. The same in case of silver carp and grass carp is within 1 lakh/kg body weight. The peak breeding efficiency of a carp female in tropical condition is recorded within 2+ to 5+ year age group.

Multiple breeding

Till 1977 it was believed that IMC are seasonal breeders, breed once in a year during monsoon months. Sporadic reports were found from 1977 to 1995 where IMC could be bred more than once. Presently, it is standardized that IMC can be bred 3–4 times commercially in an extended breeding season April to September. The spent brood of preceding breeding season are kept in a pond @ 1,000 kg/ha with partial water replenishment of the brood pond between January and March and are fed with a protein rich (30%) formulated diet These brood get gonadal maturity at least two months earlier and can breed by April. Fish which breeds by April can be bred for second time during June and third time during August, hence the inter-breeding preparatory period between two breeding is 45-60 days. Cumulative spawn production is as much as three times than the traditional breeding system.

Although IMC breeds for multiple times it has its own limitation within that extended breeding season. When initial breeding is in April all three IMCs breed at least three times during the period (April to September). When initial breeding is in May-June catla and rohu may breed for three times but mrigal breeds for two times. If initial breeding is as late as June-July: catla and rohu may breed two times but mirgal breeds once.

Winter breeding of IMC

Winter breeding of IMC based on photo-thermal manipulation has been recently initiated at the Central Institute of Freshwater Aquaculture. Prospective brood, selected from the spent fish during August, which are taken in this programme. These fishes are kept under suitably enhanced temperature and photoperiod regime, resulted gonadal maturity. Such ripe brood are successfully induced bred during winter months (December-February.) IMC breeding can also be delayed by photo-thermal manipulation during vitellogenic period. It is possible to delay vitellogenesis and final maturation when temperature and photoperiod are reduced. Thus IMC brood can be bred during October and November.

Spawning in hapa breeding

Hapa breeding system is an age-old practice for carp seed production. A breeding hapa is a rectangular, 6-walled enclosure, made of fine meshed mosquito net cloth or nylon net. The size of the breeding hapa varies from 3.5 m × 1.5 m × 1 m to 1.8 m × 0.9 m × 0.9 m. Four upper and four lower corners of the hapa are laced to fix the hapa in the water column with bamboo poles. There is an opening at one end of the upper wall. This opening is meant for introduction of brood into the hapa or removal of brood from hapa. Generally, hormone administered brood are released into the hapa during evening hours. Broods do courtship and mating in hapa and spawn. Fertilized eggs are collected during morning hours. In hapa breeding system, comparatively poor breeding response and more egg loss are recorded than that of hatchery breeding system.

Spawning in eco-hatchery

The circular Chinese type of hatchery is commonly known as the eco-hatchery in India. The spawning pool of the eco-hatchery system consists of a circular open tank of 6-12 m diameter having depth 1.2 m. The tank may be made of brick work or RCC or FRP. The base of the pool is sloped towards centre where the central outlet is located. From the central outlet spawned eggs are carried to the egg collection chamber. In recent years the single water inlet point at 60° to the tangent at the junction of the wall and floor of the spawning pool is preferred. The spawning pool may also be connected directly to the incubation pool. In this case, individual egg delivery pipe from individual central outlet increases the egg recovery rate. In no case, the single egg delivery pipe should be connected to different incubation chambers by the help of 'T', 'L' and 'Y' joints. Hormone induced male and female brood get better environment in the spawning pool than that of the breeding hapa and breed profusely.

Spawning behaviour in eco-hatchery

In a well-managed induced breeding system, the male initiates extrusion at least 45 min. to 1 hr before the spawning. Generally, male chases the female. Polyandry, a many males may chase a single female. In eco-hatchery, induced breeding system mostly three types of chasing movement of brood are seen.

Hypo-gyne: Male moves below the female. This is very common in case of the induced breeding of silver carp but occasionally seen in Indian major carp when male is considerably smaller than the female brood.

Sub-gyne: Male chase behind the female. This is very common in major carps. Sometimes male overtakes the female across the water current of the spawning pool but again takes its position and chases till spawning.

Latero-gyne: Both male and female broods, move parallel to each other on the surface water. This is the initial chase movement on sex estrusion and termed as pairing of the brood. In some defective induced breeding programmes this movement is proved to be pseudo-chasing and continues for hours together without initiating any spawning. The pseudo-chasing is also often seen much after the spawning in the spawning pool.

Un-gyne: This is the solitary movement of the male brood on hormone induction when female is not receptive or vice versa. A brood is found docile and in standstill position on the water surface with little forward movement while the male moves faster across the spawning pool. This may happen when some of the brood are in stress.

Chasing or sex extrusion movement leads broods to courtship locking and spawning. As the fertilization in major carp is external and the activated spermatozoa remain viable in water for few seconds, it is essential to shed the gametes by both male and female brood together. The shedding of gametes by male and female are more instantaneous with courtship locking mechanism. Generally, three types of such locking are seen in the spawning pool.

(i) *Pectro-caudal:* Both male and female interlock their pectoral fins together and then caudal peduncles. During spawning, the pectoral and pelvic fins of both the partners remain erect with caudal fin quivering. This locking is often seen when both the individuals of the pair are of same size and strength. The possibility of fertilization in this case is very high as the vents of both parents remain close to each other.

(ii) *Dorso-caudal:* The male encircles the female at the end of dorsal fin of the latter towards the caudal peduncle. Coiling of male starts from the dorsal end of the female keeping vents of both the individuals in water. Such type of locking is commonly seen where the male is smaller and slender than the female. Here the possibility of fertilization is equally good as in the case of pectro-caudal locking.

(iii) *Isolateral:* In fact there is no locking but both the partners come closure, take a parallel position lateral to each other and expel their gametes to the environment. This spawning posture is found when the broods are too fatty and bulky due to considerable somatic growth or old. In this posture the fertilization possibility is less.

Operational aspects of spawning pool

(i) Water temperature in the range of 28-30°C gives better breeding response.

(ii) Good quality of water with 5-6 ppm dissolved oxygen can hold 3-5 kg brood/m^3.

(iii) Water depth in the spawning pool is maintained 0.6 m to 1.0 m according to the density of the brood in pool.

(iv) Brood fishes are kept in the pool under shower before and after hormone administration.

(v) Water current is allowed in the breeding pool before 1 hr of calculated spawning time which initiates the extrulization (excitement of the spawners) and spawning.

(vi) Water inflow both in the central outlet (egg delivery pipe) and single inlet must be adjusted in such a manner that it creates a speed 3-5 m/sec maintaining the requisite water depth.

(vii) Since the effective spawning comes to an end within 1.0 to 2.5 hr from initiation of the spawning, the breeding pool should be operated at best up to 2 hr.

(viii) Water current is stopped and brood fish are removed back to the pond as soon as breeding operation ceases.

(ix) Spawning and hatching units are cleaned and disinfected with 5ppm potassium permanganate ($KMnO_4$) solution before and after each operation. Again after 5-6 continuous operations, it is preferred to disinfect with strong formaldehyde solution.

Intensive use of spawning pool

The breeding operation of the spawning pool helps to bred more brood in a stipulated time and with less water. This system enables to produce seed of different species on same day with single operation of the spawning pool. Here brood of more than one species is administered with synthetic inducing agents with a time gap of 2-3 hr between two species. Hence different species breeds in sequence as per the hormone administration time schedule. Thus more than one species can be bred at a time in same spawning pool. It helps to produce spawn of two-to-three species in one day. Generally, farmers prefer to lift spawn of all the three species of IMC in one day.

Incubation of eggs

Next to the induced spawning, the important task is the incubation of the fertilized eggs till the production of larvae or spawn. To get spawn out of fertilized eggs, there are several age-old devices starting from mud-pit, mud-pot incubator, jar incubator funnel incubator to eco-hatching pool. Out of these, only few devices have gained popularity among the carp seed producers.

Incubation in hatching hapa

Although the hapa hatching system is much old concept of carp egg incubation, it gained more popularity soon after the success of induced breeding of carp by hypophysation. The hapa incubator is a double-chambered cloth wall enclosure where outer hapa is made of bolting cloth (0.5 mm mesh) and the inner hapa is made of mosquito net cloth (2.0 mm-2.5 mm mesh). The hapa incubator is fixed in the pond by means of four bamboo poles. The water-hardened eggs, which are obtained by induced breeding, are kept in this inner hapa. The hatchlings are sieved to outer hapa through the mesh leaving the egg shell in the outer hapa. The inner hapa with the egg shell is taken out leaving the hatchlings in the outer hapa for three more days till the yolk sac absorption.

Incubation in jar hatchery

The jar incubation system consists of some vertical jars made of glass, fibre glass GI sheet or PVC cylinders. The jars are conical in shape at their bottom end where a water tap is fixed to provide bottom to top running water. The surplus water from the top is drawn down as a flow-up water circulatory system. The eggs are incubated in the flowing water facility till the egg hatched out. Newly hatched larvae or hatchlings escape out from the jar and collected in a separate tub which is known as spawnery. Eggs are loaded on a water cushion in the jars @ 7,500-10,000 eggs/litre of jar volume. During first 10-12 hr water outlet in jar is maintained to produce the water flow at 2-3 litre/min., so that eggs would not go out along with water current. They would be moving inside the jar up to 3/4 height of jar. Subsequently when hatching begins the water spread is increased which would facilitate the newly hatched larvae to go along with current and accumulate in the spawnery. The jar incubation system gives very good hatching success even up to 90%.

Incubation in eco-hatchery pool

The hatching pool or incubation pool is circular in shape and made of cement concrete, brick masonry or FRP material There are two chambers, i e inner and outer. The outer chamber is of 3-6 m diameter, whereas the inner chamber is of 1.0 m-1.5 m. The depth of the pool is 1.0-1.5 m. The circular wall that separates the outer and inner chambers is made of wire mesh. This structure is wrapped with nylon cloth (mesh size 1/ 80 inch) which allows the water to flow from outer chamber to the inner chamber. Finally, water comes out from the incubation pool through the centrally placed vertical outlet. The water inlet pipes are the duck mouth taps fixed in a circular row, placed equidistantly from each other at the floor of the outer chamber. Spawn delivery pipe is another outlet, which is fixed at the junction of the floor and side wall of the outer chamber. The spawn delivery pipe delivers spawn to the spawn collection chamber. Sometimes, the egg delivery pipe is connected to the incubation pool to deliver eggs for incubation instantly soon after spawning.

Operational aspects of incubation pool

(i) Eggs are received on a water cushion of the incubation pool.
(ii) Direction of the duck mouth and speed of water is maintained in such a way that keeps developing eggs away from both screen and water preventing them from mechanical injury.
(iii) The water speed of the pool is maintained at 4-5 m/second for first 12 hr, 1-2 m/ sec for next 6 hr and 3-4 m/sec for rest of operation. This avoids premature hatching of the developing eggs.
(iv) The hatching time is temperature-dependent varies from 16-20 hr.

(v) Eggs are loaded @ 750,000-1,000,000 eggs/m^3 of water.
(vi) Eggs are extremely sensitive to the harmful effects of various micro-organisms. Such situation is generally come across during pre-monsoon breeding. To control this problem it is preferred to sprinkle $KMnO_4$ solution intermittently at 2 hr intervals in the incubation pool.
(vii) For better recovery and survival of spawn, it is necessary to clean the chamber *in situ*.

The following devices are effectively used for cleaning of the incubation pool.

Surface cleaner: A wooden or bamboo stick of 2 cm diameter is kept on the water surface across the outer chamber in between two walls. It accumulates the foam, floating debris and insects efficiently and is removed manually.

Sub-surface cleaner: A perforated wooden plank of 4-5 cm width is fixed to the surface water half immersed. It cleans the sub-surface water of the chamber.

Column cleaner: A stick of 4 -5 cm diameter is kept across the outer chamber in between two walls. On the stick coir rope with soft bristles of 1.0-1.5 m length is tied at 10-15 cm distance. The dead eggs and spawn get stick to the bristles of the coir rope. These ropes are cleaned manually time to time during incubation operation.

Water consumption in eco-carp hatchery

Water is the most important prerequisite to create semi-natural conditions such as shower and current for induced breeding in an eco-carp hatchery. A spawning pool of 5 m diameter with single water inlet of 4 cm diameter on the floor-wall of the pool facilitates induced breeding and transfers the spawned egg efficiently from spawning pool to the egg collection chamber. The water discharge of this single inlet is ranged between 100 and 120 litres/min. The above spawning pool can accommodate 60 kg brood of either sex or produces at least 50×10^5 eggs in each operation. Eggs are incubated in two incubation pools, each of 3.0 m diameter (water space 2.4 m). Each incubation pool is provided with five number of pressed-tap duckmouths, arranged in one whorl. Water discharge in the incubation pool is recorded as 20-25 litres/min. In this system no extra water is required for the operation of egg and spawn collection chamber. A complete cycle of spawn production, i.e brood conditioning, induced breeding, incubation of the spawned eggs, rearing of spawn up to spawn disposal (four days from spawning) in the modified eco-hatchery requires 347 m^3 water (approx.). About 4 million spawn are produced per operation (at least 80% of the spawned eggs) in the above facilities in one cycle. Hence, the water requirement for production of one million of spawn is calculated as 87 m^3 (approximately). The hatchery refuge water can be recycled through a dug-well system if stored in an open earthen pond.

Water estimation for eco-carp hatchery

Spawning pool: A standard size-diameter: 5 m; height: 1.2 m, water depth: 1 m.

Inlet and outlet: Single inlet of 4 cm diameter and single central outlet (egg delivery pipe) 6.4 cm.

Water shower: 15 cm two numbers placed in 2.5 cm pipe connected with 1.3 cm taps.

Water requirement: ***shower for 5 hr @ 30 litres/min:*** 30 × 60 × 5 = 9,000 litres

Flow through single inlet is 100-120 litres which is equal to water discharge for egg collection So, flow through central outlet/egg collection for 3hr @ 120 litres/min, i.e. 120 litres × 60 × 3 = 21,600.

Initial water filling in the pool: $\sigma r^2 h = 3.14 \times 6.25 = 19.625\ m^3$ =19,625 litres

Total water requirement: 19,625 + 21,600 + 9,000 = 50,225, say 50,000 litres

Breeding performance: Brood-holding capacity @ 3 kg/m^3: 60 kg (female 35 kg + male 25 kg)

Egg production = @ $1.5 \times 10^5 \times 35 = 52.5 \times 10^5$, say 50×10^5 = 50 lakh

Incubation pool: Size: 2.4 m diameter , 1.2 m height, water depth 1 m (two numbers)

Duck mouth: 4 nos. in one whorl

Water discharge: 20-25 litres/min

Operation period (egg loading to spawn collection): 4 days

Water requirement for four days incubation: 25×60×24×4 =144,000 litres

Initial water filling: 4.5 m^3 = 4,500 litres (volume: $\delta r^2 h = 3.14 \times 1.44 \times 1 = 4.52$)

Total requirement for one incubation pool = 144,000+4,500 =148,500 litres

Water requirement for two incubation pool =148,500 ×2 =297,000 litres

Egg-holding capacity @ $7 \times 10^5 = 31.64 \times 10^5$ = say 30 lakh

Here 50 lakh eggs are incubated in two pools

Fertilization rate 90-95 % and spawn recovery rate is 90-95% of the fertilized

So expected spawn production per one operation is 40×10^5 = 4 million

Total water requirement

For 4 million spawn production in the eco-carp hatchery (breeding and incubation) 297,000 litres +50,000 litres = 347,000 litres = = 347 m^3

For 10 million of spawn production water requirement is 347 $m^3 \times 2.5 = 867.5\ m^3$ say 870 m^3 (approximately).

Common carp breeding

Common carp spawns throughout the year in tropical climate with two peak breeding periods–one during January-March and other during July-August. Although common carp breeds naturally, to intensify the seed production several techniques are adapted in many countries for their captive breeding. Captive breeding of this species is of stripped spawning and spontaneous spawning types.

Stripped spawning

In this type of artificial propagation, the female broods are induced by carp pituitary extract; the genital aperture may be sutured and kept along with the male brood. The male brood is also injected with pituitary hormone. When female become ripe for stripping, both male and female are stripped into a basin. The milt (spermatozoa) obtained from male fertilizes the eggs. Since common carp eggs are sticky in nature,

the fertilized eggs get chance to clump together. It is essential to remove the stickiness of the egg at once to make the egg free-floating for incubation. Several degumming methods are available for the purpose. The mixture of urea and sodium chloride was initially used in 1960s for removing the mucoid envelope of common carp eggs. Since then many methods have been applied to degum the common carp eggs which are described here.

Salt-carbamide method of degumming: The stripped eggs and milt mixture was treated with milk for 2-3 min and eggs are treated briefly for 5 min in a solution of 4 g sodium chloride and 3 g of urea (carbamide)/litre of water with constant stirring. These eggs are again treated in a solution containing 4 g of sodium chloride and 20 g of urea/litre for 30 min. In the second solution the eggs were stirred at only every 10-15 min. unlike continuos stirring in the first solution. Thereafter, the eggs were thoroughly washed in pond water to get the degummed-free eggs. The first solution is known as fertilization solution where spermatozoa retain their motility for at least 10 min. Human urine has also been used successfully to degum the common carp eggs.

Cream-milk method of degumming: For degumming of common stripped eggs in field condition, 20 g of full cream milk powder (fat content 26-28%) is dissolved in 1 litre of water which is equivalent with 1 part cow milk and 9 parts of water. The egg-milt mixture is treated with either of the milk preparation for 45 min and stirred to get individual eggs free from each other.

Spontaneous spawning

Common carp can be bred in hapa or in cement cistern or in earthen pond spontaneously. For this type of seed production, some substratum is required which acts as egg collector. Common aquatic weeds, viz. *Hydrilla, Najas* etc., are good egg collectors. The breeding hapas are almost same type like major carp except that the top flap which is unstitched. About 2 kg of egg collector are required for 1 kg of female brood. Egg collectors like '*Kakabans*' (made of coconut fibres) is also used. Sometimes root fibres of water hyacinth are also effectively used in village ponds. Collections of eggs by above plant origin egg collector have several disadvantages. By a new technique common carp can be bred in bulk utilizing the spawning and incubation pools of eco-carp hatchery. In this system, circular spawning pool of eco-carp hatchery use utilizes synthetic fibre of gunny bag. The incubation pool is utilized to incubate the eggs, which are sticked to the synthetic fibre

The synthetic fibres are collected from the gunny bags, those are used packing lime, fertilizer, cement etc. These are fibres washed thoroughly and cut into pieces at 2-3 feet (0.3-0.6 m). Such fibres are bunched and each bunch may contain 50 g of the fibre. At the centre of the bunch a stone weight is put to provide gravity force. Such bunches @ 200 g/kg body weight of female brood is put into the water of the spawning pool before the release of brood fish. Due to gravity force, the bunches settle at floor of the spawning pool keeping free end like submerged foliage. When depth of the water is more than the length of fibre, the bunches are completely submerged in water. In the reverse case, free fibres float on the water surface. Common carp brood are induced with any synthetic inducing agent such as Ovaprim , Ovatide or Wova-FH at 0.2 ml/kg body weight (only to the female brood) and are released into the spawning pool, which contain the synthetic fibres. Water shower facilitate the spawning act and the spawned eggs are struck to the fibres. Soon after breeding is over, broods are removed from the spawning pool and the fibres, which are laden with the eggs, are put in the running water of the incubation pool. The eggs are incubated there till they hatch out. Soon after the hatching is completed, the fibres are collected from the incubation pool leaving the newly hatched spawn in the system till the yolk sac is absorbed. The above fibres bunches can be used several time effectively as egg collector. This system has advantages over the hapa breeding system with hydrilla twigs, such as: (*i*) the fibres are readily available at a very nominal price, (*ii*) unlike any other foliage egg collector, the fibres claim no oxygen from the system, and (*iii*) no disintegration or putrefaction of foliage matter as it happens with plant origin egg collectors resulting in mortality of the developing eggs and spawn in the hatching hapa.

Grass carp breeding

Grass carp (*Ctenopharyngodon idella*) is basically an aquatic weed feeder. It grows luxuriantly with aquatic foliage and received the considerable attention as instrumental in the biological control of nuisance vegetation. This carp can grow up to 2.5 kg within a period of six months in a polyculture system. From natural range in eastern China and the former USSR, this carp has been introduced world wide. The rationale of introducing grass carp is to control the weed in an aquatic system and to increase the fish production. Like many other major carps grass carp would not breed spontaneously in the confined water of culture pond, needs hormone induction for the artificial propagation. The first induced breeding of grass carp has been reported in China during 1960, followed by formerly USSR during 1961. Successful induced breeding of the introduced grass carp in new environments has been observed in Cuttack, India (1962), Auburn, USA (1970), Nepal (1972) and in Natal, South Africa (1974). Induced breeding of grass carp by hand-stripping is a world wide practice as: (*i*) inconsistent spawning success due to improper timing of stripping, (*ii*) poor survival of spent brood due to stripping stress, and (*iii*) excessive labour requirement.

Attempts were also made to standardize the non-stripping spawning and wet fertilization, for reducing the brood damage and improve the spawning quality with higher fertilization over the stripping. Initially, sporadic inconsistent success on the non-stripping induced breeding of grass carp has been recorded in ponds, hapa, tank and pools. In 2003, the technique of induced spawning of grass carp without stripping was standardized at Central Institute of Freshwater Aquaculture, Bhubneshwar. Even double breeding of the broodstock in the same season was also achieved. The reasons for inconsistent response in spontaneous induced spawning were poor gonadal growth and more somatic growth. The *ad lib.* foliage diet causes somatic growth and fat deposit in grass carp here. Therefore, success is completely based on brood husbandry and hatchery management practices. The procedure is described here.

Ponds were stocked with grass carp yearlings (0.4-0.5 kg each) along with other carp species, viz. *C. catla*, *L. rohita*, *C. mrigala* and *Hypopthalamichthys mollitrix*, in a ratio of 70 : 10 : 10 : 7 : 3 respectively. The stocking density of the above ponds is maintained @ 1,000 kg fish/ha. Here grass carp was the principal brood component and other carps are the maintenance component of the pond. These ponds were made free from aquatic weeds and supplied with formulated non-foliage diet. Daily ration is soaked in water and fed at 2-3 % of their body mass. Feeding was applied in several trays in the column water of the pond. Broods were reared for two years, and 20-30% water of the ponds is replenished at least once in a month from January to March. Mature broods are observed in the pond during April–August. The broods were induced breed in eco-hatchery with less water depth (0.5-0.6 m) and mild water speed (2-3 m/sec). Breeding success is recorded as high as 88% in this study.

The formulated diet contains soybean 50 kg, groundnut oil-cake 25 kg, rice bran 20 kg and fish meal 5 kg in 100 kg feed. The proximate composition of the above feed was evaluated as crude protein 36.75%; crude fat 6.80%; crude fibre 14.25%, total ash 13.0%, nitrogen-free extract (NFE) 29.20% and energy was 3.252 K cal/ g.

Larval rearing

The larval rearing systems may be earthen ponds, cement cisterns or floating cages. The earthen ponds are specially prepared to grow plankton prior to stocking. The larvae are stocked in these ponds when rotifer population in dominating. If stocking is not done timely the cladoceron population grows affecting the larvae. Under heavy densities of stocking, the plankton production in the pond cannot be maintained even by regular manuring. Therefore, it is necessary to provide supplementary feed. The daily requirement of feed is estimated on the basis of fry population and then growth with appropriate initial weight of spawn (6.0-6.50 mm, average weight 1.4 mg). Finally, powered groundnut or mustard-cake and rice polish (1:1 by weight) is to be provided @ 4 times of the weight of stocked spawn for the first five days and double in quantity for 6-12 days. Optimum growth is obtained when feed having 40-45% protein and 26-30% carbohydrate. Feeds incorporating with vitamins, minerals and micronutrients like cobalt chloride have shown better growth and survival. Similarly, feed with silkworm pupae and fish meal as one of the components of feed showed better growth and survival. Soybean milk can be spread evenly in the nursery ponds 2-3 times daily. Only a portion of milk is consumed by fry and most of it serves as fertilizer accelerating rotifer production. However, the right type of feed and feeding in right time is important for nursery management. Small water bodies of 200-1,000 m^2 with a water depth of 1.0-1.5 m are preferred as nurseries. Drainable or non-drainable earthen ponds, cement cisterns, brick lined ponds with cement are generally used for the purpose. .

The most appropriate time for stocking pond is when it abounds with zooplankton, preferably rotifer (100-150 mm size) in the density of 2,000-5,000/litre. Depending on the productivity of the pond, the stocking density is determined from 1-10 million. Morning is the best time for fry harvesting. An average of 50-90% survival is possible by spawn/ha. For obtaining optimum growth and survival, it is recommended to restrict

Table 15.4. Economics of carp hatchery (spawn production capacity 200 million)

Total area	3.0 ha (cost of land has not taken into consideration)	
Production capacity	200 million	
Area of hatchery units	30 m × 20 m = 600 m ^{2} (0.06 ha)	
Broodstock ponds (4 nos)	75 m × 50 m × 4 = 15,000 m ^{2} (1.5 ha)	
Nursery/seed rearing/water intake ponds :	30 × 20 × 20 = 12,000 m ^{2} (1. 2 ha)	
Period of breeding	April-August (each brood to breed three times)	
Fixed capital investment (₹)		
Construction of ponds		
Broodstock ponds (4 nos)		560,000.00
Nursery/seed rearing/water intake ponds (20 nos)		600,000.00
Construction of hatchery		
Brick masonry breeding pool of 5 m dia. (1 no.)		50,000.00
Brick masonary incubation pool of 3 m dia. (4 no.)		60,000.00
Water storage tank of 30,000 litres capacity (open type)		70,000.00
Egg/spawn collection chamber (3 m × 2.5 m × 1.0 m)		10,000.00
Pipes and valves fitting etc.		80,000.00
Electric and diesel pump set of 5 HP (one each)		60,000.00
Pump house and store shed		100,000.00
Oxygen packing kit		10,000.00
Brood raising programme		30,000.00
Total fixed capital investment		1,630,000.00
Variable capital investment (₹)		
Brood fish replenishment (500 kg)		30,000.00
Pond maintenance (lime, manure etc.)		20,000.00
Feed for brood and seed		100,000.00
Drag net and hapa		25,000.00
Spawning inducing agents		42,000.00
Labour wages for hatchery and farm management		150,000.00
Electric charges		15,000.00
Fuel charges for pump (POL)		10,000.00
Unforeseen expenses		10,000.00
Total variable cost		402,000.00
Production (sale) (₹)		
Sale of spawn of different species		180 million
Sale of fry (20-40 mm)		10 million
Sale of culled brood		500 kg
Estimate costs and returns		
Annual fixed cost (₹)		
Depreciation on fixed investment (@ 5% of total fixed capital)		81,000 .00
Interest on fixed capital @ 9% annually		147,000 .00
Total		228, 000 .00
Annual variable cost (₹)		
Total working capital		402,000 .00
Six-monthly interest on working capital (@ 7% annually)		14,000 .00
Total		416,000 .00
Annual total cost (annual fixed cost + annual variable cost)		644,000 .00
Total returns		
Sale of spawn of different species (180 million)		1,260,000 .00
Sale of 10 million fry (20-40mm)		1,200,000 .00
Sale of culled brood (500 kg) (₹)		25,000 .00
Total (gross returns)		2,485,000 .00
Net returns (total returns-annual total cost)		1,841,000 .00
Pay-back period		One year

the rearing period for 12-15 days when they attain a size of 20-25 mm during this period. Prolonged retention is avoided by harvesting or thinning out the population.

Economics of carp seed production

The development of hatchery technology for carp seed production has a commercial venture for entrepreneurs. Economic viability of the technology has been calculated based on prevailing rates during 2009 (Table 15.4). The exercise is based on 200 million spawn productions through multiple breeding technologies. Infrastructure development, fixed capital investment and variable costs has been taken into account while computing. The economic viability is also been assessed. Net profit is up to ₹ 1,841,000 where pay-back period is one year and land involvement is 3.0 ha.

Problems in seed production sector

Over 700 hatcheries in the country do produce carp seed in different magnitudes only by induced breeding. The quality of seed is not regulated nor monitored by any agency. No definite guidelines have been framed for certification of seed in fisheries sector. To ensure the quality of the seed, it is essential to lay down a certification procedure for quality brood management, maintenance of effective population, breeding plan, environment management and sanitation practices of the hatchery complex. Hence, there is a need of agency to ensure some of the important criteria such as physical facilities, technical competency, code of practice, risk analysis and health certification in a carp seed production centre.

16. Carp Culture

Carps form the mainstay of aquaculture practice in India contributing over 85% of the total aquaculture production. The three Indian major carps, viz. catla (*Catla catla*), rohu (*Labeo rohita*), and mrigal (*Cirrhinus mrigala*), contribute bulk of the production in the country, whereas the three domesticated exotic carps such as silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) form the second important group. To in ···porate several other medium and minor carps into the carp polyculture systems several methods were used because of their region-specific consumer preference and higher market demand, besides their growth potential. Some of these include kalbasu (*Labeo calbasu*), kuria labeo (*L. gonius*), fringe-lipped carp (*L. fimbriatus*), bata (*L. bata*), Malabar labeo or thooli (*L. dussumieri*), olive barb (*Puntius sarana*), silver barb (*P. gonionotus*), Jerdon's barb (*P. jerdoni*), Cauvery carp (*Cirrhinus cirrhosa*) etc.

Carp culture in India was restricted only to a homestead backyard pond activity in West Bengal and Odisha until late 1950s, with seed from riverine sources as the only input resulting low level of production. Though importance of fish culture as an economically promising enterprise was gradually realized by then, non-availability of quality fish seed and lack of scientific culture know-how constrained the development of carp farming.

The technological breakthrough in induced breeding of carps through hypophysation in 1957 revolutionalized freshwater aquaculture of the country. With assured supply of quality seed, the techniques of seed rearing and grow-out culture of carps had undergone faster development and refinement through research made by the Pond Culture Division of the CIFRI and further by their multi-locational trials. The All India Coordinated Research Projects on Composite Fish Culture and Fish Seed Production, launched by the ICAR through the Central Inland Fisheries Research Institute, Barrackpore, operated at 12 centres covering all over the country till 1984, virtually laid the foundation of scientific carp farming in the country. Carp culture, since then has expanded its dimensions in terms of area coverage and intensity of operation, with Andhra Pradesh, Punjab, Haryana, Maharashtra, etc. taking up fish culture as a commercial farming enterprise.

The research and development efforts during last 6 decades have placed the carp farming as an important economic enterprise and revolutionized the freshwater aquaculture sector to the level of a fast growing industry. The nation mean production levels from still-water ponds has gone up from about 600 kg/ha/year in 1974 to over 2.5 tonnes/ha/year at present, and several farmers are even demonstrating higher production levels of 8 to 12 tonnes/ha/year.

Seed rearing and grow-out culture are the two main components of carp culture technology, which have undergone several modifications and refinements over the

years to evolve to the present day's package of farming practices. Culture systems, from extensive to intensive, have been developed depending on the varied input use. The technologies of seed rearing, comprising rearing spawn to fry in nursery and further fry to fingerlings in rearing ponds, have been accepted as economically viable activities at the farmer's level throughout the country.

PACKAGES OF PRACTICES

The packages of practices were developed for the seed production and grow-out farming of carps are discussed here.

Seed production

Nursery pond management: Seed of carps are delicate in nature and their growth and survival largely depend on the environment in which they live. The biological characteristics like the food preference and feeding habit of these carps are almost similar during their initial life stages, thus requiring almost similar management at any particular stage. However, the management measures for different life stages vary since several physiological modifications, such as in the structure and function of their digestive organs and feed intake system, take place during the initial stages. The survival and growth of these seeds in rearing systems largely depend on the presence or absence of aquatic weeds, aquatic insects and predatory and weed-fishes, water and soil quality, availability of natural feed, population density, supplementary feed, rearing period, etc. Thus, appropriate management of these aspects is the guiding principle for the success of the carp seed rearing.

The nursery phase refers to the rearing of the three to 4-day-old spawn (5 to 6 mm) in nursery ponds for a 15 to 20 days for major carps and 20 to 25 days for medium carps till they grow to fry stage. Stored yolk of larvae/hatchlings is absorbed within the first 3 days in the hatchery phase and there is requirement of food in the nursery from the first day onwards. Thus, availability of suitable natural feed is the most critical factor during the transition, from yolk nourishment to natural feeding. Further, the delicate hatchlings are prone to predation and competition for oxygen and food from the aquatic insects, predatory and weed fishes. Suitable ecological condition in the nursery also plays a great role for the spawn survival. Generally, smaller seasonal earthen ponds of 0.02 to 0.1 ha size with average water depth of 1.0 to 1.5 m is preferred for carp nursery, as these offer easy management. Concrete tanks of 50 to 100 m^2 provided with a soil base 15 to 20 cm are found to be effective for raising multiple crops with minimum management. Smaller enclosures like cage and pens sometimes are also used as alternatives for the nursery ponds in large water-bodies. Drying of ponds during summer helps in eradication of predatory and weed fishes and organic mineralization. Perennial water-bodies are often infested with aquatic weeds and harbour predatory and weed fishes. Thus, these perennial ponds when used as nurseries need a series of pre-stocking management measures to provide a suitable growing environment for the seed. Besides to the basal liming and manuring, the follow up activities like intermittent fertilization, supplementary feeding, health care and water management also contribute to a great extent for better performance of nursery rearing.

Control of aquatic weeds: The earthen ponds are often infested with marginal, floating, submerged and emergent aquatic weeds. The presence of these weeds cause many problems: (*i*) they absorb major portion of the available nutrients retarding the growth of plankton, (*ii*) prevent light penetration during overgrowth, thereby reducing photosynthesis, (*iii*) cause oxygen deficiency during night, (*iv*) cause higher diurnal *p*H fluctuation, (*v*) harbour aquatic insects and predators, (*vi*) reduce living space for fish, (*vii*) hinder free movement of fish, (*viii*) cause problem in netting operation, and (*ix*) increase siltation in the pond. Complete removal or control of these weeds thus is a pre-requisite.

The aquatic weeds are controlled by employing manual, mechanical, chemical and biological methods. Generally, the method is selected based on the dimension of the weed infestation, size of pond and time available. Manual methods are commonly advocated for removal of weeds from smaller nursery ponds. Floating weeds like *Eichhornia, Sagitaria, Salvinea, Pistia, Azolla, Lemna, Spirodela* etc. are removed manually by dragging these weeds with a rope or ropes tied to bamboo on both sides. Simple implements like sickle, rakes and hooks are used for removing the marginal weeds like *Phragmites, Ipomoea, Colocasia, Jussiaa* and *Marselia*, and submerged weeds like *Hydrilla, Vallisneria, Potamogeton, Ottelia, Nechamandra, Nymphae, Nymphoides, Nelumbo, Ceratophyllum, Najas, Utricularia* etc. Winch, weed cutter, etc. are employed in larger ponds with heavy infestations. However, it is advisable to reduce the water depth in pond suitably for uprooting the rooted submerged weeds in case of heavy infestation. Specialized weed cutter mounted on boat is also used for cutting the heavy infestation of rooted and non-rooted submerged weeds.

Stocking of weed-eating fishes like grass carp, common carp, gourami (*Osphronemus goramy*), and silver barb (*Puntius gonionotus*) is an effective method for the long-term control and maintenance of the weed population, especially in grow-out carp ponds. Grass carp voraciously feeds on the submerged weed and its daily intake is even higher than its own body weight. Common carp not only feeds on the bud, tender leaf and shoots of the aquatic plant, but also its nibbling habit helps uprooting the germinating plants and prevent their establishment.

The aquatic weeds sometimes are also controlled by application of chemicals as weedicides. These chemicals are selected based on certain criteria, viz. (*i*) low cost and easy availability, (*ii*) effectiveness at low dose, (*iii*) easy method of application, (*iv*) non-toxic to animals and human beings, (*v*) short half-life, and (*vi*) no residual effect on fish and pond ecosystem. A wide range of weedicides is available for control of heavy infestation of aquatic weeds. Marginal and emergent weeds like *Typha* and *Cyperus* are controlled by spraying a suitable weedicide (which is not banned) within two weeks of its application. Foliar spray of a suitable weedicide is also effective in controlling marginal weeds like *Ipomoea*, *Jussiaea* and also some emergent weeds within 10 days. Heavy mat of water-hyacinth (*Eichhornia* sp.) is controlled with foliar spray of a suitable weedicide for small, medium and larger categories of plants respectively. Application of a suitable algicide was found to be effective in controlling the phytoplankton bloom within two weeks, but higher dosage of these chemicals are required against the scam or mat forming filamentous algae. Application of anhydrous ammonia at 20 ppm N is also effective not only in controlling the submerged weeds, but also helps in eradication of predatory and weed fishes, apart from serving as an inorganic nitrogen (N_2) source during the subsequent phases of culture. However, handling and transportation problems along with non-availability of ammonia cylinder at all places restrict its use on a large-scale.

Application of chemicals for aquatic weed control often fails to produce the desired results. Most of the rooted submerged weeds as well as the marginal vegetation propagate by means of their rhizomes. These rhizomes are often present in sub-soil and pond bottom where the weedicide cannot reach. Application of the chemicals, though destroys the foliage of the plants, the rhizome remains unaffected and sprouts back once the toxicity is gone. Further, most of the weedicides are effective against a narrow spectrum of weeds and fail to control the weed populations of a pond, which is usually a complex one. Even when one chemical is effective to control two or more types of weeds, the dosage of application for each case may also be different. Besides all the above reasons, the longer time lag required for getting the desired result often renders the chemical methods of weed control to be the second choice over the other methods.

Soil correction: The productivity of a fish pond depends on the physical, chemical and biological properties of the pond soil. Pond bottom acts as the laboratory where process of mineralization of the organic matter takes place and nutrients are released to the overlying water column. Physical properties of soil like texture and water retentivity, and chemical properties like *p*H, organic carbon, available nitrogen and available phosphorus are important parameters which require considerable attention for effective pond management. Slightly acidic to neutral soil with *p*H 6.5 to 7.0 is considered to be productive. Since low soil *p*H is always associated with low productivity, pond bottom with such *p*H needs correction, which is usually done through application of lime. However, liming alone is not helpful for correction of soil *p*H in pond with acid sulphate soil. In such ponds, the high levels of pyrite (FeS_2) present in the soil remain reduced and undergo little change as long as the soil is submerged and anaerobic. When the soil is exposed, aerobic condition helps in oxidation of these pyrite resulting in formation of sulphuric acid, which mixes with the water in the pond and reduces its *p*H. Production of such acid from dyke is more prevalent than the pond bottom since the former remains exposed. Ponds in such area require correction of the soil before pond preparation that involves: (*i*) repeated drying and filling to oxidize pyrite in the soil, (*ii*) filling with water and holding till water *p*H drops to below 4, and (*iii*) draining of the pond. The last two steps are repeated until the water *p*H stabilizes at above 5. Such soil correction is followed by the application of lime at standard doses (Table 16.1) depending on the prevailing soil *p*H. The north-eastern regions of India faces problems of such acidic soil.

A range of liming materials such as calcium carbonate [agricultural lime or calcite-$CaCO_3$], dolomite [$CaMg(CO_3)_2$], calcium hydroxide [slaked lime-$Ca(OH)_2$] and

Table 16.1. Lime requirement for soil treatment during pond preparation

Soil *p*H	Pure $CaCO_3$	Amount of lime substances required (× 100 kg)						
		Agricultural lime	Calcite	Dolomite	Hydrated lime	Hydrated granules	Quick lime	Shell powder
6.5	2.5	2.8	2.8	2.8	4.2	3.9	2.3	3.2
6.0	5.0	5.5	5.6	5.7	8.5	7.7	4.6	6.4
5.5	7.5	8.3	8.4	8.5	12.7	11.6	6.9	9.6
5.0	10.0	11.1	11.1	11.3	17.0	15.5	9.2	12.8
4.5	12.5	13.9	13.9	14.2	21.2	19.3	11.5	16.0
4.0	15.0	16.6	16.7	17.0	25.5	23.2	13.8	19.2
Efficiency (%)	100	90.2	89.7	88.3	58.9	64.6	108.5	78.2

calcium oxide [quick lime-CaO] are applied for correction of acidity in culture ponds. Similarly, alkaline *p*H in pond water are corrected through application of agricultural gypsum ($CaSO_4$) or alum. The dose of a particular type of lime depends on its effectiveness for soil correction. Liming is also done as a disinfecting agent in pond with a neutral soil *p*H and for correction of water *p*H or control of turbidity in subsequent period of culture operations. Quick lime is preferred for soil treatment during pond preparation for its quick and caustic action, while calcite and dolomites are used for the treatment and *p*H correction of pond water during culture operation.

Eradication of predatory and weed fishes: Perennial water-bodies harbour a number of predatory animals like fish, snakes, tortoise, frogs, etc., which cause extensive damage to the seed population. Predatory fish species found in the perennial water-bodies include murrels (*Channa punctatus, C. striatus, C. marulius,* and *C. orientalis*), goby (*Glossogobius* spp.), featherbacks (*Chitala chitala,* and *N. notopterus*), magur (*Clarias batrachus*), singhi (*Heteropneustes fossilis*), freshwater shark (*Wallago attu*), climbing perch (*Anabus testudineus*) and several other catfishes like *Mystus* spp., *Ompok* spp. etc. Besides, a number of weed fish population commonly found in these water-bodies include *Puntius* spp., *Barbus* spp., *Oxygaster* spp., *Ambasis* spp., *Gadusia chapra, Osteobrama cotio, Amblypharyngodon mola, Colisa* spp., *Aplocheilus* spp. etc. These fishes also enter into the pond ecosystem through the incoming surface runoff during monsoon. Most of these undesirable fishes normally breed in the pond prior to the onset of carp spawning season and establish their population. These fishes not only feed on the carp spawn, drastically reducing their population, but also compete with them for food, space and oxygen, severely affecting their survival and growth. Therefore, removal of these fishes from the nursery pond is a prime requirement to ensure higher seed survival and optimum environment for their growth.

In drainable ponds, dewatering followed by drying is the common method adopted for eradication of these unwanted fishes. However, in ponds where dewatering is not possible, these fishes are removed through repeated netting or application of suitable piscicides. A wide range of herbal and chemical derivatives is used as piscicides during nursery pond preparation which are selected based on certain criteria like, (*i*) effectiveness at low dose; (*ii*) non-hazardous to human being or livestock; (*iii*) shorter persistence of toxicity; (*iv*) no/minimal residual effect; (*v*) suitability of killed fish for human consumption; and (*vi*) low cost and easy availability.

Mahua (*Bassia latifolia*) oil-cake contains 4 to 6% saponin (mowrin) as the toxicant, which enters into the respiratory system through gills and buccal tissue, and haemolyses the red blood corpuscles causing death. It is the most common piscicide of plant origin used in nursery preparation, since it not only kills the undesirable fishes but also acts as organic manure after decomposition. A dose of 2,000-2,500 kg mahua oil-cake/ha-m of water (200-250 ppm) is required to kill the fishes in the pond. The oil-cake is applied three weeks prior to seed stocking for total detoxification of the poison from water. Derris root powder, another plant derivative, containing 5% rotenone ($C_{23}H_{22}O_6$) acts as contact poison damaging the respiratory system. It is effective for shallow ponds with 1.0 to 1.5 m depth, especially in hot sunny days with water temperature above 25°C. Application level of 15 to 20 kg/ha-m of derris root powder is sufficient to kill the weed fishes, tadpoles and air-breathing fish. It also partly destroys the snail population and aquatic insects such as dragonfly nymph and back-swimmers. Zooplankton and bottom dwelling chironomid larvae are killed at once but phytoplankton are not affected. The poisonous effect of this root extract persists for 4-12 days depending on the dose of application; however, a time lag of about one month is usually advocated before release of spawn in the pond. Studies carried out at the CIFA with application of cube root powder (9% rotenone) at 25 kg/ha revealed suitability of pond for stocking of carp spawn on 8^{th} day, as against 11^{th} day in case of bleaching powder ($CaOCl_2$). Further, its affect on phytoplankton was also found to be minimum compared to bleaching powder. Though several other materials of plant origin such as tobacco dust, safed siris (*Albizzia* spp.), *banalu* (*Dioscorea* spp.), *akhrot* (*Juglans regia*), hazarmani (*Phyllanthus urinaria*), *kuchla* (*Strychnos nuxvomica*), *sarphonka* (*Tephrosia purpurea*) and root powder of *Millettia pachycarpa*, powdered seed kernel of *Croton tiglium* have been experimentally evaluated and found to be having potential poisonous effect, their commercial application is still non-existent.

Chemicals such as bleaching powder, urea and anhydrous ammonia are also used for eradication of unwanted fishes. Application of commercial grade bleaching powder with 30% chlorine applied at 350 kg/ha-m of water (10 ppm chlorine) kills the fishes in ponds. Alternatively, application of 100 kg urea/ha-m followed by 175 kg bleaching powder/ha-m after 18-24 hr is found to be equally effective. When bleaching powder is applied as a piscicide, it results in crash of plankton population, thereby requiring longer period for its re-establishment. However, its application significantly reduces the basal lime application. Anhydrous ammonia at 20-25 ppm has also been found to be an effective fish toxicant, apart of its usefulness for weed control. However, non-availability of ammonia cylinder in all places and involvement of possible risk factors limits its use. Draining the pond to a minimum possible water level prior to the application of piscicides considerably reduces the above dose.

Pond fertilization: The Indian major carps and exotic carps at their early stages are planktivorous, with zooplankton as the preferred natural food. Sustained zooplankton population in a pond depends on a good phytoplankton population base,

Table 16.1. Lime requirement for soil treatment during pond preparation

Soil pH	Pure $CaCO_3$	Amount of lime substances required (× 100 kg)						
		Agricultural lime	Calcite	Dolomite	Hydrated lime	Hydrated granules	Quick lime	Shell powder
6.5	2.5	2.8	2.8	2.8	4.2	3.9	2.3	3.2
6.0	5.0	5.5	5.6	5.7	8.5	7.7	4.6	6.4
5.5	7.5	8.3	8.4	8.5	12.7	11.6	6.9	9.6
5.0	10.0	11.1	11.1	11.3	17.0	15.5	9.2	12.8
4.5	12.5	13.9	13.9	14.2	21.2	19.3	11.5	16.0
4.0	15.0	16.6	16.7	17.0	25.5	23.2	13.8	19.2
Efficiency (%)	100	90.2	89.7	88.3	58.9	64.6	108.5	78.2

calcium oxide [quick lime-CaO] are applied for correction of acidity in culture ponds. Similarly, alkaline *p*H in pond water are corrected through application of agricultural gypsum ($CaSO_4$) or alum. The dose of a particular type of lime depends on its effectiveness for soil correction. Liming is also done as a disinfecting agent in pond with a neutral soil *p*H and for correction of water *p*H or control of turbidity in subsequent period of culture operations. Quick lime is preferred for soil treatment during pond preparation for its quick and caustic action, while calcite and dolomites are used for the treatment and *p*H correction of pond water during culture operation.

Eradication of predatory and weed fishes: Perennial water-bodies harbour a number of predatory animals like fish, snakes, tortoise, frogs, etc., which cause extensive damage to the seed population. Predatory fish species found in the perennial water-bodies include murrels (*Channa punctatus, C. striatus, C. marulius,* and *C. orientalis*), goby (*Glossogobius* spp.), featherbacks (*Chitala chitala,* and *N. notopterus*), magur (*Clarias batrachus*), singhi (*Heteropneustes fossilis*), freshwater shark (*Wallago attu*), climbing perch (*Anabus testudineus*) and several other catfishes like *Mystus* spp., *Ompok* spp. etc. Besides, a number of weed fish population commonly found in these water-bodies include *Puntius* spp., *Barbus* spp., *Oxygaster* spp., *Ambasis* spp., *Gadusia chapra, Osteobrama cotio, Amblypharyngodon mola, Colisa* spp., *Aplocheilus* spp. etc. These fishes also enter into the pond ecosystem through the incoming surface runoff during monsoon. Most of these undesirable fishes normally breed in the pond prior to the onset of carp spawning season and establish their population. These fishes not only feed on the carp spawn, drastically reducing their population, but also compete with them for food, space and oxygen, severely affecting their survival and growth. Therefore, removal of these fishes from the nursery pond is a prime requirement to ensure higher seed survival and optimum environment for their growth.

In drainable ponds, dewatering followed by drying is the common method adopted for eradication of these unwanted fishes. However, in ponds where dewatering is not possible, these fishes are removed through repeated netting or application of suitable piscicides. A wide range of herbal and chemical derivatives is used as piscicides during nursery pond preparation which are selected based on certain criteria like, (*i*) effectiveness at low dose; (*ii*) non-hazardous to human being or livestock; (*iii*) shorter persistence of toxicity; (*iv*) no/minimal residual effect; (*v*) suitability of killed fish for human consumption; and (*vi*) low cost and easy availability.

Mahua (*Bassia latifolia*) oil-cake contains 4 to 6% saponin (mowrin) as the toxicant, which enters into the respiratory system through gills and buccal tissue, and haemolyses the red blood corpuscles causing death. It is the most common piscicide of plant origin used in nursery preparation, since it not only kills the undesirable fishes but also acts as organic manure after decomposition. A dose of 2,000-2,500 kg mahua oil-cake/ha-m of water (200-250 ppm) is required to kill the fishes in the pond. The oil-cake is applied three weeks prior to seed stocking for total detoxification of the poison from water. Derris root powder, another plant derivative, containing 5% rotenone ($C_{23}H_{22}O_6$) acts as contact poison damaging the respiratory system. It is effective for shallow ponds with 1.0 to 1.5 m depth, especially in hot sunny days with water temperature above 25°C. Application level of 15 to 20 kg/ha-m of derris root powder is sufficient to kill the weed fishes, tadpoles and air-breathing fish. It also partly destroys the snail population and aquatic insects such as dragonfly nymph and back-swimmers. Zooplankton and bottom dwelling chironomid larvae are killed at once but phytoplankton are not affected. The poisonous effect of this root extract persists for 4-12 days depending on the dose of application; however, a time lag of about one month is usually advocated before release of spawn in the pond. Studies carried out at the CIFA with application of cube root powder (9% rotenone) at 25 kg/ha revealed suitability of pond for stocking of carp spawn on 8th day, as against 11th day in case of bleaching powder ($CaOCl_2$). Further, its affect on phytoplankton was also found to be minimum compared to bleaching powder. Though several other materials of plant origin such as tobacco dust, safed siris (*Albizzia* spp.), *banalu* (*Dioscorea* spp.), *akhrot* (*Juglans regia*), hazarmani (*Phyllanthus urinaria*), *kuchla* (*Strychnos nuxvomica*), *sarphonka* (*Tephrosia purpurea*) and root powder of *Millettia pachycarpa*, powdered seed kernel of *Croton tiglium* have been experimentally evaluated and found to be having potential poisonous effect, their commercial application is still non-existent.

Chemicals such as bleaching powder, urea and anhydrous ammonia are also used for eradication of unwanted fishes. Application of commercial grade bleaching powder with 30% chlorine applied at 350 kg/ha-m of water (10 ppm chlorine) kills the fishes in ponds. Alternatively, application of 100 kg urea/ha-m followed by 175 kg bleaching powder/ha-m after 18-24 hr is found to be equally effective. When bleaching powder is applied as a piscicide, it results in crash of plankton population, thereby requiring longer period for its re-establishment. However, its application significantly reduces the basal lime application. Anhydrous ammonia at 20-25 ppm has also been found to be an effective fish toxicant, apart of its usefulness for weed control. However, non-availability of ammonia cylinder in all places and involvement of possible risk factors limits its use. Draining the pond to a minimum possible water level prior to the application of piscicides considerably reduces the above dose.

Pond fertilization: The Indian major carps and exotic carps at their early stages are planktivorous, with zooplankton as the preferred natural food. Sustained zooplankton population in a pond depends on a good phytoplankton population base, which is further ensured through adequate availability of major nutrients like nitrogen, phosphorus and carbon, besides certain micronutrients in water. The *in-situ* availability of these nutrients in pond sediment and water is often at lower levels and need to be added from external sources for sustaining good plankton growth. Such nutrients are supplied to the pond water through application of organic and inorganic fertilizers. Efficiency of these manures and fertilizers for stimulating the pond productivity largely depends on the N, P and C availability, N : P ratio and C : N ratio in pond sediment. The N : P ratio of 2:1 to 4:1 and C : N ratio of 10:1 to 20:1 in pond sediment are desirable for sustaining productivity of the pond water. Estimation of the required dose of organic manure or inorganic fertilizers is done depending on the nutrient status of the sediment and water.

Decomposition of organic manures in the pond bottom leads to slow release of nutrients to the overlying water column and helps in long-term maintenance of rich plankton population. In contrast, inorganic fertilizers dissociate into elemental form, which are readily available for utilization by phytoplankton. Combined use of manures and fertilizers give good result. Several types of fertilization schedules have been suggested for sustaining the natural productivity of ponds. Raw cattle dung is generally applied @ 10 tonnes/ha 15 days before stocking, or in phases with two-thirds of the amount as the basal dose applied 15 days before stocking and remaining quantity as the second dose after a week of stocking. When mahua oil-cake is used as fish poison, the application of cattle dung is reduced only to 5 tonnes/ha. Poultry manures are 2-3 times rich in nitrogen content than that of cattle dung, thus the dosages is decided accordingly when applied as substitute of cattle dung. When ponds are used for more than one crop, the dosage for subsequent crop is reduced considerably based on the water quality and plankton population.

Several phased-manuring practices have been advocated by the researchers over the years and showed encouraging results. However, not many of these could be adopted in large scale due to their complex application schedule. Phased manuring with a mixture of 750 kg/ha groundnut/mustard oil-cake, 200 kg/ha raw cattle dung and 50 kg/ha single super phosphate showed to be effective in production of desired plankton in nursery. Half of the above amounts, made into thick paste by addition of sufficient water, are applied as basal dose 2 to 3 days prior to stocking and the remaining amount is applied later in 2 to 3 splits depending on the plankton population of the ponds.

Control of aquatic insects: Pond ecosystem harbours number of aquatic insect species. These insects often find their way from the adjacent ponds into the prepared nursery and increase their population tremendously just after fertilization of the pond. They not only compete with the carp seed for food, but also cause extensive damage, often killing them through devouring or pricking and sucking the body fluid resulting in poor seed survival. The aquatic insects belonging to orders Coleoptera, Hemiptera and Odonata are relatively more important. Among these, the back-swimmers (Family: Notonectidae, Order: Hemiptera) cause maximum loss to carp spawn by eating upon the spawn as soon as they are released. These back-swimmers are capable of killing the carp fry of even 10-13 mm in size through piercing their sharp sucking beak into the body of fry and suck out the body fluids. *Anisops bouvieri* is the most common back-swimmer encountered in nursery ponds. The other aquatic insects often cause damages to spawn include several other water bugs like pond skater (*Gerris*), lesser water boatman (*Corixa*), water scorpion (*Nepa*), water measurer (*Hydrometra*), water cricket (*Velia*), water stick insects (*Ranatra*); diving beetles (*Cybister*); adults and their larvae of mayfly (*Cloeon*), dragon fly, alder fry (*Sialis*), etc.

The simple and effective method of eradication of aquatic insects had been through the application of soap-oil emulsion, i.e. 18 kg/ha of cheap soap and 56 kg/ha of vegetable oil, applied at one to two days before stocking of spawn. Since these insects are air breathing, they come to the water surface for respiration and killed though chocking of gills by the emulsion layer. Application of such emulsion is more effective during calm weather. Kerosene @ 100-200 litres or diesel @ 75 litres/ha is used for this purpose. Detergent powder (2-3 kg/ha) can be used effectively as substitute of soap-cake. In smaller ponds, repeated netting with suitable mesh size just before stocking of spawn can be an alternative method for insect control. Aquatic insects with their shorter multiplication time and flying ability pose problem for their control. Some of these insects fly away from the nursery pond at the emulsion application and comes back later when the ecosystem becomes suitable. Therefore, complete eradication of these insects is difficult, thus stress should be given for their maximum control prior to the release of spawn.

Seed stocking in ponds: Carp spawn transported from the hatchery is acclimatized in the nursery pond itself and released during cool hours of the day, i.e. in the morning or evening. Acclimatization is an important aspect for the spawn survival and needs attention to avoid sudden exposure to any abrupt change in the water quality, importantly temperature and *p*H. Spawn transported in open containers is acclimatized with gradual addition of pond water into it. Closed oxygenated polythene bags containing seed are left floating on the water surface for a few minutes to simulate the inside water temperature at par with that of nursery pond. Water can also be sprinkled on these bags to facilitate faster acclimatization. After temperature simulation, the packs are opened for gradual addition of pond water followed by dipping the mouth of the pack to facilitate the spawn to swim out into the pond.

Generally mono-species rearing of the spawn is practised in carp nursery, while multispecies rearing is also feasible in limitation in availability of ponds. However, in the latter case, species-wise segregation of fry is difficult at the harvest. Further, stocking more than one species at particular ratio often does not result in fry output at same ratio, thereby making it difficult to maintain desired species proportions in seed supply. Stocking density of the spawn is determined based on the pond productivity and the type of management measures to be followed. The stocking density in the earthen nurseries normally ranges 3-5 million/ha. However, density can be increased up to 10 million/ha with better management measures. The stocking density is further increased up to 20 million/ha when concrete tanks are used as nursery. With proper pond management, while a survival of 30-40% of fry is normally achieved in earthen nursery at the end of 15-20 days, still higher survival levels of 50-60% is achieved in concrete

ursery tanks. Provision of aeration with the use of air blower/compressor in can
nproves survival and growth at high density rearing. In nursery rearing generally
erformance of mrigal in terms of growth and survival remains better followed by
ohu and catla at a particular density. While size of fry at harvest usually remains
niform in rohu and mrigal, wide disparity is observed in catla.

Supplementary feeding: Natural production of fish food organisms in the nursery
cosystem, even with regular manuring and management, does not meet the total food
quirement of the stocked spawn. Thus, provision of supplementary feed becomes an
tegral part of management for the optimum nourishment of the seed. The nutrient
quirements for carp spawn have been evaluated over the years as 35-40% of protein;
6% of fat; 22-26% of carbohydrate; 0.1% of vitamin B complex, 600 mg/kg vitamin
and 200 IU/kg diet of vitamin A. Locally available materials such as cakes of
oundnut, mustard and soybean, rice polish, wheat bran, fish meal, silk-worm pupae,
:. have been evaluated over the years in varied proportions, based on their proximate
mposition along with incorporation of vitamins, mineral and micronutrients.
owever, availability of formulated commercial feed for carp fry is still a constraint
d traditional powdered mixture of groundnut oilcake and rice bran at 1:1 ratio has
en the most commonly used supplementary feed during seed rearing of all the major
ps. Though the above feed mixture does not meet the nutritional requirements of
carp seed, large-scale use of these ingredients is mainly due to their low cost and
y availability.

The dry feed mixture is normally supplied in nurseries @ 400% of the initial spawn
mass (1 million spawn weigh about 1.5 kg), i.e. 6 kg/million/day for the first 5
's, and 800% of the initial spawn biomass, i.e. 12 kg/million/day for the subsequent
s. The daily ration may be supplied once during morning hours or divided into two
al splits supplied during morning and evening. The powdered feed mixture is
adcast over the water surface for easy availability to the seeds. The spawn are
ed in the nurseries for 15-20 days during which they reach size of about 25 mm in
th, known as fry. Thinning of the population is required, if the seed is to be retained
ond this period so as to avoid mortality.

Harvesting: Harvesting of the fry is done during the cool hours, preferably
orning or evening. Conditioning of fry prior to packaging is an essential step
educe the stress and mortality during transportation. For such conditioning,
harvested fry are kept in *hapa* fixed in the same nursery pond in crowded
lition for 2-3 hr with water sprinkling at periodic intervals. Use of shower for
purpose ensures better conditioning. Such conditioning facilitates release of
l matters and minimizes the faecal load in the seed pack during transportation.
ls are packed in polyethylene bags filled with water up to one-third of the
tive volume and rest two-thirds being oxygen. With such package, the seeds
be transported to long distance involving 20-24 hr journey. Depending on the
nce and mode of transportation, the polythene bags are supported by suitable tin
ainers, bamboo baskets, paper cartons or nylon bags to prevent damage to the
s.

Rearing pond management for fingerlings production

The fry of carps are raised further for two to three months to fingerlings in relatively larger ponds of 0.05 to 0.2 ha area with 1.2 to 1.5 m water depth. The food preference and feeding habit of the carps gradually changes during this stage and they occupy different food niches, i.e. top, column and bottom of the pond. Series of management measures, as that of the nursery pond, is also followed to ensure higher growth and survival during raising of fingerlings.

Pond preparation: Some of the basic operations such as clearance of aquatic weeds, soil correction and control of predatory and weed fishes are similar to the ones discussed for the nursery pond. Except competing for feed, aquatic insects do not pose any major threat to seeds in rearing pond. Unlike single species culture in nursery, polyculture of combined carp species are practised in rearing ponds, which requires different management measures. Such rearing ponds are fertilized with raw cattle dung @ 5 to 10 tonnes/ha depending on the organic carbon load of the soil. While one-third of the above amount is applied 8 to 10 days before stocking fry, the remaining amount is applied in equal splits at fortnightly intervals after the seed stocking. In case of use of poultry droppings, the dose may be reduced to one-third to half of the amount of cattle dung. Further, application of inorganic fertilizers such as urea and single super phosphate at 10 and 15 kg/ha, respectively, at fortnight intervals in between organic manuring gives encouraging results.

Stocking of fry: Stocking is preferably done during morning or evening hours after proper acclimatization to the new environment, as discussed earlier. In earthen ponds, the usual stocking density followed is 0.2-0.3 million fry/ha, which can further be increased in ponds with facilities for water circulation/exchange and/or aeration etc. Various species combinations and species ratios of Indian major carps and exotic carps have been evaluated over the years with reference to the pond conditions and requirements. Some of the suggested combinations are as follows:

Catla : rohu : mrigal at 1:1:1 or 1:2:2 or 3:4:3

Silver carp: grass carp: common carp at 4:3:3 or 1:1:1

Catla: rohu: mrigal: silver carp: grass carp: common carp at 1:1:1:1:1:1

Some of the medium-size carps, viz. *Labeo fimbriatus, L. gonius, L. calbasu, Puntius sarana, P. gonionotus, Cirrhinus reba*, have been incorporated into the major carp based polyculture as a step towards species diversification in culture system. Growth performance of some of these species like *P. gonionotus, L. fimbriatus* and *L. gonius* during the fingerlings raising have been observed to be even higher than those of Indian major carps at similar level of incorporations under multi-species rearing.

Supplementary feeding: Feed requirements of the growing fingerlings are met through available natural food and provision of supplementary feed, commonly in the form of mixture of groundnut/mustard oil-cake and rice bran/wheat bran at 1.1 ratio by weight. Other ingredients such as fishmeal, soybean flour, vitamin-mineral mixture, etc. are also suggested to be incorporated for improving the feed quality. Incorporation of several other non-conventional feed ingredients has also been evaluated and shown to be effective for partial substitution of protein supplement.

Feed requirement in the rearing pond is calculated based on the initial biomass of the fry and subsequently through samplings at fortnightly intervals. Feed is provided @8 to 10% of initial biomass of fry per day during the first month, followed by 6 to 8% of the standing biomass during the subsequent two months. The daily ration is provided in two equal installments during morning and evening hours. A part of the ration may be broadcast in powder form to facilitate feeding of the surface feeders and the rest is placed in feeding tray or through suspended feedbags so as to reduce feed wastage. Duckweeds like *Spirodela, Lemna, Azolla, Wolffia* etc. are provided when grass carp is stocked as a component.

Water management and health care: Liming and fertilization of the rearing ponds are done at periodic intervals, or as per requirement based on the routine observation of the soil and water characteristics. The evaporation and seepage loss in the pond is periodically compensated to maintain the water depth at 1.2 to 1.5 m. In high density rearing system, aeration and/or water exchange is given to maintain the overall water quality, particularly the dissolved oxygen content. Regular sampling of the seeds helps in assessing their health condition and accordingly, suitable preventive or curative measures against any parasitic or microbial infections are taken. As prevention is better than cure, it is better to have preventive measures for any possible outbreak of the disease by minimizing the stress through proper environmental management and less handling. Parasitic infections by *Myxobolus, Trichodina* etc. are common problems encountered in rearing system which may be treated with due consultation with aquaculture expert.

Harvesting of fingerlings: Within 2-3 months of rearing, the fry grows to fingerlings of 80 to 100 mm in length (8 to 10 g). Fingerlings are effectively harvested by using a closed-meshed drag net. Morning hours with low water temperature is the most preferred time for harvesting. Normally survival of 60 to 70% is achieved in rearing ponds with proper management. When the fingerlings are to be transported, feeding is usually stopped one day prior to harvesting. The harvested fingerlings are conditioned and transported in polythene bags with oxygen. Fingerlings can be further reared in the rearing pond to obtain bigger juveniles. However, in such case, the population has to be thinned out. One of the recent concepts followed in fingerling rearing is to raise the seed at higher stocking density round the year with low rate of feeding so as to obtain stunted seed. This method ensures round the year availability of fingerlings for stocking in grow-out ponds. Further, grow-out ponds stocked with stunted fingerlings are reported to give better survival, high feed utilization efficiency and higher production than those stocked with normal ones. Stocking with stunted fingerlings has been increasingly in practice in certain regions of the country like that in Kolleru lake region of Andhra Pradesh where the fingerlings are grown to juveniles of 150 to 250 g size in separate ponds for stocking in grow-out ponds.

Grow-out culture of carps

Indian aquaculture is mainly carp-based where the three Indian major carps, viz. catla, rohu and mrigal, are grown together under polyculture system or along with the

three exotic carps, viz. silver carp, grass carp and common carp, as the six species composite carp culture systems. These six species are selected considering their compatibility for habitat and food preference to utilize the entire ecological niches of the culture system. While catla and silver carp are surface feeders showing preference for zoo- and phytoplankton, respectively, mrigal and common carps are omnivorous bottom feeders. Rohu is a column feeder and grass carp shows preference for aquatic vegetation. Weeds having soft foliage like *Hydrilla, Ceratophyllum*, duckweeds such as *Lemna, Spirodela, Wolffia* etc., are preferred by the grass carp. Besides, some marginal vegetation and terrestrial grasses can also be provided for the species. The major carps utilize the natural productivity by feeding at the base of the food chain, viz. phyto- and zooplankton, detritus and aquatic weeds. Among the six species, the three Indian major carps are comparatively slow growing than their exotic counterparts. Thus, polyculture of the three Indian carps usually yields lower production than the six-species composite culture system or the system with three exotic carps. These carps are also cultured under mixed culture system incorporating freshwater prawn (*Macrobrachium rosenbergii, M. malcolmsonii*), catfishes like magur (*Clarias batrachus*) and singhi (*Heteropneustes fossilis*).

The technology of carp farming has evolved with incorporation of compatible medium carp species in the major carp based production system. While species like *L. calbasu, L. gonius* and *P. sarana* are incorporated as bottom dwelling components, *L. fimbriatus* and *P. gonionotus* are used as column feeders. Incorporation of these medium carps suitably at 5 to 15% in the major carp system has shown to yield production levels comparable to that of the major carp system, besides widening scope for the farmers to diversify their species spectrum in the culture ponds. The initial higher growth of some of these species like *P. gonionotus* and *L. fimbriatus* also give opportunity for the farmers to utilize the seasonal ponds effectively. Since these medium carps are marketed at smaller size (250 to 300 g), in perennial ponds, these species can be harvested after 5 to 6 months of culture allowing the major carps to grow further. Alternatively, restocking of the pond with these species can also be done for raising their second crop along with the major carps. Such practice can provide interim economic return to the farmers to plough back his income for reinvestment.

Carp culture is undertaken mostly in earthen ponds of varying dimensions. Over the years, several culture practices were evolved in the country for different water resources utilizing wide spectrum of fish species, fertilizers and feed resources as main inputs. The standardized packages of practices for carp polyculture include pond preparation, liming, fertilization, stocking management, supplementary feeding, water quality management, health management etc. With an understanding of the biological basis of fish production, a series of systems are available with varying levels of inputs and outputs, which could be categorized as low, medium and high input technologies. The three categories are almost equivalent to those of the extensive, semi-intensive and intensive culture systems.

Low-input system: Seed forms the principal input in extensive aquaculture and natural food forms the sole source of nutrition for the fish. The natural productivity of such system is augmented through use of different low-cost inputs such as organic and inorganic fertilizers, biogas slurry, aquatic weeds etc. The fertilizer-based systems make use of both organic and inorganic fertilizers as major inputs besides stocking of carp fingerlings at comparatively low density up to 3,000/ha. A fish production level of 2-3 tonnes/ha/year is achieved in such system without provision of any supplementary feeding. Slurry from the biogas plant acts as a good organic manure since it contains manures in partially or fully decomposed form that demands considerably less oxygen for further decomposition in fish pond. Application of biogas slurry 30 to 45 tonnes/ha/year at fortnightly equal splits showed high phytoplankton productivity registering production levels of 2 to 3 tonnes/ha/year. Alternatively, daily application of the slurry at 80 to 120 kg/ha showed better result.

Grass carp is a voracious feeder for submerged vegetation. The faecal matter of this fish is partially digested and acts as a rich fertilizer besides being utilized as feed for other species. Weed-based system of carp culture at stocking density of 4,000 to 5,000 fingerlings/ha with grass carp as the main component (40 to 50%) can yield production levels of 3 to 4 tonnes/ha/year without provision of supplementary feed.

Medium-input system: In culture practices of medium level input, supplementary feed is provided apart from addition of elements of fertilization for enhancing the fish production. Carp polyculture systems with three Indian major carps alone or along with the three exotic carps, tried in different agro-climatic conditions of India using judicious combination of feed and fertilizers, showed production levels of 4-8 tonnes/ha/year. Proper pond preparation, stocking density, periodic fertilization and regular feeding with oil-cake-bran mixture (protein 25 to 27%) coupled with water quality and fish health monitoring have been the main features of this technology. Further, this technology has the scope for diversification through integration of other agricultural activities for increasing production, employment and income besides maximizing the resource utilization. Livestock-based aquaculture utilizes the wastes (both leftover feed and excreta) from poultry birds, ducks, rabbits, pigs or sheep/goats. Production rates ranging from 3,000 to 6,500 kg/ha/year were registered under different systems, with duck-cum-fish farming being the least and the pig-cum-fish farming being the most productive.

High-input systems: Higher stocking density combined with higher feed inputs is the typical characteristics of intensive culture system aimed at higher fish production from unit area. Such high input based culture system uses balanced diet together with intensive aeration and water replenishment apart from other inputs. Though fertilizers are used in this system, their contribution to fish production is comparatively low. Water exchange and aeration helps in reducing the metabolite load from the ponds. Production levels of over 15 tonnes/ha/year have been possible by adoption of this high-input technology. It is evident that while high production is not difficult from undrainable static ponds, increased water replenishment may be vital factor for maintaining higher growth and production.

Based on the production cycle, the carp culture can be of single stocking–single harvest, single stocking-multiple harvest and multistocking- multiharvest or rotational type culture. The single stocking-single harvest method of culture is usually done for six months to one year. Such method is followed in both traditional and semi-intensive practices. Semi-intensive method also makes use of single stocking-multiple harvest method where comparatively higher stocking density is maintained than that of single stocking-single harvest. As fish biomass in the pond increases, larger fishes are partially harvested at monthly intervals. In multistocking-multiharvest, marketable size fishes are harvested from ponds at regular intervals with periodical restocking.

Grow-out culture of carps are carried out in earthen ponds ranging from 0.04 to 10.0 ha in area and 1 to 4 m in depth in different regions of the country, while ponds of 0.4 to 1.0 ha size with water depth of 2 to 3 m are considered ideal. While small and shallow stagnant ponds have several inherent problems, which adversely affect the growth of fish, the large and deep ponds have their own problems of management. Essentially, the management practices in carp polyculture involve environmental and biological manipulations for obtaining higher levels of fish production, which can be broadly classified as pre-stocking, stocking and post-stocking operations.

Pre-stocking pond preparations: Eradication of aquatic weed and predatory fishes, and generating adequate natural food through fertilization are the prime requirements to ensure high survival and growth during the culture period. Ponds that dry up in summer or could be drained out easily do not give much problems. Perennial ponds, however, harbour weeds, predators and competitors and require control measures. Besides, improvement of soil and water quality is the other important aspect for the success of grow-out culture. The pre-stocking management measures for grow-out culture includes the preliminary steps namely control of aquatic weeds, predatory and weed fish control and soil correction process that are discussed earlier in this chapter. Some other practices followed for these ponds are disecussed here.

Fertilization practices: Pond fertilization aims at enhancement of the autotrophic and heterotrophic production of the ecosystem, which is stimulated by application of organic manures and inorganic fertilizers. In carp culture, the usual practice involves application of both organic manures and nitrogenous and/or phosphatic fertilizers for improving the productivity. The amount of potassium available in sediments of ponds in most part of the country is adequate for maintaining the natural productivity, thus it is not a limiting nutrient for fish farming. So supplementary application of this fertilizer is not usually required. Cattle dung or poultry droppings are the most commonly used organic manures, often used in combination with urea and super phosphate as the inorganic nitrogen and phosphorus sources. The conventional dosage followed in carp culture practice in India usually range from 10 to 20 tonnes/ha/year cattle dung or 4 to 8 tonnes/ha/year poultry manure alone or in combination with urea @100 kg N/ha/year and super phosphate @ 50 kg P/ha/year. Generally, the carp ponds are classified into low, medium and high productive groups based on their soil nutrient levels and the recommended fertilization measures followed for these groups are given in Table 16.2. Of the total amount of organic manures, while 25 to 30% is generally applied as basal dose a fortnight before the stocking, the remaining amount is applied in equal installments at fortnightly intervals. Besides cattle dung and poultry droppings, other organic manures with high nitrogen (N) and phosphorus (P) content such as pig manures, duck droppings, domestic sewage etc. are also used depending on the availability.

Table 16.2. Categorization of ponds based on nutrient status and recommended dose of fertilizers

Nutrient	Low	Medium	High
Organic carbon (%)	0.5-1.5	1.5-2.5	> 2.5
Available nitrogen (mg N/100 g soil)	25-50	50-75	> 75
Available phosphorus (mg P/100 g soil)	<3	3-6	> 6
Recommended dose of fertilizers/ha/year			
Raw cattle dung (tonnes)	20	15	10
Urea (46% N) (kg)	150 kg N	100 kg N	50 kg N
	≈ 322 kg urea	≈ 218 kg urea	≈ 104 kg urea
Single super phosphate (16% P) (kg)	75 kg P	50 kg P	25 kg P
	≈ 470 kg SSP	≈ 310 kg SSP	≈ 155 kg SSP

Attention has been shifted towards use of biofertilizers and bioprocessed organic material for ensuring sustainability of aquaculture practices and to avoid the possible environmental fall-outs due to use of high amount of fertilizers. Several non-conventional materials were tested for their efficacy. *Azolla*, a nitrogen-fixing aquatic fern with high protein content (15 to 17%), was standardized as an ideal nitrogenous biofertilizer for aquaculture. At an application rate of 40 tonnes/ha/year, *Azolla* provides almost full complement of nutrients required for intensive carp culture (100 kg nitrogen, 25 kg phosphorus, 90 kg potassium, and 1,500 kg organic matter). The detritus resulting from the decomposition of the material applied in the ponds serves as a trophic component of carps and prawns. The bioprocessed organic manure such as biogas slurry was standardized as manure in carp culture, at application rates of 30-45 tonnes/ha/year, with distinct advantages in terms lower oxygen demand and faster nutrient liberation rates. The use of both *Azolla* and biogas slurry has shown to be economical compared to the traditional fertilization practices.

Stocking: The stocking density of carps for a culture pond is predetermined based on the targeted production, pond productivity and carrying capacity, species to be cultured, their feed conversion efficiencies, size at stocking, growing period, level of management, etc. Though fingerlings of more than 100 mm in size considered to be the suitable stocking material for grow-out culture, constraints in their availability often force the farmers to resort to stocking of smaller fry. In intensive culture, a size of 50 to 100 g is preferred for stocking to realize higher survival and better growth. Generally a density of 5,000 to 10,000 fingerlings/ha is kept as a standard stocking rate in carp polyculture for a production target of 3 to 5 tonnes/ha/year. With provision of water exchange and aeration, higher targeted fish production levels of 10 to 15 tonnes/ha/year are achieved by resorting to stocking the ponds at a density of 15,000 to 25,000/ha. However, the density is reduced to 2,000 to 3,000 fingerlings/ha in seasonal ponds or where water level becomes limiting during summer to obtain higher

growth. Although the major carps are expected to reach an average of 0.8 to 1.0 kg in the first year, the growth rate is invariably reduced at higher stocking densities.

Selection of compatible species and stocking them at appropriate ratio suiting to the culture environment is another important criterion in carp culture. Manipulation of the species ratio is for minimizing the inter-specific and intra-specific competition for available food at various trophic levels in a pond. Either single species or more than one species occupying different niches could be utilized in a pond for exploiting the available natural food. Several combinations of Indian major carps alone and in combination with the exotic carps were experimented under different stocking densities keeping growth as an index of performance. A combination of six species, viz. catla, silver carp, rohu, grass carp, mrigal and common carp, proved to be the ideal combination for freshwater carp culture in India. A proportion of 30 to 40% surface feeders (silver carp and catla), 30-35% mid-water feeders (rohu) and 30 to 40% bottom feeders (common carp and mrigal) is commonly adopted depending on the productivity of the pond. When there is possibility of providing aquatic vegetation as food for grass carp on a regular basis, the same may be included at 5 to 10% of the total. As discussed earlier, medium carp components can also be suitably incorporated with partial substitution of major carps according to their niche preference. While ponds with higher organic matter can be stocked with higher proportion of bottom feeders, surface feeder may be kept more in newly excavated ponds. Similarly, rohu may be stocked at higher ration in ponds with higher water depth.

Supplementary feeding: The natural productivity of pond, irrespective of the level of its augmentation through fertilization, is not capable to sustain a higher level of fish biomass in semi-intensive grow-out practice. Due to the limitation in availability of natural fish food in pond at higher stocking density, the energy requirement for somatic growth can be met only through provision of supplementary feed. Over the years, the nutritional requirement of carps was studied. Although various ingredients of both plant and animal origin were evaluated, mixture of groundnut/mustard oil cake and rice bran at 1:1 ratio was commonly used in carp culture. In ponds, the vitamins and minerals requirements of carps are normally met through the intake of natural food (at least 50% of the diet). But at higher stocking density, where supplementary feed forms the major source of nutrition, fortification of vitamins and minerals becomes necessary in such diet. With the shift towards intensive fish culture during recent years, formulations of balanced feed have received considerable attention. Several balanced feed formulations were developed making up the deficient essential amino acids, fatty acids, and incorporating vitamins and minerals. All these ingredients are blended together at required proportion for preparation of carp feed. The commercial production of supplementary feed comprise both floating and sinking pellets of different diameter, which are developed to provide higher water stability, consumption and utilization by the fish. Use of floating feed has become popular in commercial carp farming owing to the ease in feed management and reduction of feed wastage.

Underfeeding depresses fish growth while over-feeding results in wastage of food, leading to deterioration of water quality. As the cost of feed constitutes more than

60% of the recurring expenditure in carp culture, feed management therefore is an important aspect for ensuring optimum growth of carps and limiting the production cost, besides maintenance of pond condition. The recommended practice is to provide feed at 3 to 5% of the body weight of stocking material initially and subsequently at sliding scale from 3 to 1%. The feed requirement of the pond is calculated using the following formula:

Feed required = Estimated fish biomass in pond × Feeding rate %

where biomass, average body weight of fish × total number of fish stocked × expected percentage survival.

In grow-out ponds the survival level usually reduces to around 80% during the initial two months of culture, beyond which the survival remains almost constant in properly managed ponds. Therefore, survival percentage of 70 to 80 is considered for estimation of biomass. The daily ration is adjusted according to the biomass estimated from monthly sampling. Daily ration is provided in pond preferably in two splits, during morning and evening in feeding trays or perforated gunny bags suspended at regular intervals in the pond. Grass carps are provided with aquatic vegetations like *Lemna, Spirodela* and *Wolffia; Hydrilla, Najas* and *Ceratophyllum* at periodical intervals. To overcome the shortage in supply of desired vegetation with the heavy demand consequent on low conversion rate of aquatic vegetation to fish flesh, marginal vegetation, land grasses and other fodder, banana leaves and vegetable refuse can also be used.

Management of soil and water quality: Management of soil and water quality in carp culture ponds are integral part of the culture operation for a successful crop. A number of environmental problems are sometimes encountered in grow-out ponds some of which are inherently associated with the site characteristics like porosity, acidity and high organic matter content of bottom soils and some are encountered during culture operations. Drying of pond bottom to crack between the crops helps in aeration, which enhances microbial decomposition of soil organic matter. The porosity of the pond bottom is corrected through application of bentonite, lining with plastic sheet at 0.3-0.5 m depth, application of heavy doses of organic manures (cattle dung @ 10,000-15,000 kg/ha/year), etc. Pond with acid sulphate soil is reclaimed through repeated drying and filling as discussed in earlier section. After reclamation, the normal dose of lime (Table 16.1) is followed for soil correction. Since of such ponds is a major source of sulphuric acid that drains into the pond water and reduces the *p*H, additional liming is also advocated along the slope of the dyke.

The water quality parameters required for the optimum growth of carps are *p*H 7.5 to 8.3, temperature 27° to 32°C, dissolved oxygen more than 4 mg/litre, total alkalinity of 80-120 mg $CaCO_3$/ litre, secchi disk visibility of 25 to 30 cm, total inorganic nitrogen 0.5 to 1.0 mg/litre and phosphorus 0.2-0.3 mg/litre. Variations in these water parameters occur in the culture pond and need periodic correction/management measures during the culture operation. The low water *p*H is corrected through intermittent application of lime materials. Lime helps in improving alkalinity, hardness, controlling turbidity

and reducing the H_2S build up. Dolomite is particularly useful when augmentation of phytoplankton growth is required. Agricultural gypsum ($CaSO_4$) is applied to correct alkaline *p*H. It is also applied to increase total hardness without affecting the alkalinity. It is particularly used in pond with high afternoon *p*H, i.e. higher *p*H fluctuation. Aeration, a proven method for improving the pond dissolved oxygen availability, also helps in mineralization process reducing the organic load. Water exchange helps to a great extent in reducing metabolic load. Addition of water into pond, particularly during winter, helps in improving the temperature regime and prevents temperature stratification. Turbidity with suspended soil particles can be controlled by application of cattle manure (500 to 1,000 kg/ha), gypsum (250 to 500 kg/ha) or alum (25 to 50 kg/ha). The ammonia load in pond can be reduced through encouraging healthy growth of phytoplankton or aeration. The H_2S build up in pond can be subsided through frequent water exchange.

Aeration and water exchange: Dissolved oxygen content in water is probably the most important variable regulating production of fish in intensive culture. Photosynthetic process is the major source of dissolved oxygen in pond, while minimal amount comes through surface diffusion. A large quantity of oxygen is utilized for the mineralization of the organic matter, faeces as well as uneaten feed and the rest is available for fish respiration. Low oxygen availability in pond usually results in respiratory stress leading to poor fish growth. When stocked at higher density, the dissolved oxygen content of the pond may not be sufficient to meet the respiratory demand of the higher fish biomass, thus requiring additional aeration.

Aeration of pond helps in improving oxygen content, expediting mineralization process and ensuring mixing of water column that prevents thermal and oxygen stratification, which ultimately contribute for higher fish production. Aeration is also required during prolonged cloudy weather. Carps gulping for air at the surface water, particularly in morning hours, are the typical sign of dissolved oxygen deficiency in ponds. Sometimes, mass mortality of carps occurs due to prolonged oxygen deficiency in pond water. A typical traditional method of aerating a pond is by pumping the same pond water on to a series of bamboo baskets fitted vertically one below the other from a common vertical pole. However, paddle wheel aerator, aspirator aerator and air diffuser are the common mechanical means of aeration in intensive ponds. While the peddle wheel aerator agitate the surface water and may be ideal for water depth of 1.0 to 1.5 m, the other two are more effective in deeper ponds due of their high capacity of injecting air bubbles into water. Air compressor can also be used to improve oxygen content in the ponds through underwater pipelines. Placement of aerator is an important consideration for enhancing the efficiency.

Water exchange is another important activity considered to be crucial in intensive aquaculture operations. Continuous accumulation of metabolites and unutilized feed, besides heavy organic manuring, deteriorate the water quality, which often lead to outbreak of diseases. Water exchange helps in reducing these metabolic loads in pond. Thus, water exchange at regular intervals is essential in highly stocked carp ponds, especially during later part of the culture period.

Health management: The fish is a cold-blooded animal and is more prone to the environmental changes. A balanced relationship among the host, pathogen and the environment is a pre-requisite for the optimum growth and health of any organism. Any imbalance in this relationship leads to the diseased condition of the host, i.e. animal. In the event of a disease outbreak, it affects fishes in groups or the whole population. Further, treating a diseased fish is relatively difficult when compared to the terrestrial animals, as individual treatment is not possible in the former, thereby requiring mass treatment of the population or the environment. Therefore, prevention is always a preferred method in aquaculture to control the disease outbreak than curing the disease. Due to increase in the intensity of culture, disease management and health care has become an important aspect of management for preventing sudden outbreak of epizootics that occur because of environmental deterioration, improper feeding and overcrowding.

Under feeding leads to malnutrition, resulting in growth retardation and low disease resistance. Liver lipoid disease, scoliosis and lordosis etc. are the examples of such malnutrition disorders. Many of the fish may carry small numbers of pathogens like bacteria, virus, fungi and parasites, either at chronic low-grade infections or serving as carriers. Such pathogens are also present in the deteriorated pond water and sediment and their population increases to a very high level when the pond is heavily stocked. Weak disease resistance of the fish makes them susceptible to attack from these pathogens. Infection through an individual pathogen or sometimes by a group in sequence results in outbreak of disease, often leading to fish loss.

The best way to avoid disease outbreak in the pond during culture is through taking preventive measures which are ensured by proper management of the soil and water quality, following proper feeding schedule, use of balanced feed, periodic sampling for health check, minimizing outside influence on the pond etc. Some of the common diseases infecting carps in culture ponds and their remedy are listed in Table 16.3.

Harvesting and marketing: Generally carps are harvested after a grow-out period of one year during which it reaches to marketable size of 0.8 to 1.0 kg. However, these carps are even marketed in smaller sizes of over 300 g, except that of silver carp, the marketable size for which is over 1 kg. In multi-harvesting system, the fishes attending the market size are periodically harvested from the pond, releasing back the smaller ones for further growth. While intermittent harvesting is done with the help of dragnet of suitable mesh size, final harvesting is usually done by complete draining of the pond.

Carps produced from the culture ponds are mostly sold in the local market either in live or dead condition. The Indian major carps are also transported to the adjacent deficit areas as well as to distant places, even 2,000 to 3,000 km away from the production site, in insulated vans with ice. The price in the domestic market is influenced by the demand and supply. Fresh fish fetches about 1.5-fold higher market price than the iced ones. When sold in live condition, the carps command still higher sale value of over 2-fold compared to that of iced ones.

Aquaculture is identified as one of the most promising farming enterprise in India.

Table 16.3. Common diseases, symptoms and control measures in carps

Diseases	Cause	Symptoms	Control measures
Ulcer	*Aeromonas, Pseudomonas*	Raised white plaques, often with reddish peripheral zone leading to haemorragic ulcers	Badly infected ones to be destroyed; pond disinfections with 0.5 ppm solution of $KMnO_4$; Sulphadiazine in feed @ 100 mg/kg or Terramycin@ 75-80 mg/kg with feed for 10-12 days
Dropsy	*Aeromonas*	Scale protrusion, exopthalmic condition, accumulation of fluid inside the body cavity, haemorrhages on the skin and fin	Pond disinfections: 1 ppm $KMnO_4$; dip treatment 5 ppm $KMnO_4$ for 2 min
Saprolegniasis	*Saprolegnia parasitica*	Secondary infection over injury/bruise/haemorrhage in the form of white cotton wool like outgrowth	NaCl 3-4% bath; $KMnO_4$ 160 mg/litre bath for five days; malachite green 1-2 mg/litre bath for 30 min to 1 hr. Formalin 20 ml/litre in pond treatment
Dactylogyrosis and Gyrodactylosis	*Dactylogyrus, Gyrodactylus*	Fading of colours, scale dropping, excessive mucous secretion on caudal peduncle, fins and gill surface. Fish rub its body against hard surface.	NaCl 3-5% dip treatment for 5-10 min; Formalin 100 ppm bath; pond treatment with formalin @ 25 ppm or $KMnO_4$ @ 4 ppm
Argulosis	*Argulus*	Parasites attach to the body and fins by means of sucker and hooks which are visible to the naked eye, infected fish gets emaciated, growth stunting, scale loss, appearance of red spot	Ponds showing severe *Argulus* infection should be drained and dried. Short duration dip $KMnO_4$ @ 5 ppm; treatment with 'Butox', a chemical substance, @ 35 ml/ha-m at weekly intervals three times
Epizootic ulcerative syndrome	*Aeromonas hydrophila, A. sorbia, Aphanomyces invadans*	Ulcerations in reddish patches on the body, severely affected ones lose fins and muscles leading to death	Use of lime @ 200 kg/ha; CIFAX (a CIFA formulation) @ 0.1 ppm

At its average annual growth at 6% for the last two decades, the sector poised to become the major supplier of fish protein in coming days. While the fish production from marine capture is projected at 3.5 million tonnes by 2020 from the present level of 3.0 million tonnes (2009), freshwater aquaculture production at the same time is expected to contribute 7.0 million tonnes from the present level of 3.5 million tonnes, showing the importance of the sector in future fish supply. Carp being the main component species, it is expected to contribute major share of the freshwater aquaculture produce in the coming days. The efforts made for diversifying the species and culture system, therefore, needs further emphasis. Technology for polyculture of carps with air-breathing catfishes and freshwater prawn has to be made more promising and remunerative. Technology of cage and pen culture for utilizing deeper water-bodies like reservoir and lakes, and running water system has to be refined further for making it economically viable. With only 40% of utilization of the 2.36 million ha available ponds and tanks in the country at present and excavation of new pond area being added every year, the sector provides enormous scope for horizontal expansion. Further, there is a necessity to improve the unit area productivity through intensification of the farming systems with due emphasis on environmental health and sustainability.

17. Catfish Breeding and Culture

Catfishes, owing to their unique taste, are considered a delicacy for the fish consumers, but production of different indigenous catfishes through aquaculture is unexplored in India, although aquaculture contribution of some of the catfish varieties like *Ictalurus*, *Silurus* and *Clarias* spp. has been exemplary in the world scenario.

Aquaculture in India has become an industry since late eighties with several entrepreneurs taking up aquaculture with carps, catfishes and prawns. Of late, Government of India has also identified catfish farming as a National priority and has emphasized on diversification of culture practices. The major chunk of catfish, however, comes from capture resources, which includes air-breathing as well as non-air-breathing varieties. Air-breathing catfishes have greater potentiality to utilize shallow, swampy, marshy and derelict water-bodies for aquaculture; whereas non-air-breathing catfishes can be well suited to normal pond environment.

Breeding and rearing of different catfishes

Clarias batrachus

Clarias batrachus, known as magur is the most preferred indigenous catfish in India. It is obligatory air-breathing catfish, hardy in nature and an annual breeder, which spawns during monsoon months in large waterlogged areas. In nature, it shows parental care. Female scoops nests and fertilized eggs are deposited in them. Such natural simulations are made for natural breeding of *Clarias* spp. in South-East Asian countries for getting stocking material.

Maintenance of healthy brood fish is a pre-requisite for successful seed production in captivity. Usually, this species attains maturity in one year with 100-150 g in weight and can be employed for breeding. Brood fishes, collected from culture ponds, are stocked at 2-3 fishes/m^2 in specially prepared cemented tanks (12 m × 5 m × 1 m) during January-March. A soil base of 5-10 cm thickness is provided in tanks. To facilitate continuous flow of water (2 litres/min), an inlet at the top of the tank with an outlet at a desired level (0.5 m from below) is provided. A mixture of fish meal, groundnut oil-cake, soybean meal and rice bran with vitamin and minerals, resulting in 30% protein level at 2-3% of the body weight, is fed to the stocked fishes. To maintain hygiene, the tanks are replenished with water at fortnightly interval.

Magur usually breeds in monsoon during June-August. The fishes are taken out of the broodstock tanks and kept separately in plastic containers for breeding operation. Males and females can be distinguished by secondary sexual characters. The abdomen of a gravid female is round, bulging with a reddish coloured vent having round and button-shaped genital papilla and the males have elongated and pointed papilla. They are either bred through hormone administration or through environmental manipulation.

Females are induced bred through commercially available synthetic hormones, i.e. ovaprim/ovatide/WOVA-FH @ 1.0-1.5 ml/kg body weight. However, they could also be induced bred using the conventional carp pituitary extract at 30-40 mg/kg of body weight. The above hormones are injected to female fishes on the dorsal side of the body during evening hours in a single injection schedule. The stripped eggs are fertilized artificially with sperm suspension. However, males do not require hormonal administration.

Unlike carps, males of this species do not ooze sperm on its own and thus they are cut open at the abdomen, testes are removed and macerated keeping it in normal saline solution (0.9% sodium chloride) to get sperm suspension, which could be used within 24 hr at room temperature.

Females are stripped after a latency period of 15-17 hr and eggs are fertilized with sperm suspension. The fertilized eggs are then washed thoroughly and transferred to flow-through hatchery for hatching. The eggs of this species are adhesive in nature. Light brown eggs are considered good while white are unfertilized ones. The fecundity of the species is low, about 400-500 eggs/g of ovary weight.

The flow-through hatchery consists of a metallic stand or cemented platform on which plastic tubs are placed. A row of small tubs of 12 cm diameter with 6 cm height is placed under separate taps. Each plastic tubs can accommodate 1,500-2,000 eggs. Water supply is provided from an overhead tank through a common pipe to all the tubs with individual control taps. Each tub is having provision of an outlet at a height of about 4 cm. For large-scale hatching, an improvised hatchery system has also been developed. The system consists of a circular tank of 2 m diameter with inlets at a height of 15 cm at an angle of 45°. The system can accommodate about 1.0 lakh fertilized eggs in a single operation with 60-80% hatching rate. The fertilized eggs are uniformly spread in the plastic tubs/circular container and a feeble current of water is provided to maintain optimum oxygen level. Ideal temperature for hatching is between 27 and 30°C and hatching takes place within 24-26 hr. After hatching, the larvae are collected by siphoning from the tubs/bottom of the hatching tank. The yolk sack of the newly hatched larva gets absorbed in 3-4 days. The hatchlings are transferred to circular/rectangular fibre-reinforced plastic (FRP) hatchery or plastic containers for rearing.

The species can also be bred by providing congenial environment either in the pond itself or simulating the condition of paddy field in the cemented cisterns. Specially designed ponds of 0.04-0.10 ha with 0.75-1.0 m depth are prepared with several pits at the bottom (15-25 cm deep) to be used as nests by fish. A continuous trench of 50 cm depth is dug-out along the margin of the pond. Brood fishes are released into the trench during December-January and fed with a mixture of fishmeal, groundnut oil-cake, soybean meal and rice bran at 2-3% of their body weight. During this period, the pond bottom is kept exposed and paddy is grown there. During monsoon (June-July), pond bottom is inundated with rain and water level is maintained at 25 cm. The brood fishes move in pairs and congregate in pits and spawn there. Water level in the ponds is reduced after 8-10 days and spent fishes go back to trench leaving behind fry in pits, which are subsequently scooped out.

It is possible to breed this species at least twice in a season. The hormone treatment is given to the fish in the form of sustained hormone pellets, which are implanted into the musculature. The hormone used is LHRHa @ 100 mg/fish which is a super-active analogue of luteinizing hormone releasing hormone or 150 IU hCG/fish. The pellets are made of LHRHa and hCG with cholesterol-base with a binder (gelatin and gum acacia). The pellets are implanted into the fishes during preparatory period of gonadal cycle. The above treatments bring about early maturity in fish, well in advance of monsoon, which could be induced to breed as early as in April through October.

The larvae measure about 5.0-5.5 mm in length with heavy yolk sac. Absorption of yolk sac takes three days and thereafter feeding is initiated. Larvae are reared for about 12-14 days in indoor rearing system. The quantity of feed depends on the density of the larvae reared in the container, growth of the spawn including their food acceptability. Identification of acceptable feed and particle size matters a lot during rearing. Mixed zooplankton, *Artemia nauplii*, molluscan meat, tubifex or egg custard mixed with vitamin and mineral mixture can be provided as larval feed. The above feed items contain 41-65% protein level is ideal for good survival rate. Organisms/particles ranging between 20 and 30 m are ideal for initial feeding. Size can be increased gradually to 50-60 m for one-week-old fry. Since there may be a differential growth in fry from the beginning, it is wise to proceed with the visual observation for selecting size of the feed. The fry of magur develop gregarious habit within a week and being nocturnal and photo-negative in nature, they normally congregate in the corners of the rearing container to avoid light during day time. However, they get fully dispersed all over the container during night and as soon as they are exposed to light, they move to corners in groups.

Since it is important to provide a congenial environment to larvae, the indoor rearing tanks are provided with continuous aeration and water exchange facilities. A stocking density of 2,000-3,000 larvae/m^2 is considered optimum for better growth and survival during indoor rearing.

Water management is an important aspect during rearing as aerial respiration in larvae commences after 10-11 days, hence, aeration must be provided to the larval rearing tanks by blowers. it is advisable to replenish 70-80% of water on a daily basis to maintain 10-15 cm depth and avoid accumulation of metabolites and unconsumed feed in the rearing containers which will otherwise pollute the environment, lead to oxygen depletion, disease incidence and mortality.

During high density of fry-rearing, increase of carbon dioxide in the environment may result in stress. The CO_2, NH_3, NH_4 concentration levels up to 15 ppm, 0.05 ppm, 0.25 ppm, respectively, may not affect larvae but it could be dangerous, if the level continues for a longer time. So vigorous aeration and frequent water exchange are required to get rid of this problem.

The larvae take 12-14 days in indoor rearing system to reach fry stage (10-20 mm/30-50 mg). Fry should be transferred immediately to well-prepared nursery or outdoor fingerling raising tanks. Delay in transferring fry reduces survival. Rectangular fibre glass cisterns/cement cisterns/earthen ponds may be used for this. Generally, advanced fry reared in pond condition do not show good survival due to natural mortality or predation; as at this stage fish does not have much capacity to escape from predators. Therefore, small-size cemented tanks of 10-20 m^2 are suitable for better survival and easy management. These cisterns are provided with 5-8 cm soil base and a water level of 25-30 cm. Single superphosphate (100 g) and filtered cowdung (2 kg) are also provided. The tanks are inoculated with plankton and advanced fry are stocked after 5-7 days of preparation. It can be provided with floating weeds like water-hyacinth for shade and shelter for fry. Fry are reared at a density of 200-300 fry/m^2, and fed with formulated feed containing 30-35% protein, grows to 0.8-1.0 g during 30-40 days of rearing.

The earthen ponds/stone pitched ponds/cemented tanks are suitable for grow-out culture of magur. Generally, high density of 50,000-70,000/ha is recommended for culture of this fish. Bigger sized seed (5-10 g) show good survival and growth during culture. The fishes are fed at 3-5% of their body weight with pelleted feed in feeding basket placed in different places of the pond.

Since the fish is air-breather, they normally come up to the water surface for gulping atmospheric oxygen. This kind of habit attracts birds for predation. Therefore, it is required to cover ponds with net to protect the catfishes. The fishes attain a marketable size of 100-120 g during a culture period of 7-8 months. Harvesting is done by complete dewatering and picking them manually from culture ponds. Production to the tune of 3-4 tonnes can be achieved from one hectare of water area.

The culture of magur got impetus by the standardization of its breeding and grow-out culture techniques at the Central Institute of Freshwater Aquaculture (CIFA), and by the funds provided by National Fisheries Development Board (NFDB) for its culture on priority basis The fish is currently propagated on a large scale along north- eastern regions mainly Asom. Twelve hatcheries are in place along the region, producing around 7 lakh seed/year. The ICAR through its Mega seed project at various Agricultural Universities and Institutes is also instrumental in making available its seed to farmers in different regions of the country.

Heteropneustes fossilis

Heteropneustes fossilis is commonly known as singhi or stinging catfish, has a great potentiality as a candidate species for aquaculture. The presence of accessory respiratory organ helps this to thrive well in shallow and derelict waters with poor oxygen. It contributes to about 15% of inland landings, mostly from eastern regions and some few south Indian states.

The species is found in ponds, ditches, bheels, swamps, marshes and muddy rivers and spawns during monsoon season. It does not show any spawning migration. Prolonged spawning behaviour is found with intermittent mating. Mating frequency is quicker initially, while longer time gap is seen in later part. It is polygamous in nature. It releases few numbers of eggs at each batch, which continues for 8-10 hr. The species has a short and distinct spawning period during July-August in eastern

India. It sometimes extends till September in West-Bengal and Asom region, which depends on the pattern of rainfall. Single peak of mature ova in ovaries indicates that fish spawns only once during breeding season.

Artificial seed production in domesticated singhi is possible through hormonal administration in hatchery. It matures at the age of one year. Successful breeding requires good brood husbandry. The broods collected from natural sources or culture ponds are maintained in small earthen or cement tanks for easy collection. High-density rearing during brood management is discouraged to avoid stress; 3-5 no./m^2 is followed to get healthy brood. Regular feeding of 30-35% protein containing diet is highly essential during brood rearing. Periodical manuring is advocated to ensure availability of natural food.

During monsoon, the broods are ready for spawning, and segregation for perspective spawner is essential for good breeding response. Females with soft and swollen belly are suitable for induced spawning. Maturity of eggs is checked by catheterization. Females possessing uniform size eggs are suitable for inducement, whereas irregular shape eggs indicate immaturity of female. The suitability of male is judged from red and swollen pointed genital papilla.

Singhi is bred by injecting 60 and 80 mg carp pituitary/kg of body weight, male and female fish respectively. A good mature female requires less dosage of pituitary (15-20 mg/kg body weight). Apart from hypophyzation, some synthetic hormones and steroids are used for its induced spawning; 0.6-0.9 ml Ovaprim, LHRHa 50 µg + pimozide 5 mg, 8 mg 17α-hydroxy-progesterone, 2 mg 17α, 20β-dihydroxy progesterone/kg body weight are suitable for successful spawning. Mammalian hormones like desoxycorticosteroid acetate (DOCA, 5 mg); human chorionic gonadotropin (hCG, 75-100 IU) and pregnant mare serum (PMS, 500 IU) are suitable to breed a 60-80 g female. Free-flowing eggs are found after 8-10 hr of injection, and females are suitable for stripping. Eggs are fertilized with sperm suspension made by macerating the testes with normal saline solution. The fecundity varies from 200 to350/ g fish weight. Eggs are greenish and 1.4-1.6 mm in diameter. Fertilized eggs are adhesive, demersal and spherical. The hatching of larvae takes place within 18-20 hr. No parental care is seen in nature. The newly hatched larvae are 2.5-2.7 mm in length. Yolk-sac gets absorbed at third day of their life and they show free but slow movement. The mouth is completely formed with prominent barbels and fins during this period. The body of the larvae looks darker and prefers to congregate at the edge of the rearing container. At this time the larvae require external feeding.

The larvae are very delicate and require good environment at this stage. The congenial water parameters required during this stage are dissolved oxygen 5-6 ppm, *p*H 6.5-7.5 and water temperature 26-28°C. The larvae prefer live feed during their initial rearing. Mixed zooplankton, Artemia nauplii and tubifex worms are good feed during larval rearing. Particle size varies from 10 to 20 µ during initial rearing period, which can be increased to 40-50 µ for 8-10 days old larvae. Chicken egg yolk mixed with condensed milk as well as chopped molluscan meat form a good feed for growing larvae, but less preferred compared to live feed. Regular cleaning of debris, uneaten feed and dead/weak larvae, is essential to keep the environment healthy. The larvae usually grow to a size of 12-15 mm during 14-15 days and are called fry.

After attaining fry stage, they are to be stocked either in earthen nursery or cement tanks to provide enough space and congenial environment. A higher mortality is encountered in earthen nursery compared to cement tanks due to natural predation as well as poor food searching ability of fry in former. Water height of rearing tanks, density of fry and suitable feed are some of the criteria, which contribute to survival rate. The air-breathing organ is developed at the age of 10-12 day. At this early stage, passing through a longer water column for natural air gulping may be stressful for the fry. Similarly, higher stocking may result stress and feed deprivation, resulting heterogeneous growth. Hence stocking 300-500 fry/m^2 is good for higher growth and survival. Minced trash fish or molluscan meat with rice-bran in equal proportion is good feed for singhi fry apart from compound feed made up of fish meal (20%), groundnut oil-cake (30%), soybean meal (10%), wheat flour (20%), rice bran (19.8%) and mineral mixture (0.1%).

Singhi has potentialities for mono- and polyculture. It is well compatible to carps, *Clarias* and *Anabas*. Its feeding habit indicates that it is omnivorous in nature, mostly feeds on protozoa, crustaceans, worms, insects, organic debris, algae and higher plants in natural environment. It also responds well to compound diet during grow-out culture. So, slaughter house waste, trash/dry fish, silkworm pupae, biogas slurry, oil-cake and rice bran are being used in various proportions as feed for singhi by the aqua farmers. Its production potentiality has been estimated to about 4-15 tonnes/ha during 4-12 months culture period under All India Coordinated Research Project (AICRP).

Pangasius pangasius

Pangasius pangasius (Pangas) is the only species of the genus *Pangasius* found in Indian water-bodies. It is mainly an estuarine habitant, displaying long migration from esturine to upper stretch of river. Biologists have reported two sub-species, *P. pangasius godavari* and *P. pangasius upiensis*. The populations of species from open waters have registered a decline in recent past. Pangas is a hardy species and can withstand wide fluctuations of temperature, salinity and turbidity. It feeds on offals, gastropods, lamellibranchs, insects, plankton and even vegetable matter. Because of the preference of *P. pangasius* towards molluscans, it exercises biological control of many species of helminthes causing human infestations and diseases; for which molluscans are known vectors.

Pangas is a seasonal spawner. It performs a long spawning migration in rivers. The male and female populations are almost equal during spawning run. Though spawning season is between June and August, it sometimes breeds early in the monsoon. Preferably, it breeds in flooded river and inundated areas as well as rocky belt of river. The larvae and fry are believed to be washed to downstream of tidal zone and spend a few years there. After maturing, they again migrate to freshwater for spawning. Spawning is reported in upper reaches of rivers and reservoirs.

Apart from natural spawning, *P. pangasius* spawns artificially by hypophysation.

Males mature at 2-3 years, and females take 2-3 years more to be gravid. Their ovaries appear like a sac, looking slight bulge at the anterior portion. The ova usually develop from the central column of the ovary radiating outwardly. The diameter of matured ova varies from 0.90 to 1.35 mm. The gonado-somatic index in female ranges between 16 and 26%, while it is 6-7% in milting male. Pangas males and females cannot be distinguished externally except during breeding season. Mature females show bulging abdomen with a wide genital opening. Similarly, males ooze milt freely with gentle pressure on abdomen like carps. During spawning induction, the female receives 5 mg carp pituitary extract/kg body weight as first dose, followed by subsequent dose of 10 mg/kg after 6 hr, while male receives a single dose of 3 mg/kg body weight. Synthetic hormones available in market (ovaprim/ovatide/wova-FH) can be used @ 1.0-1.5 ml/kg body weight to female, either in single or split doses. The success rate is observed to be low due to severe stress in female due to hormone injection, leading to mortality of the females. The response to stripping of female was found inconsistent with a wider range of hormone dose. The variations of ovulation rate ranged from 3.5 o19%, which indicated an uneven maturity between the females. Usually, the fertilization and hatching ranged from 55 to 88 and 19 to 74% respectively. Eggs are fertilized by stripping method, which are 1.07 mm in diameter. The eggs are sticky in nature. Egg clumping is generally observed during fertilization process. Incubation of clumped eggs may not hatch well. The eggs usually hatch after 22 hr of incubation and larvae are 4.13 mm in size. The yolk sac acting as stored feed for larvae gets absorbed during 3-4 days of life. The larvae show cannibalism behaviour during their early stage. The mouth remains opened during larval stage. The mobility of larvae during this stage is poor and they usually accumulate in few patches in the rearing tanks. So most of the larvae get injured and die during this delicate stage. The larvae accept well to live plankton during this phase. The larvae grow to 15-21 mm during 15-20 days hatchery rearing. At this stage the fish showed well acceptance to compound diet. These fry grew to 4.5-6.5 cm in length in 30 days of growing period resulting >50% survival during fingerling raising programme. It is required to rear the larvae at least 15-20 days in indoor system before releasing them to fingerling tanks to avoid mortality. The larvae of 5-10 days old, when released in fingerling raising tanks showed 0-30% survival. *P. pangasius* fingerlings of 16 g showed a growth rate of 25-35 g at a low density (1-1.5/m^2) during a two-month rearing period.

As it is a hardy species and withstands low oxygen level, it is suitable for culturing in sewage-fed ponds and low-lying fellow waters. Preliminary experiments indicated possibilities for culture of *P. pangasius* in carp ponds, where the fish is compatible with major carps and does not adversely affect their growth at very low rate of stocking. Higher population of pangas in carp pond adversely affects the growth of carp as it is a swift feeder. But in composite fish culture, ponds based on ecological niche approach, *Pangasius* is stocked to consume molluscs. Apart from natural food, it accepts well to compound pelleted feed. It grows swiftly at an early stage in nature as well as in ponds. This catfish attains 1.0-1.3 kg in second year and 3-4 kg during third year under pond culture, which is similar to the growth rate in natural waters.

Pangasius sutchi, one of the swift growing catfishes under Pangasidae family is widely cultured in Asian countries. Vietnam being the largest producer of this fish enjoys its dominance of supplying sutchi catfish and its fillet to European market. This exotic catfish entered to India through Bangladesh during mid 90's. There after a number of hatcheries have been developed in West Bengal and seed has been transported to different parts of India. As shrimp-farming activity in Andhra Pradesh was affected due to disease, many farmers of Andhra Pradesh diverted their farming activity towards this catfish culture. About 17,000 ha in Andhra Pradesh is under culture of this catfish. The catfish grows to 1-1.5 kg during one year. A minimum of 10-15 tonnes/ha is harvested due to culture of this fish. As this catfish has potentiality of tolerating higher density and production, the farmers are lured for higher production. But the bad impact on water bodies cannot be ignored due to intensive culture. Similarly, the aquaculture area for carp culture may be reduced due to upgrowing demand for its culture. So the Government of India has published guidelines for regulating introduction of *P. sutchi* in the country. The guidelines clearly suggested to keep an upper limit of production to a level of 20 tonnes/ha.

Wallago attu

Wallago attu is a member of family Siluridae. It is known as freshwater shark. It is one of the large catfishes, fished across rivers, reservoirs and in connected water sheets of Indian subcontinent. It is highly carnivorous and predatory in nature. Its rapid growth and high nutritional quality of flesh indicates its aquaculture potential. The decline in yield from the wild fisheries enlists this fish as an endangered species.

It breeds once in a year during monsoon in inundated marginal areas of rivers and reservoirs, and is also seen to breed in large tanks after heavy showers, followed by a run-off flow of water into the tanks. Severe knock by the male on the abdomen of female is seen during sex play. Vigorous mating activities remain for a while and end with the release of eggs. In nature, the released eggs are seen attached to substratum.

Captive breeding of domesticated *Wallago* is also possible. It matures in 2-3 years in confinement. Sexual dimorphism is prominent during breeding season. The female has bulging abdomen and round genital papilla. The male posses pointed genital papilla, and also free milt comes out by gentle pressure on its abdomen. The hypophysation of this fish indicated that injection of 5-6 and 16 mg carp pituitary extract/kg body weight, to male and female, respectively, in two split doses induces ovulation after 5-6 hr of second injection. The injection of a synthetic hormone like Ovaprim @ 0.3 ml and 0.5 ml/kg body weight to male and female, respectively, results successful induced spawning of the species, and broods are ready for stripping after 8-10 hr of post-injection. The eggs are highly adhesive, demersal, spherical and pale-yellow. The fully swollen *Wallago* eggs measure about 2.5-3.0 mm. The relative fecundity is 25-30/g fish weight and G.S.I is estimated at 0.030-0.040. Hatching occurred between 16 and18 hr after fertilization.

The hatchlings of *W. attu* are free swimmers and show cannibalistic behaviour. Larvae predate upon small to even equal size larvae among them. Higher stocking density during rearing initiates higher cannibalism, and lower stocking density enhances survival during its rearing. Providing shelters as hide-out does not help to reduce cannibalism like other cannibalistic fishes, and resulted in low survival. This is due to the predation tactic of the larvae. The larvae first swim along with the prey and then bite suddenly which is unpredictable and swim with prey in their mouth and completely swallow the prey. Further, the anatomical feature of incurved vomerine teeth facilitates predation and the prey cannot escape.

The larvae can be reared by feeding live zooplankton, molluscan meat, fish muscle or goat liver. Among the feeds, goat liver is superior for higher survival. But combination with live zooplankton, regular segregation of larger larvae and increased frequency of feeding enhance the survival during hatchery rearing. Feeding of compound feed along with zooplankton to larvae is seen to be effective. Compound feeds are made up of fish-meal, meat-meal or shrimp-meal along with groundnut oil cake, wheat flour, blackgram flour, cord liver oil, soybean oil, vitamin and minerals in different proportions. The red light during rearing enhances survival by suppressing cannibalism, while complete darkness enhances cannibalism among the larvae.

Ompok species

Ompok bimaculatus, *O. pabda* and *O. malabaricus* are the three medium-size catfishes under family Siluridae. They have great importance as food fish and have good demand among the consumers. The former two species are distributed in rivers, tanks, ponds and other water-bodies of Indian sub-continent, and *O. malabaricus* is confined to low lands and near the coast of Goa and Kerala. While *O. bimaculatus* and *O. malabaricus* attain a size of 40-50 cm in length, *O. pabda* attains a length of 17 cm.

The induced breeding of *O. pabda* has been undertaken in confinement with different inducing agents. Initial results indicate that matured pabda spawns by injecting carp pituitary extract as well as Ovaprim by stripping or natural hapa breeding after 6-8 hr of injection. Higher dose (3 ml/kg) of Ovaprim leads to success in release of eggs. Hatching takes place during 18-20 hr. The yolk-sac gets absorbed in three days. Larvae show preference for feed from fourth day. The larvae in nature thrive well on zooplankton and insect larvae during its initial phase. Mixed zooplankton serves as a good food, while rearing in laboratory, they grow about 10-15 mm during two weeks., and 40-50 mm during 5-6 weeks. Feed preferred is tubifex worm. Adults are carnivorous and predatory in habit, take mostly small fish, prawn, mussels, snail and insect larvae with no preference for pelleted feed. Pond culture of this fish indicates that fish fed with boiled chicken or goat viscera attain 24-26 g weight during 7-8 weeks.

Ompok bimaculatus is popularly known as butter-fish. The matured fish of 200-300 g can be induced to spawn in hatchery with a single intra-muscular injection of ovaprim @ 0.5 ml/kg to both sexes. After 5-6 hr of post-injection, the fish releases egg naturally with a high rate of fertilization. The number of eggs spawned varies from 3,000 to 4,000 in the size range of 300-350 g. The eggs measure about a size of 1.22 mm. Hatching occurs at 24-25 hr after spawning and hatchlings are 2.4-26 mm in total length. The larvae start feeding on 4th day. The larvae show preference for live zooplankton, chironomid larvae or boiled egg-yolk. Usual growth rate of the larvae is 10-15 mm during second week period. At this stage fish needs a change in feed for its rearing. Finely chopped beef liver is the best preferred feed at this stage. The fish generally grows to 3-4 g in weight during 5-6 weeks. Survival and growth rate of the species in pond culture depend upon the size of the seed and type of feed. By stocking seed of 3-4 g and fed with chicken viscera, growth of 30-100 g is obtained during 18-24 weeks culture period.

Ompok malabaricus is another potential culturable small catfish available in natural-water-bodies. The fish of both the sexes of 80-100 g size are perspective spanners and spawn during monsoon. It responds to different inducing agents, i.e. 90-110 mg carp pituitary extract, 0.3-0.7 ml ovaprim or ovatide, or 3,000-5,000 IU hCG/kg body weight. Females become ready for egg collection within 6-12 hr. Fecundity ranges between 4,000 and 5,000. The yolk-sac is absorbed in three days and larvae feed on zooplankton, chironomid larvae, mosquito-larvae or earthworm during their initial period. Larvae grow to fry stage (1-2 g size) during 2-3 weeks. At this stage fishes show preference of feed of animal origin, like intestine and liver of animals, etc. They also accept compound feed with over 50% ingredients from animal source. The growth rate is likely to be 3-5 g within four weeks of rearing and is suitable for pond stocking. The fishes grow to 80-90 g during 12-week culture.

Sperata species

Sperata seenghala and *S. aor* are two large bagrids, widely distributed in almost all principal river systems of Indian subcontinent. They have good growth potentiality and attain 3-6 feet (0.9-1.8 m), as recorded from open waters. These two species are considered as good candidate species for aquaculture due to their high growth and delicacy of flesh. No systematic programme on culture of the species has yet been undertaken, but some attempts of captive breeding and larval rearing have been documented during last few years.

The breeding season of the species varies in different regions of India. It is between March and May in peninsular rivers and between April and August in Indo-Gangetic rivers . The species exhibit parental care. They migrate in shoals during breeding period, for finding suitable site/ nests to lay eggs. Both male and female are involved. Nests/circular pits are constructed mostly in shallow area of river. The size of nests varies according to the size of brood. Usually three types of nest are seen like under-formed, abandoned and live-nests. A specified parental care is observed after spawning by male.

These fish mature in 3-4 years. Mature females have distended abdomen without genital papilla; papillary outgrowth is seen above urinogenital pore in males. The captive breeding of these species is scanty except *S. aor*. During hypophysation, both sexes of *S. aor* receive 12-20 mg carp pituitary/kg body weight in two split dosages at 4-6 hr interval. The fecundity has been estimated at 3,500-5,000/kg body weight. The intra-ovarian eggs are 1.0-1.2 mm. The fertilized eggs are free, demersal and 1.30-1.6 mm and hatch within 28-30 hr. The larvae are 3-4 mm and complete yolk-sac absorption takes place during 50 hr. *Sperata seenghala* is reported to have spawning fecundity between 9,000 and 10,000/single spawning in riverine condition, eggs are 1.0-1.2 mm and newly hatched larvae are 4 mm in total length.

Male, in nature, nurses the larvae of these fishes. The larvae feed on the slimy secretion on the abdomen of male. The larvae remain in the nest till they grow to 40-45 mm. Feeding a heterogeneous mixture of egg-yolk, vitamin mixture and skimmed milk-powder serves as the feed during larvae culture of *S. aor* in hatchery. Very low survival of 10-15% and growth of 1.5 g is observed during 30 days. The larvae culture of *S. seenghala* is also carried out by feeding chironomid egg-mass. *S. seenghala* performs well under monoculture in low density and grows to 700-800 g in more than two-year culture period.

Horabagrus species

Horabagrus brachysoma (yellow catfish or sun catfish) and *H. nigricollaris* are colourful species belonging to family Bagridae, endemic to the west flowing rivers of the Western Ghats. Both the species enjoy good market value as ornamental fish during their early life and as food fish during adult stage, especially the former which grows to 70-75 cm and 500 g and is preferred food fish of Kerala. Due to over-exploitation and habitat alteration, both the species have exhibited a drastic decline in natural water-bodies.

In nature these are present in river stretches having temperature range of 27-32°C, are omnivorous, feed on plant matters, crustaceans, insects, fish larvae and detritus and breed during monsoon months. Males mature early than the females. Captive breeding and milt cryopreservation technique of *H. brachysoma* have been standardized. The species does not exhibit sexual dimorphism, parental care and cannibalism like many other catfishes.

In captivity the female respond to 1 ml of ovaprim/ kg body weight in two doses at an interval of 10-12 hr and males to 0.5 ml/kg body weight . Milt and eggs can be stripped after 12-13 hr. The spawning fecundity ranges from 18,000 to19,000/100 g female. Fertilized eggs are 0.9-1.2 mm in size, demersal in nature, yellowish in colour and non-adhesive. Fertilized eggs hatch after 22 hr of incubation at a water temperature of 28-30°C. The newly hatched larvae were 4-5 mm in length and 12 mg in weight and take three days to absorb yolk-sac. The larvae are nocturnal; accept both natural feed like live mixed-zooplankton, chironomid and mosquito larvae and artificial compounded feed during its rearing. The fry attain fingerling size (30-40 g) during 30-40 days when stocked at 100-150 fry/m^2 in nursery tank.

Introduction of exotic catfish–implications

Apart from the native catfishes, there is a great concern with regard to entry of the African catfish, *Clarias gariepinus*, popularly known as Thai magur. Being highly predatory and cannibalistic in nature, its entry into natural waters has resulted in the decline of indigenous fish species. Besides, it does not have palatable flavour and taste compared to native magur and fetches much less price. It has gained wide popularity among fish farmers for its faster growth. However, farmers are unaware of the adverse implications of this catfish on the ecology. Its propagation is being discouraged.

Although packages of practices for seed production and grow-out culture are available for few catfishes like *C. batrachus, H. fossilis* and *H. brachysoma,* most other catfishes as discussed above have high potential for breeding and culture. Further, several other catfishes like *Rita rita, Clarias dussumieri, Silonia silondia, Bagarius bagarius* etc. and small catfishes like *Mystus* spp., *Clupisoma garua* and *H. nigricollaris* etc. possess huge market demand, and can also be considered as potential species for culture. Thus, it is necessary to have a greater thrust on research on all relevant aspects involving seed production and culture.

18. Freshwater Prawn Breeding and Culture

Freshwater prawns have become an important component of global aquaculture both in terms of quantity and value. Freshwater prawns belong to the family Palaemonidae and majority of the commercially important freshwater prawns belong to the genus *Macrobrachium*. There are more than 200 species of *Macrobrachium* recorded from different parts of the world, of which nearly 30 species are found in India. Among the commercially important freshwater prawns of India, three species, namely *Macrobrachium rosenbergii, M. malcolmsonii* and *M. gangeticum,* are suitable for aquaculture.

Global status of freshwater prawn farming

Most of present global production is from only three species, viz. *M. rosenbergii, M. nipponense* and *M. malcolmsonii*. While *M. rosenbergii* is cultured in many countries, *M. nipponense* is only cultured in China and *M. malcolmsonii* only in India. In 2007 the total global production of all the three freshwater prawns together was nearly 409,771 tonnes with a value of over US$1.65 billion. Asia contributed more than 99% of farmed production of freshwater prawns. The global production of giant river prawn *M. rosenbergii* stood at 213,274 tonnes (52% of the total production) in 2007 with a value of over US$ 943million and that of *M. nipponense* stood at 192,397 tonnes (46.95%) with a value of US$ 698 million (*Source:* FAO, 2009). Total production of *M. malcolmsonii* in 2007 was 4,100 tonnes with a value of US$ 11.9 million. China is the top producer of freshwater prawns with a production of 124,520 tonnes of *M. rosenbergii* and 192,397 tonnes of *M. nipponense* in 2007. India is the second largest producer with a production 27,262 tonnes of *M. rosenbergii* and 4,100 tonnes of *M. malcolmsonii*. Thailand ranked third with a production 27,650 tonnes of *M. rosenbergii*. Other major producers are Bangladesh (23,240 tonnes) and Taiwan (8,316 tonnes).

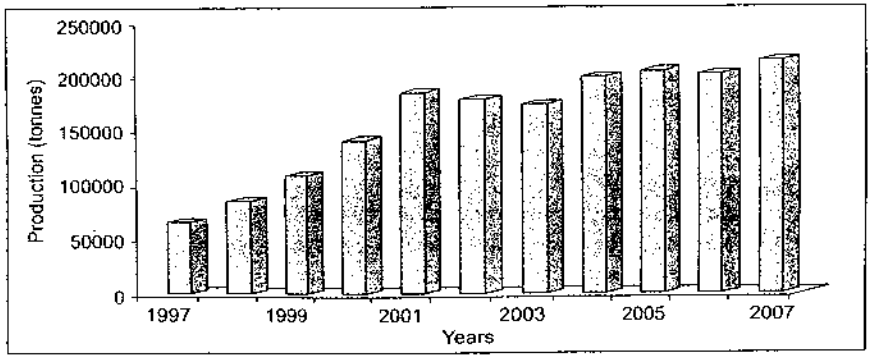


Fig 18.1. Global aquaculture production of *Macrobrachium rosenbergii*

Among the cultivable freshwater prawns, *M. rosenbergii*, the giant river prawn completely dominated the commercial freshwater prawn culture in all producing countries except China owing to its superior cultivable attributes such as very fast growth rate, high market demand, hardiness, euryhaline nature and its compatibility to grow with cultivable fin-fishes such as Indian major carps, tilapia and catfishes. It also has good consumer preference and domestic as well as export market demand. There has been a rapid global expansion in farming of *M. rosenbergii* from 1995 till 2001. The average annual expansion rate of freshwater prawn farming between 1992 and 2001 was over 29%. However, 83% of the expansion during the decade occurred due to the phenomenal increase in the production in China. From 2002 till 2007 the global production of *M. rosenbergii* from culture stabilized near 2 00,000 tonnes (Fig. 18.1). Eleven nations produced more than 100 tonnes in 2007. USA, Brazil and Dominican Republic are the only three countries outside Asia that produced more than 100 tonnes (Table 18.1).

Table 18.1. Major global producers of farmed *Macrobrachium rosenbergii* in 2006 and 2007

Country	Aquaculture production (tonnes)	
	2006	2007
China	108,592	124,520
India	30,115	27,262
Thailand	29,500	27,650
Bangladesh	20,810	23,240
China, Taiwan	9,878	8,316
Indonesia	1,199	989
Brazil	373	230
Iran	270	258
USA	218	200
Malaysia	194	246
Dominican Republic	110	110

Source: FAO 2009.

Status of freshwater prawn farming in India

India is the second largest producer of freshwater prawns with a production of 31,362 tonnes in 2007. *M. rosenbergii* contributed the bulk of the production

Table 18.2. State-wise details of *Macrobrachium rosenbergii* culture in India

State	2006-07			2007-08		
	Area under culture (ha)	Production (tonnes)	Productivity (tonnes/ ha/year)	Area under culture (ha)	Production (tonnes)	Productivity (tonnes/ ha/year)
Andhra Pradesh	17,335	24,056	1.39	38,819	19,887	0.51
West Bengal	4,744	4,471	0.94	4,744	4,516	0.95
Odisha	3,591	856	0.24	3,786	915	0.24
Tamil Nadu	324	449	1.39	404	376	0.93
Kerala	1,211	88	0.07	2,171	539	0.25
Karnataka	90	46	0.51	265	180	0.68
Maharashtra	2,711	115	0.04	15.6	6.95	0.45
Gujarat	34	34	1.00	0.70	0.45	0.64
Production from reservoirs					808	
Production from village ponds					32	
Total	30,042	30,115	1.00	50,206	27,262	0.54

Source: MPEDA.

(27,262 tonnes; 86.9%) and rest of the production (4,100 tonnes; 13.1%) was contributed by *M. malcolmsonii*. The estimated value of freshwater prawns during 2007-08 was ₹ 436 crore. Table 18.2 gives the state-wise details of production of *M. rosenbergii*.

The farmed production of *M. rosenbergii* in India has shown phenomenal increase since mid-nineties till 2005, the production increasing from less than 178 tonnes in 1996 to 42,870 tonnes in 2005 (*Source:* FAO, 2008). In 2006, however, farmed production showed a 30% decrease to 30,115 tonnes (Table 18.2, Fig. 18.2) due to reduction in productivity and disease outbreaks in major production areas. In 2007 also, the trend continued and the production showed a 9.5% decrease to 27,262 tonnes (Table 18.2). During 2007-08, though there was an increase of 20,160 ha (67%) in culture area the production showed a 9.5% reduction (2,853 tonnes) compared to the previous year. The productivity showed a steep fall from 1,000 kg/ha during 2006-07 to 540 kg/ha/year in 2007-08.

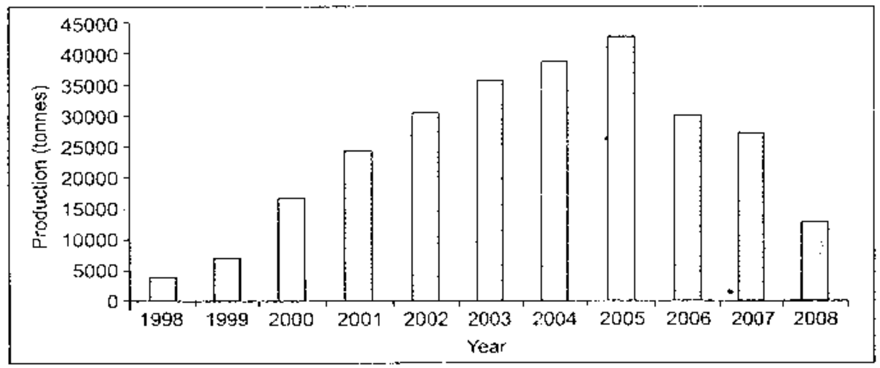


Fig 18.2. Aquaculture production of *Macrobrachium rosenbergii* in India

Andhra Pradesh is the top producer with a production of 19,887 tonnes in 2007-08 and accounted for 73% of the production. The production of scampi as well as its productivity in Andhra Pradesh declined in 2007-08 when compared to the previous year. The major problems faced by the scampi farmers were the poor growth rate of prawns in ponds and disease outbreaks. West Bengal is the second largest producer of scampi with a production of 4,516 tonnes in 2007-08. The production showed a marginal increase of 45 tonnes when compared to 2006-07.

Odisha is the third largest producer with a production of 915 tonnes in 2007-08. Kerala emerged as the fourth largest producer in 2007-08 with a production of 539 tonnes. Both production and productivity in Kerala showed a dramatic increase in 2007-08. The production from Tamil Nadu (fifth largest producer) declined from 449 tonnes in 2006-07 to 376 tonnes in 2007-08. Karnataka on the other hand showed an increase in production from 46 tonnes of the previous year to 180 tonnes in 2007-08.

Though overall production trend of scampi in India in 2007-08 revealed a declining trend when compared to 2006-07 it could be seen from Tables 18.2 and 18.3 that the declining trend in production was mainly restricted to Andhra Pradesh and Tamil Nadu only. Since Andhra Pradesh produces the bulk of production the declining trend in production in Andhra Pradesh is reflected in the overall production trend. The main reason for the decline in production was the reduction in productivity from 1,390 kg/ha/year in 2006-07 to 510 kg/ha/year in 2007-08. Besides this, there are several other factors that contributed to the decrease in production in Andhra Pradesh. Disease outbreaks, increase in input cost, fluctuating farm-gate prices and low export demand due to global recession are some of the them.

Biology of cultivable freshwater prawns

Distribution and habit

Macrobrachium rosenbergii, the most important cultured species, is widely distributed in the Indo-Pacific region including India, Thailand, Malaysia, Singapore, Philippines, North-Guano. The distribution of the species is limited to the estuarine and freshwater zones of river mouths and backwaters with temperature usually ranging from 25 to 34°C and salinity (0-20 ppt). In India, it is distributed in almost all the river systems in both the east and west coast such as Hooghly estuarine system (West Bengal), Mahanadi river system (Odisha), Krishna and Godavari river system (Andhra Pradesh), Cauvery river system (Tamil Nadu), Cochin backwater system (Kerala), and in Narmada and Tapti river system (Gujarat).

Macrobrachium malcolmsonii, the second largest cultivable species has a restricted distribution when compared to *M. rosenbergii.* It is endemic to Indian subcontinent and is found in Pakistan, India, Bangladesh and Myanmar. In India it is extensively distributed in all major river systems draining into Bay of Bengal like Ganga, Brahmaputra, Mahanadi, Godavari, Krishna and Cauvery. It is found in the entire 1,400 km stretch of the river Godavari. This species unlike *M. rosenbergii* has thus extended its distribution to the uppermost reaches of the rivers. An extensive survey of all the river systems of Odisha revealed that juveniles of this species are available in all the river systems of Odisha, viz. Mahanadi, Brahmani, Baitarani, Rushikulya, Budhabalanga and Subarnarekha. It breeds during May/August in the Hooghly-Matlah estuary and larvae are available at Naihati, Nawabganj and Dumurdaha during September and post-larvae at Dumurdaha and Balagarh during August and September. In river Godavari, juveniles of the size range 15-30 mm occur at four anicuts, viz. Dowlaiswaram, Bobbrlanka, Maddurlanka and Vijjeswaram and also across all the locks and weirs of the irrigation canal system of the river. In Tamil Nadu, juveniles are available in anicut, weirs and regulators of Jaderpalayam, Grand anicut, Rajagiri, Thirukattapalli, Omanpuliyur, Padupoolanudu, Pinnalore, Maduranthakam, Thenneri and Sembarampakkam. Below the Mettur Dam in river Cauvery also young occur in the post-monsoon months. Availability of juveniles in few stretches of Chambal, Parvati and Kali Sindh rivers in Rajasthan and in Fenny and Gumti rivers in Tripura has been reported recently. *M. gangeticum*, the third largest cultivable freshwater prawn species, has even restricted distribution. It is distributed in the upper and middle stretches of

river Ganga and Brahmaputra draining through Uttar Pradesh, Bihar, West Bengal, and Asom in India.

Food and feeding

Freshwater prawns are bottom feeders and omnivore and feeds on benthic macro and micro flora and fauna. They also feed on detritus. Gut content analysis of the prawns revealed variety of feed particles such as insect and crustacean remains, molluscan remains, filamentous algae, sand and detritus. Prawns accept a variety of food items ranging from grains, worms, flesh pieces of molluscs, crustaceans and fish. They locate their food mostly by touch with feelers. The first pair of cheliped is the chief organs of food capture and is assisted by the second pair. Freshly moulted soft-shelled prawns are highly vulnerable to predation by other prawns..

Growth

In freshwater prawns growth is not a continuous process because of the hard exoskeletal covering of the body and appendages. Visible growth takes place only at the time or immediately after molting. Frequency of molting depends on the age, quality and quantity of food consumed and environmental parameters. Growth rate is characterized by sexually dimorphic patterns and highly variable rates. Both the males and females grow at similar rates until the females begin to divert much energy intake into ovarian development and less into growth whereas males continue to grow at the same rate. Due to this, under culture conditions males grows faster than females and attain marketable size earlier than females.

Breeding characteristics

Majority of large freshwater prawns migrate downstream to estuarine reaches for purposes of hatching their young. The breeding season of the different species vary in different habitats but coincides with the onset of monsoon in most cases. In the three large and cultivable freshwater prawns discussed earlier the sexes are separate and male has proportionately larger head than female. The second legs (pereiopods) in male are usually long, robust when compared to that of female. The abdominal space is also narrower in male than female. Female has broad abdominal space to serve as brood chamber for incubating eggs. The genital pores are located between the bases of fifth and the third walking legs in case of males and females respectively. The secondary sexual character of the species is the presence of appendix masculina in males, a rod like process situated on the endopodite of the second pleopod. The male and female of *M. rosenbergii* attain first maturity at about 140-150 mm in total length in nature, however, under culture conditions even much smaller size female prawns (<120 mm) are also found carrying eggs. First sexual maturity in *M. malcolmsonii* is reported to occur at a much smaller size of 41-70 mm total length. In *M. gangeticum* first sexual maturity was recorded at 85 mm total length.

The fecundity of *M. rosenbergii* from different riverine systems in India is reported to be varying from 100,000 to 160,000 on the south-west coast of India; 7,000 to 111,400 on the Hooghly estuary and 20,880 to 1,62,078 on the Kolleru Lake. The fecundity of *M. malcolmsonii* females ranging from 40 mm to 164 mm from river Godavari ranged from 3,000 to 63,000. In the same species from Lake Kolleru, the fecundity varied from 12,556 to 77,420 in females ranging from 83 to 165 mm and the minimum size at first sexual maturity in females was observed at 81-85 mm size group. In *M. gangeticum* from Ganga river system, the fecundity ranged from 1,997 to 81,978. The size at first sexual maturity in females has been observed at about 60 mm in total length. In the Ganga river system the females outnumbered the males in all the months and the sex ratio was 1:1.4.

The sexually mature females of freshwater prawns complete the pre-spawning molt before mating. Mating occurs between a hard-shelled male and soft-shelled female. During mating, male deposit sperms as gelatinous mass on the ventral thoracic region of female between the walking legs. Spawning occurs in about 5-6 hr after mating. During spawning the eggs gets fertilized with the sperms deposited on the ventral thoracic region of the female. Fertilization is external and takes place as soon as the eggs are extruded. The fertilized eggs adhere to the ovigerous setae of the first four pairs of pleopods of the female. The female continuously incubates the eggs and provides sufficient aeration for the development of embryo by constantly fanning the pleopods. The incubation period (embryonic period) lasts from 17 to 21 days in *M. rosenbergii* 14-15 days in *M. malcolmsonii* and 12-13 days in *M. gangeticum*. Mating and incubation take place in freshwater. However, the newly hatched larvae require brackishwater for their survival and growth.

The fertilized eggs are slightly elliptical and measures 0.6-0.7 mm on long axis in *M. rosenbergii*. The colour of freshly spawned egg is bright orange in *M. rosenbergii*, light yellow in *M. malcolmsonii* and *M. gangeticum*. The colour of the eggs changes as the embryonic development progresses and one or two days before hatching the colour changes to grey. Larvae of freshwater prawn are called zoea. Larvae are planktonic in habit and are active swimmers, positively phototactic and attracted by light. The early larvae (Stage I to V) exhibit schooling behaviour and move in swarms. This gregarious habit of larvae gradually disappears from VI stage onwards; the larvae remain mostly dispersed and swim at the surface and in mid-column but settle down to bottom during molting time. The larvae actively feed on small zooplankton available in the natural habitat and undergo metamorphosis after completion of its development and transforms into post-larvae. The post-larvae is a miniature prawn and resembles juveniles except for the under development of body parts and can survive in freshwater. Post-larvae are benthic in habit and feeds on benthic flora and fauna.

In *M. rosenbergii* there are 11 distinct zoeal stages and the larval duration is 23-32 days depending on the temperature (28-32°C), food and the water quality. In *M. malcolmsonii* and *M. gangeticum* also 11 larval stages are reported, though duration of larval cycle varies, 40 to 60 days in *M. malcolmsonii* and 22-32 days in *M. gangeticum*. Table 18.3 provides the list of larval stages of *M. rosenbergii* and their distinguishing characters.

Table 18.3. Larval stages of *M. rosenbergii* and their distinguishing characters

Larval stage	Age (days)	Total length (mm)	Identifying characters
I	1	1.92	Sessile eyes
II	2	1.99	Stalked eyes
III	3-4	2.14	Presence of uropod
IV	4-6	2.50	Two dorsal rostral teeth, uropod biramous with setae
V	8-10	2.80	Telson narrow and elongated (rectangular)
VI	11-12	3.75	Pleopod buds present on the ventral abdominal region
VII	13-17	4.06	Pleopods biramous, but without setae
VIII	14-19	4.68	Pleopods fully formed, biramous with setae
IX	15-22	6.07	Endopods of pleopods with appendices internae
X	17-24	7.05	Three or four dorsal rostral teeth
XI	19-26	7.73	Teeth on half of the dorsal margin of rostrum
PL	21-32	7.69	Teeth on both dorsal and ventral side of rostrum

Breeding and seed production under controlled conditions

Pioneering efforts towards the breeding of the giant freshwater prawn, *M. rosenbergii* were made by S W Ling in Malaysia in 1969, followed by T Fujimura in Hawaii. Fujimura has developed mass rearing and culturing technique of the larvae. The larval rearing technique initially developed by Fujimura and Okamota is called green water technique. This technique was based on rearing larvae in a medium of mixed plankton predominated by *Chlorella* species. The phytoplankton helps in removing the toxic byproducts and wastes such as ammonia and nitrite, but does not provide any nutrition to the larvae. This technique though simple and less labour-intensive was not widely adopted due to low post-larval output (5-25/litre) and occasional collapse of the system due to difficulties in maintaining the stable environment. Subsequently, another larval rearing technique was developed by AQUACOP in 1976, which is known as clear water technique. In this technique larval rearing media is clear without any plankton culture. Larvae are stocked at very high density (200-400 larvae/litre). Most important rearing parameters (temperature, light, food, water quality) are kept under constant and strict control and independent from the ambient environmental conditions. The advantage of this technique was higher post larval out put (>40/litre). There is no need of maintenance of algal culture. However this system has the disadvantage of high initial cost and investment and wastage of water when static system is used. Due to high post-larval out put clear water technique is widely used in most of the countries.

In India, the Central Inland Fisheries Research Institute (CIFRI), Barrackpore was the first to develop the technique of breeding *M. rosenbergii*, *M. malcolmsonii*, *M. lamarrei* and *M. gangeticum*. Success was achieved in rearing all the larval stages of *M. rosenbergii* at Kakinada in Andhra Pradesh in 1975 using laboratory aged offshore water as a medium. The rearing period was 38-42 days with 15 to 25% zoeal survival.

Subsequently a technique of mass rearing of larvae of *M. rosenbergii* was developed which helped in successfully production of post larvae on a commercial level at Azhikode, Kerala. The Central Institute of Fisheries Education (CIFE) also developed a mass rearing technique of *M. rosenbergii* larvae. Commercial production of scampi seed using synthetic brackishwater was also carried out in Kerala. No significant differences could be observed in the percentage survival production, moulting frequency, duration and growth between synthetic larval media and natural media.

The Central Institute of Freshwater Aquaculture (CIFA), Bhubaneshwar has developed and standardized a semi-closed two phase clear water larval rearing technique of *M. rosenbergii* involving high density rearing (200-300/litre) of early larvae (I-V/VI zoea), followed by low density rearing of advanced larvae (V/VI) till metamorphosis. During the first phase the larvae were fed exclusively with *Artemia* nauplii and in the second phase the larvae were fed with wet diet (egg custard, mussel meat) in addition to *Artemia* nauplii. Average survival in the first phase is >80% and 60% in the second phase. Average post-larval output is 40/litre. Bhattacharya and Saha in 2003 reported commercial scale seed production of *M. rosenbergii* using constituted brackishwater in the land locked state Tripura. The larvae were reared in a two-phase system. Early larvae are reared in high density (400-500/litre) and later larvae were reared in low density (43-106/litre). Post-larval output ranged from 40 to 45/litre.

Hatchery production of seed

Hatchery is a self-contained life support system producing good quality seed in commercial scale. A freshwater prawn hatchery can be established in a location where good quality seawater and freshwater are available and the temperature remains above 24°C at least for eight months. The following section gives an account of the important factors that need to be kept in mind while establishing a freshwater prawn hatchery.

Site selection: A careful selection of site is essential for the successful operation of hatcheries in a particular locality. It is also equally important to consider the following essential factors to ensure success in achieving the production target.

Climatic conditions: Temperature is a key environmental factor for successful operation of hatchery for at least 8-10 months in a year. Since the optimum temperature range required during seed production of scampi is 28-31°C, the hatchery should be located in tropical and sub-tropical zones. Besides temperature, the rainfall, sunlight, humidity and wind speed of the site are also considered before selecting a site for hatchery. Areas vulnerable to natural calamities such as floods, cyclones and earthquakes are not suitable for hatchery construction.

Topography: Assessment of transects, evaluation of slope and determination of most economic ways of constructing hatchery are important. Flat or slightly sloping lands are good and slope close to 2% minimizes the construction cost for broodstock ponds associated with hatcheries. In addition, gravity water-filling and draining out water from the pond becomes cost-effective and easy.

Soil: The soils that provide support for biological activities and have water retention capacity apart from structural stability are considered suitable.

Availability of adequate freshwater and seawater: The hatchery site should be preferably near the coastal areas. Seawater used in the hatchery should be free from pollutants. Seawater can be pumped from the surface water of the sea or estuary during high tide phases through an *in-situ* filter bed. Saltwater also can be drawn from underground source by sinking deep tube-well fitted with suitable pumps. Freshwater can be drawn from a river/canal source or from shallow underground water source. Un-contaminated freshwater is essential for hatchery operations mainly for broodstock management, for diluting seawater (larval medium) and for general use.

Good physical access to the site: The site should have good all-weather approach road for facilitating easy and low-cost transportation of construction material, pond and hatchery inputs and marketing of seeds.

Uninterrupted power supply: Adequate power supply is the most important consideration during hatchery activity. Therefore the site should have good proximity to uninterrupted power supply.

Hatchery facilities: A functional hatchery should have the following essential components.

Water storage tanks: Huge quantity of brackishwater (salinity- 12 ‰) is normally required in a hatchery with open water system. Larval rearing medium of about 12 times volume of the total rearing tanks are required for each seed production cycle. The hatchery should have the storage facility at least three times the volume of its larval rearing tanks to allow for adequate water storage treatment and mixing time for preparation of larval medium. The storage tanks should be of 50-100 tonnes capacity each and constructed in an elevated position. All the tanks should be made of cement concrete and provided with inlet and outlets. The roof of the tanks may be covered with fibro-cement corrugated sheets. Water should flow by gravity through pipes to different tanks. Separate rectangular cement tanks are preferred for storing seawater, freshwater and mixed water/brackish water. The capacity of these tanks depends on the seed production capacity of the hatchery. They should be constructed at a higher level than the rearing tanks to facilitate gravitation flow.

Larval rearing tanks: Larval rearing can be carried out in tanks made of brick and cement, concrete or fibreglass reinforced plastic etc. Tanks can be circular, rectangular or cylindrico-conical in shape. Usually rectangular tanks of 2 to 10 tonnes capacity are preferred. All right angled corners should be rounded off to facilitate cleaning and to prevent algal growth. The tank bottom should be preferably 'U' shaped and have sufficient slope so as to drain completely. The interior of the tanks should be painted with several layers of dark coloured pure epoxy resin to prevent leaching of toxic chemicals and to provide smooth surface. The number of larval rearing tanks depends on the hatchery capacity.

Post-larval holding tanks: Rectangular cement or concrete tanks of 10 to 20 tonnes capacity are suitable for holding post-larvae till disposal. The number of such tanks depends on the hatchery capacity.

Broodstock holding tanks: Rectangular cement or concrete tanks of 20 tonnes capacity are suitable for holding berried females till they release the larvae. One ort for such tanks is enough. Post-larval holding tanks also can function as broodstock holding tank.

***Artemia* cyst hatching tanks:** Cylindrico-conical fibreglass reinforced plastic tanks of 100 to 500 litres capacity with a central drain and water control structure can be used as *Artemia* cyst hatching tanks.

Aeration and water supply system: A ring type of main aeration distribution should be provided with a suitable PVC pipe running throughout the hatchery connected to a blower (Roots type). Reducers can be used to connect the main PVC pipe to supply aeration to every tank. A spare blower in working condition is required on rotation basis. The water system is simple and all the storage tanks should be sufficiently elevated above the larval rearing tanks so that brackishwater can be introduced by gravity. All the tanks should be connected with suitable pipes with regulators. The waste water from the hatchery should be discharged away from supply wells and other water source.

Electricity: A dependable power source with a standby generator of suitable capacity is essential.

Hatchery building: The area of the building or a shed depends on the capacity of the hatchery. The roof is covered with fibre-cement corrugated sheets provided with translucent material in a row to allow passage of sunlight. The larval rearing tanks are placed on the eastern side, where sunlight falls directly.

Two-phase clear water larval rearing technology of *M. rosenbergii*

The operational details of the two-phase clear water larval rearing technology developed and standardized by the CIFA for larval rearing of *M. rosenbergii* is provided here.

Healthy mother prawns (bearing grey eggs on their pleopods; ~60 g) are selected from the broodstock pond/tank and disinfected with 0.3 ppm copper sulphate or 30 ppm formalin for 30 min under aeration. Mother prawns are then stocked @100-150 g/m^2 (2-3 nos of ~ 60 g female) in brackish water (salinity-5 ppt) and reared till hatching. The prawns are fed daily with fish/prawn meat or formulated pellet diet @ 5% of their biomass. Tanks are checked daily for appearance of larvae. Once hatching occurs it may continue for 24-48 hr. The spent females are then removed from the tank and released back to the broodstock pond. As the newly hatched larvae require brackish water (10-12 ppt) for survival and growth the salinity of the larval rearing medium is increased to 10-12 ppt and the rearing is continued in the same tank or the larvae are estimated and stocked in another tank for first phase rearing. In the first phase the larvae (Stage I or Zoea I) are stocked at high density (300 larvae/litre). About 80% of the medium is exchanged daily with fresh medium of identical salinity. The larvae are reared for about 10 days in this phase. In the second phase, the advanced larvae are stocked in larger tanks with a greater surface area @ 50-60/litre and reared till metamorphosis. About 60-80% of the medium is exchanged every day. The freshly hatched *Artemia* nauplii are given as live food to the prawn larvae, 4-5 times/day in the early stages (stages II to V or VI) and later, once during late evening in combination

with wet larval feed which is usually given during day time. The brine shrimp nauplii are fed to the prawn larvae @ 5 to 50 nauplii/larva/day. Wet larval feed (egg custard, minced fish /mollusc flesh; protein > 50%) is fed @ 50-200 mg/larva/day depending on the larval stage. The wet feed is given during day time. Feeding commence in the early morning and continue till late afternoon at an interval of one hour with constant supervision. The larval rearing tanks are cleaned daily by siphoning off excess food particles and metabolic waste from the bottom of the tank. This is done after stopping aeration, in the evening hours before exchange of water and introduction of live food (*Artemia* nauplii). Water quality in a hatchery deteriorates due to accumulation of metabolites and decomposition of unutilized feed. Daily water exchange @ 60-80% is the most efficient method of management of water quality. Daily monitoring of temperature, salinity, *p*H and dissolved oxygen levels are essential to maintain the water quality at optimum levels. The optimum ranges of water quality parameters for successful seed production are given in Table 18.4.

Table 18.4. Optimum range of water quality parameters for successful seed production of *Macrobrachium rosenbergii*

Water quality parameter	Optimum range
Water temperature	28-31°C
Salinity	10-12 ‰
*p*H	7.5-8.5
Dissolved oxygen	>5 ppm
Nitrite	< 0.1 ppm
Ammonia (NH_3-N)	< 0.1 ppm

Larvae normally take one to four days to go through each larval stage. Healthy larvae swim at the water surface up to stage V and feed actively and unhealthy larvae accumulate at the tank bottom. Larval metamorphosis is non-synchronous in *M. rosenbergii*. The first post-larva is usually observed 20 days after hatching, normally between 22 and 26 days (at 28-32°C) and 90% larvae metamorphose within next 10 days. The post-larva is characterized by a radial change in behaviour and appearance. For the first time they resemble miniature adult prawns and swim freely and crawl or cling to the tank surface. The post-larval production normally ranges between 35 and 45/litre and the cycle lasts for 32-40 days. The pre and post-metamorphosis stages are critical and mortalities due to cannibalism can be minimized by providing a variety of substrata. Molluscan shells, plastic or nylon net materials are fabricated into vertical multistage tier system or horizontal frames with close webbing and placed in the tank for the post-larvae to settle. The post-larvae are gradually acclimatized to freshwater. After acclimatization to freshwater the post-larvae (seed) are weaned from larval diet and fed on formulated pellet diet in fine crumble form 3-4 times a day @ 100% of the biomass/day. The post-larvae are stocked @ 2,000-5,000/m^2. After a week or fortnight the post-larvae are suitable for stocking in grow-out ponds. Survival rates decrease if the seed are grown for more than two weeks under crowded conditions in the larval rearing tanks.

Larval rearing techniques of *M. malcolmsonii*

Controlled breeding and rearing of this species was successfully completed during 1971 in Maharashtra. Breeding and large-scale seed production of the species was achieved in 18-20‰ saline media using air lift re-circulatory system, besides a post-larval output of 25/litre and the duration of rearing ranged from 39 to 80 days. Brine shrimp nauplii coupled with egg custard and mussel meat were found to be suitable larval diet. Successful seed production of *M. malcolmsonii* in synthetic seawater was also reported. The CIFA has developed and standardized an airlift recirculatory larval rearing system for the seed production of *M. malcolmsonii*. The salinity requirement of larval rearing was 18-20 ppt and the duration of rearing ranged from 40-60 days at 28-31°C.

Larval rearing techniques of *M. gangeticum*

Successful breeding and seed production of this species was achieved in synthetic saline water (3.5‰) and in 10-18‰ brackishwater. The larval diet consisted of egg powder, fish powder, green water + a feed supplement for infants (Probofex) and Orabolin (anabolic protein preparation). The survival rate was however, very low. The broodstock were collected from wild (river Ganga near Patna, Bihar and river Padma, Lalgola, West Bengal) and transported to the laboratory. The egg bearing females were transferred to 5‰ media till hatching. Embryonic period was 12-13 days. Larvae were reared following a clear water technique using an airlift biofilter recirculatory system. *Artemia* nauplii and egg custard were used as the main feed. First zoea passed through 18 moults and 11 larval stages before metamorphosing to post-larvae. First post-larvae appeared on 22nd day after hatching. The seed output (nos/l) ranged from 2.2 to 9.3/litre.

Culture of freshwater prawns

Freshwater prawns could be cultured in almost all freshwater bodies such as ponds, tanks, canals, cages, pens and raceways. They can also be grown in low saline brackish water areas (salinity <7 ppt) and can be cultured either alone (mono culture) or in combination with carps, tilapia and chanos (polyculture). It is also a suitable species for incorporation in the rice-fish system of culture. Based on management practices applied freshwater prawn monoculture can be extensive, semi-intensive or intensive. According to the intensity of the system, production may range from below 500 kg/ha/year to in excess of 5,000 kg/ha/year. Extensive systems are stocked at low densities (0.5-2/m^2) using post-larvae or juveniles. There is no control of water quality nor the growth or mortality of prawns and supplementary feeding is usually not provided. The intervention of farmer is generally restricted to stocking and harvesting but may include fertilization of ponds to improve natural productivity. Productivity is generally below 500 kg/ha/year. Semi-intensive freshwater prawn culture has been the most commonly used system throughout the world. Semi-intensive culture is carried out in earthen ponds using a number of management approaches. Stocking is done with post-larvae or juveniles in densities that vary from 3-20/m^2. Fertilization and supplemental feeds are applied. Predators and competitors are controlled and water quality, prawn health and growth are monitored. Operating costs and production are variable according to the level of technology and place. Yields vary from 500 to 5,000 kg/ha /year. Intensive system includes culture in small earth or concrete ponds (up to 0.2 ha), provided with high water exchange and continuous aeration. Stocking rate is >20/m^2. Production is totally dependent on formulated feed. Predators and competitors are eliminated and all water parameters are strictly controlled. Costs are high and productivity can exceed >5 tonnes/ha/year. However, this system is not compatible with the biological characteristics of *M. rosenbergii*.

Nursery rearing

Nursery phase of rearing is an intermediate step between hatchery and grow-out rearing of freshwater prawn. It involves rearing of the 10-15-day-old delicate post-larvae in well-prepared earthen ponds or cement tanks for period ranging from 45 to 60 days till they grow to juveniles (1-2 g). Stocking larger juvenile prawns of more than 1 g has shown to yield good and predictable production than those stocking post larvae. Hence, it is always recommended to involve a nursery phase prior to grow-out. Preparation and management of nursery pond are similar to that of grow-out ponds described below, except that hide-outs are not provided in nursery ponds. Aquatic plants with dense root system such as *Eichhornia* sp. may be used to cover 5-10% of the pond surface area to provide shade and shelter to the post-larvae. Care should be taken to keep the weeds inside a PVC frame or bamboo frame to avoid its spreading in the pond.

Site selection: Proper site selection is essential to obtain best results from freshwater prawn culture operations. The selected site should have the following major qualities:

- Supply of good quality, pollution-free freshwater or brackish water (< 7 ppt) for at least six months
- Soil having good water retention capacity
- Warm climate for nearly 6-8 months (temperature: > 24°C).

Pond construction: Ponds should be preferably embankment ponds that can be fully drained by gravity. Important points to be remembered while construction of ponds is provided below:

- Ponds should have an inlet and an outlet
- Pond bottom should have a gradient slope towards the outlet (1:200)
- Ponds bunds should have a suitable slope (1:2, 1:3)
- A water control structure should be installed (wooden/concrete) to aid water exchange
- Pond size : 0.2-2 ha (0.2-0.5 ha)
- Shape : Rectangular ponds with their long axis oriented in the direction of prevailing wind is most suitable.
- Soil : Clay loam, sandy loam
- Depth : 2 m

Water quality: Water used for culture should be free from toxic chemicals and pollutants. The optimum range of few most important water quality parameters for fresh water prawn culture are given below:

Salinity	: Freshwater/low saline (< 7ppt)
Temperature	: 26-31°C

*p*H - 7.0-8.5
Total hardness - 40-100 mg/litre
Dissolved oxygen - > 4 ppm
Calcium - 50-100 mg/litre

Culture operation: The important steps involved in culture operation are provided below:

- Eradication of competitors and predators
- Liming
- Fertilization
- Provision of hide-outs
- Stocking and feeding
- Monitoring and management of water quality parameters
- Sampling of prawns for growth measurement
- Disease control
- Harvesting

Eradication of competitors and predators: In a newly constructed pond this step may not be necessary as there may be nothing to eradicate, but in old ponds all the unwanted species such as predatory fishes and weed fishes including aquatic vegetation should be removed. The best way to eradicate predators and competitors is by drying the pond and exposing the bottom to sunlight until cracks develop. Drying and exposing the pond bottom to sunlight also kill all pathogenic microbes and oxidize the pond bottom. Tilling the dry pond bottom helps in removing the trapped gases and helps in obtaining better production.

Those ponds that cannot be drained should be applied with poison to kill all predatory fishes and other animals. Poisons of plant origin such as mahua oilcake, tea seed cake or derris root powder are preferred as they also would act as fertilizer after a period of time. Bleaching powder and urea @ 300 and 100 kg/ha, respectively, can also be applied to kill all predatory species in the pond. For this first urea and after 18 hr bleaching powder has to be applied. Before applying the poison water level should be lowered as much as possible. Stocking with prawn seed can be done two weeks after eradication of pests and predators. The dose levels of commonly used piscicidal agents are given in Table 18.5.

Table 18.5. Levels of commonly used piscicidal agents

Name	Quantity/ha-m	Toxicity retention
Mahua oilcake	2,500 kg	Three weeks
Derris root powder	150-200 kg	Three weeks
Bleaching powder	350 kg	One week
Bleaching powder and urea	175 kg and 100 kg	One week

Liming: Application of lime is an important step in pond preparation for prawn grow-out. The common liming agents are agricultural lime, slaked lime, dolomite or quick lime. Liming is done after drying the pond by spreading the lime uniformly on the pond bottom. In undrainable pond it should be applied by reducing the water level to a minimum possible level. Rate of application vary with the soil *p*H. Ponds having a soil *p*H of above 6 is applied @ 200-250 kg/ha of agricultural lime. Lime has many beneficial properties. It helps to correct the *p*H, increases the buffering capacity of the water and disinfects the pond bottom. Lime is also act as a source of calcium, which is very important for exoskeleton formation of prawns.

Fertilization: After liming water is let into the pond to a height of 1-2 feet (30-60 cm) and manure or fertilizers are applied for the development of plankton. Fertilizer helps in the development of phytoplankton cover, which in turn, prevents the development of benthic algae and rooted vegetation in the ponds. Phytoplankton also purifies the water and produce oxygen during daytime. It also helps in the development of bottom living animals (benthic micro and macro fauna) on which prawn feed. Cowdung @1,000 kg/ha or poultry manure @ 500 kg/ha and super phosphate @100 kg/ha may be applied to initiate a plankton bloom. After the initial manuring water can be filled up to the desired level (4-5 feet or 1.21-1.52 m).

Provision of hide-out: Prawn needs shelter during moulting to avoid predation by other prawns. Hence it is desirable to provide hide-outs and more surface area for clinging. Cut branches of trees, nylon screen, earthen pipes etc can be used as hide-outs. They may be placed in different pre-determined places as we may have to remove them during sampling and partial harvesting.

Stocking the pond: After preparing the ponds and laying the hide-outs the ponds can be stocked with post-larvae or juveniles as the case may be. Prior to stocking the pond water quality should be tested and necessary correction should be made. Seed can be collected from natural collections or from hatchery. Natural seed may contain unwanted species and its availability is restricted. It is advisable to collect healthy and active seed (15-20 mm size) from a reputed hatchery.

Characteristics of healthy seed are:

- Body translucent and glossy with no whitish patches on abdominal portion
- Active, fast moving, cling to the sides of the container when a circular water current is created in the container
- No fouling on body or appendages
- No black or brown spots on the body

On arrival to the farm site care should be taken to acclimatise the post-larvae to the temperature of the pond by floating the transport bags in the ponds for 15 min. After opening the bag some pond water should be allowed into the container and slowly the post-larvae should be released into the pond. Early morning and late evening are considered ideal period for stocking the seed. The density of stocking depends on the market size desired and intensity of management. A stocking rate of 3-4/m^2 is desirable. In polyculture stocking density of prawn is reduced to 50% and compatible carp species such catla, rohu, silver carp and grass carp are also stocked @ 3,000/ha.

Feed and feeding: Freshwater prawns are omnivorous in feeding habit and in nature they feed on aquatic insects and larvae, algae, small molluscs, worms, crustaceans etc. Farmers in most regions of the world relies farm made feed rather than commercial feed for freshwater prawn grow-out. Ingredients for farm made feed reported from around the world include corn silage, fresh leaves, silkworm pupae, beef liver, peeled sweet potatoes, turnip greens, carrot tops, dry sugar cane yeast, marine shrimp meal, fish meal, meat meal, squid waste etc. In India the feed ingredients consists of rice bran, broken rice, groundnut oil-cake, tapioca powder, fish meal, tubificid worms or pila (apple snail) meat. Replacing fish meal in diets of *M. rosenbergii* with a mixture of clam meat, shrimp waste and silk worm pupae did not have any negative effect on the growth of prawns. Use of different feeds and feeding strategies has also produced differences in the level of benthic prey organisms. It is observed that prawns feed on macro-invertebrate populations, particularly when nutritionally deficient diets are provided.

Feeding rates ranged from 25% of the biomass during the first two months and gradually reducing to 2% of prawn biomass towards the end of the culture period. Feed is usually spread around the periphery of the pond in the shallow areas. Check trays kept in different areas of the pond will help in deciding the quantum of feed per day. Under culture conditions freshwater prawns are found to readily accept formulated pellet diets, feed mixture in form of balls or powdered feeds, chopped butchery waste, oilcakes etc. Artificial feeds have been used with the main objective of providing supplementary feed in addition to natural food. Studies have shown that *M. rosenbergii* is able to utilize a higher proportion of plant-derived protein. Successful commercial farming of freshwater prawns, especially semi-intensive culture must involves supplementary feeding. Pellet diets are preferred to maintain the water quality in the ponds. Experiments have shown that these prawns require 25-30% protein and 8-10% fat in their diet.

Since the prawns are more active during night feeding should be done during late evening and early morning. Daily observation regarding the consumption of feed and pond water should be the main criteria for deciding the quantum of feeding. Feed rate should be revised once every three weeks. To arrive at the revised feed rate sampling of prawns using cast net may be done and based on the average weight of prawns the new feeding rate may be calculated. Weight dependent feeding rates are provided in Table 18.6.

Table 18.6. Weight-dependent feeding rates for *Macrobrachium rosenbergii*

Prawn weight (g)	Percentage of body weight fed daily
<1	>25
1-2	20
2-5	12
5-10	10
10-15	8
15-20	6
20-25	5
25-30	4
>30	3

Water quality management: Visibility and colour of the pond water gives an idea about the health of the pond ecosystem. In unproductive ponds the visibility can be up to the bottom and this will lead to the growth of bottom algae that adversely affect the growth and survival of prawns. In highly blooming and or turbid ponds the visibility will be only a few centimetres (<10 cm). Such ponds face the danger of dissolved oxygen depletion and mortality of stock. Visibility should be maintained in the range of 30-40 cm to avoid water quality deterioration.

Daily monitoring of critical water quality parameters such as dissolved oxygen and *p*H is essential to prevent any loss of stock due to poor water quality. Loss of prawn stock is usually associated with low dissolved oxygen in the pond. Therefore it

is essential to maintain dissolved oxygen at optimum levels (>4 ppm) at all times. Dissolved oxygen should be monitored during early morning. On cloudy days and rainy days depletion of oxygen may occur during daytime also. Phytoplankton bloom and decaying waste material are the main reasons for dissolved oxygen depletion usually seen in prawn ponds. When the oxygen level in pond water is critically low prawns come to the surface along the periphery of the pond. Immediate remedial actions such as water exchange (with good quality water) or operation of pond aerators should be taken to avoid mortality of stock.

Stock monitoring: Regular sampling of prawns with cast nets or small mesh seine nets at 3-4 week interval is essential to assess the growth of the prawns. Feed rate is revised after every sampling based on the body weight and estimated biomass. The growth rate and survival of a population of prawn depends on many factors including stocking density, predation, feed and temperature. Since these factors are highly-site and operator-specific it is very difficult to predict the growth rate.

Health management: In freshwater prawn grow-out diseases are usually found to be linked to poor rearing conditions (over-feeding, water shortage, silting). Bacteria and fungus are the most common disease causing organisms. Loss of appendages, brown or black coloration of the exoskeleton, fouling on the body are some of the symptoms seen in diseased prawns. If disease symptoms are noted water should be replaced. Water quality should be tested to determine the dissolved oxygen, *p*H and ammonia levels and necessary correction should be made.

White muscle virus disease caused by noda virus has caused large-scale mortality of post-larval prawns in some of the southern states of the country. Screening of post-larvae using latest available diagnostic kits is hence recommended when seed is sourced from the affected areas.

Following good rearing practice mentioned below will help to avoid diseases to a great extent:

- Use good quality seed sourced from a reputed hatchery and avoid high density stocking
- Use good quality pellet feed, monitor feeding using check trays and avoid over-feeding
- Dry out the ponds between production cycles so that the beds can be re-oxidized
- Exchange water (renewing 30-50% of the pond volume in 24 hr) which rinses the pond and induces moulting
- Regularly monitor the water quality, especially dissolved oxygen.

Harvesting: Good quality post-larvae stocked at moderate density of 3-4/m^2 and fed with good quality pellet diet at sufficient quantities will grow to an average size 50-60 g in 6-8 months. Because of the heterogeneous growth pattern of *Macrobrachium rosenbergii*, individual weight is highly variable for individuals of the same age. Periodic harvesting is always preferred. After four months larger prawns (>50 g) are removed by using a seine net of suitable mesh size. Selective harvesting should continue once every 3-4 weeks for another 3-4 months and finally the pond may be harvested by complete draining.

Processing and marketing: Processing yield (tail weight percentage) of freshwater prawns (<50%) is less than that of marine shrimps (> 60%) and decreases with the increase in size of the prawn and is better for females than males. Prawns are sold either head-on or headless. Sometimes they are sold live also. Ice chilled uncooked prawns have a short shelf-life (3 days) before they become mushy. 'Kill chilling' by dipping prawns in iced water prior to blanching at 65°C for 15-20 seconds before icing for transport to market significantly improves quality.

Usually harvested prawns are washed and iced immediately to prevent quality deterioration. In the processing plants they are removed from ice and washed again. The washed and drained prawns are weighed and sent for de-heading. The iced headless prawns are then size-graded by weight. After size grading the product then goes for further value-addition according to the requirement of the buyer, such as 'peeled and deveined' (PD), 'peeled deveined tail-on' (PDTO). Most of the freshwater prawns from India are exported in a headless tail on style. The prawns are either bulk frozen or individually quick frozen at –40°C. Packed material is finally stored at –20°C. Removal of head and intensive washing decreases initial microbial load and improves the post-storage quality of prawns which can be stored frozen for up to six months with almost no deterioration of flavour.

Europe is the most significant marine export destination, accounting for over 35% of India's seafood exports, followed by Japan with 16%, China 14% and the US with 13%. The major markets for frozen freshwater prawns from India are USA, European Union and UAE.

Management strategies to reduce differential growth

Heterogeneous individual growth rate (HIG) is the most prominent characteristic of cultured populations of freshwater prawns. In a pond stocked with a single batch of post larvae some animals have been observed to grow 10-15 times faster than others. Size heterogeneity is more prominent in males and has been shown to arise from group interactions within populations rather than differences in genetic growth potential. The management of stocking and harvesting in freshwater prawn ponds is greatly complicated by the HIG.

At present there are mostly two management strategies commonly adopted by the researchers and farmers, i.e. batch culture and continuous culture. In simple batch culture a single stocking is followed by a single total harvest at the end of the grow-out period and then the pond is prepared for the next cycle. This approach produces a wide size range among the prawns and since nearly 30% of the population will be below the market size the farmer suffers due to low market price of small prawns. The multiple harvest approach involves a single stocking and multiple harvesting. Cull harvesting is the most widely adopted method to increase yield in freshwater prawn culture. Partial harvesting of the bigger prawns (>50 g) using seine net with a mesh size of 3.8-5 cm once every 3-4 weeks from fifth month of culture is widely adopted.

Continuous culture technique, on the other hand, involves multiple stocking and multiple harvesting for 3-5 years. This approach takes advantage of year-round water supply and growing season. In Taiwan operations are reported to produce annual yields of more than 4,000 kg/ha when good pond management is applied.

A modified batch system was used in a commercial farm in Puerto Rico. In this system nursed post larvae (1 g), which were reared at 296,000/ha for 30-45 days, are stocked into and reared in advanced nursery (AN) ponds for 2-3 months. From the AN ponds 10-15 g advanced juveniles are removed by seine harvesting for transfer to production ponds. From production ponds 35-100 g prawns are regularly harvested. Yields during the harvest phase can exceed 3,400 kg/ha/year. This system is believed to be suitable for locations where there is a continuous water supply and optimum temperature. To reduce size heterogeneity at harvest and increase overall yields, the possibility of culturing mono sex populations and size graded sub-populations has been investigated.

Culture practices of freshwater prawns

Mixed culture or polyculture: *M. rosenbergii* has been successfully reared in polyculture with tilapia in Columbia and Puerto Rico and with channel catfish in the USA and with carps in India. In Panama, polyculture of prawns with tilapia and grass carp were shown to be potentially more profitable than prawn monoculture. Culture trials conducted in India have been in combination of *M. malcolmsonii* and Indian major carps and minor carps. Observations indicate that with any combination of major carps, the growth rate and survival of prawns were higher. Many studies where *Macrobrachium* are added at low stocking densities to systems rearing a variety of fish such as tilapia and carp have shown that food competition does not occur. The juvenile or adult prawns do not prey upon or otherwise injure fish. Other advantages of polyculture are that there is often higher survival and less marked size hierarchy among prawn population than that is found in intensive monoculture. The presence of fish also improved water quality and prevented undesirable algal blooms. The fecal matter of fish might be an added source of direct or indirect food for the prawns which are known to be detritus feeders or scavengers. Good survival of prawns in polyculture are obtained when juveniles of 2-5 g are used rather than postlarvae.

The population structure and weight distribution of *M. rosenbergii* was studied in earthen ponds in polyculture with common carp, tilapia, grass carp and silver carp. The prawns were stocked at 1, 2, 3 or 4/m^2 and reared for 110 days. The authors have reported a significant increase in the total prawn yield for each increment in stocking density. However, much of the total yield at highest density consisted of small sized prawns. The most profitable density was 2/m^2. In Israel typical stocking rates for prawn in polyculture have been given as 0.5-1.5/m^2 combined with 1.2/m^2 of fish (carp and tilapia) with resulting yields of 6,700-10,100 kg fish/ha/crop and 220-780 kg/ha/crop of large prawns. The profitability and technological acceptability of fish-prawn polyculture were evaluated in farmer's ponds in Bangladesh. *M. rosenbergii* and five carp species (Chinese and Indian) were stocked at 12,000-18,000/ha and 8,500/ha respectively. After 10 months of rearing the yield of prawn varied from 162 to 428 kg/ha while fish production ranged from 4,604 to 5,821 kg/ha. In mixed culture in India, maximum production of *M. malcolmsonii* at 30,000/ha stocking rate was 327 kg of prawns and 2,084 kg of fish. Comparsion of monoculture, bispecies culture and composite culture of *M. rosenbergii* and *M. malcolmsonii* in small earthen ponds (500-1,000 m^2) showed better yield and survival of prawns in composite culture with a total average yield of 529.8 kg/ha of prawns and 2,599.4 kg/ ha of carps in six months.

Monosex culture: Monosex culture of all male populations of *M. rosenbergii* is being practised in Andhra Pradesh, Tamil Nadu and Karnataka with encouraging results. All male culture is reported to have several advantages over the conventional culture of mixed sex populations such as improved growth rate, better feed conversion ratio, shorter crop period, greater individual prawn size and yield and less proportion of runts and improved net profit by about 60%.

In practice the post-larvae are reared for 45-60 days to juveniles of 3-5 g in nursery ponds and are then harvested by small mesh seine net or cast net and segregated sex-wise by skilled labourers. These labourers can segregate 3,000-5,000 juveniles/day with an accuracy of 95%. The male prawns are stocked for grow-out at low stocking densities of 1-1.5 juveniles/m^2. Female prawns are sometimes stocked in separate ponds or are sold at low prices. After 90-120 days of grow-out partial harvest by seining is carried out to remove the larger size prawns (>70 g). Subsequently seining is carried out once every month for the next two months completing the culture in 6-8 months (including the nursery phase). Feed conversion ratio in all male culture has been comparatively low (1.2:1) than for mixed culture (1.9:1). Manual segregation of males and females which depends on skilled labourers and the stress associated with the procedure resulting in low survival during grow-out in some cases are still the problem areas in this culture practice.

Rotational paddy-cum-prawn culture

Rotational paddy-cum-prawn culture is another culture practice being carried out mainly in Kerala that has vast stretches of waterlogged areas (Kuttanad areas and Kole Wet lands) where paddy cultivation is carried out for four months during November-February. During the rest of the year these areas remain waterlogged and kept unused. These areas are suitable for freshwater prawn culture and since 2002 efforts were made for farming of freshwater prawns with carps in these wet lands during off season. Though the farming practice in Kuttanad areas and Kole lands are similar, Kuttanad areas suffer from water quality problems due to soil acidity. Presently, nearly 1,200 ha is under fish and prawn farming following a rotational farming practice of paddy-cum-prawn culture. The culture is extensive in nature with low stocking densities of 10,000-20,000/ha with supplementary feeding and <5,000/ha without supplementary feeding. In most cases, prawns are not provided with any commercial feed during grow-out and they rely solely on the natural food available in the field. Fast growing fishes such as grass carp, silver carp, catla, rohu or common carp are also stocked @100-1,200/ha. The culture operations start after harvesting of paddy during February-March. The field is filled with water up to a level of 0.5-1.0 m from the supply canal and held for 10-15 days allowing the left-over paddy stumps to completely decay. This water is then pumped out before filling again. Eradication of predators and competitors is carried out mainly in the secondary canals inside the field. About 10% of the total area is demarcated for nursery rearing by erecting earthen bunds or net pens. Standard practices are followed for preparing the nursery for stocking. The required numbers of post-larvae are stocked in the nursery in March/April and are fed twice daily with commercial diet (30% crude protein). Nursery period ranges from 30 to 40 days after which the juveniles are released to the entire field by raising the water level in the nursery and grow-out field. Harvesting is usually carried out by October-November by pumping of water from the field to the canals using axial flow pump and normally take 15-30 day to complete draining of the field depending on the area. Most of the stock is caught by gill net set at various parts of the field. When the water level recedes the fishes and prawns move towards the inner canals or into the deeper areas of the field and are caught by drag net. Average marketable prawn size of 70 g is obtained in 6-8 months giving an overall yield of 500-750 kg/ha with supplementary feeding and 150-250 kg/ha without supplementary feeding. The individual weight of fishes range from 1.5 to 2.0 kg and the production range from 125 to 200 kg/ha. In addition to the stocked fish a major portion of the catch is composed of wild fish such as *Puntius* spp., *Anabas testudineaus* and *Channa* spp.

Prawn culture in saline soils

In India approximately 8.7 million ha of land is salt-affected and are distributed in almost all parts of India including Punjab, Haryana, Uttar Pradesh, Rajasthan, Maharashtra, Karnataka and Kerala. These areas have become unsuitable for agriculture and lying fallow. Attempts made to culture freshwater prawn in the saline-affected soils in Punjab and Haryana had given encouraging results. Ponds were constructed and salinity level was reduced to less than 10 ppt using canal water. Polyculture of *M. rosenbergii* with Indian major carps has yielded a production of 270 kg of prawn and 2,655 kg of fish from 1.8 ha of saline area. Monoculture trials have reported production ranging from 872-2,282 kg/ha in a culture period of 6-7 months.

Prawn culture in reservoirs

India has plenty of small, medium and few very large reservoirs constructed primarily for irrigation and hydro-electric power generation. In many of the reservoirs cultivable fishes are being stocked to enhance production. Culture trials of freshwater prawn *M. rosenbergii* have been carried out successfully in two of the reservoirs in Kerala in Palakkad District (Meenkara and Malampuzha). Post-larvae were stocked and held for six months before harvesting. Harvesting of prawns from the reservoirs is difficult due to the vastness of the area and great depth. Gill nets made of monofilament of mesh size 12, 15, and 20 cm are used for catching both fish and prawns. Gill nets are set near the water surface and prawns starts appearing in the net 6-7 months after stocking. In Meenkara reservoir, the post larvae were stocked at a very low density of 467/ha and the average production was 4.62 kg/ha with a mean initial size of 250 g. In the Malampuzha reservoir prawns attained an average weight of 500 g in six months. The large-sized prawns caught from the reservoirs fetch a premium price and are in great demand.

Package of practices for nursery and grow-out culture of freshwater prawns is described here.

Nursery rearing

- In the nursery phase hatchery produced post-larvae are reared in well-prepared earthen nurseries (0.02-0.1 ha) @ 20-50/m^2 for 30-60 days
- Prior to initiation of culture the ponds should be well prepared. The pond bunds/dykes should be repaired and strengthened
- Ponds should be drained and the pond bottom should be exposed to sun for a week to kill all predatory fishes
- Lime may be applied as per the requirement after testing the soil *p*H. It can be applied @ 200 kg/ha if the soil *p*H is between 6.5 and 7.0. Higher dose will be required if the soil *p*H values are low
- Water should be let into the pond up to two feet using nylon mesh nets to prevent the entry of eggs and larvae of predatory fishes and competitors
- Pond should be fertilized with organic manure and super phosphate as per the requirement
- As a general guide for ponds with medium nutrient content fertilizers may be applied at the following rate: raw cowdung @ 5 tonnes/ha/crop, urea @ 200 kg/ha/crop and super phosphate @ 300 kg/ha/crop
- After a week of fertilization the pond should be filled up to 4 feet (1.2 m) water level
- Transparency of pond water should be checked after 2-3 days using a seechi-disk
- Once the transparency reaches 30-35 cm ponds can be stocked with post-larvae during early morning or late evening hours
- Post-larvae (8-10 mg) may be fed with pellet diet (crude protein- 35%; lipid- 8%) in crumble form @ 100% of the biomass during the first fortnight
- In the absence of pellet diet a mixture of groundnut oil-cake (powdered) and rice bran may be given as feed
- The feed should be broadcasted in the pond twice daily preferably in the morning and in the late evenings
- In nursery ponds approximately 10% of the pond surface may be covered with floating weeds with dense root system such as *Eichhornia* sp. to improve the survival rate of post-larvae. The weeds should be kept inside a PVC frame or bamboo frame to avoid their spreading in the pond
- Aeration should be provided from an aerator for ~6-8 hr/day
- A fortnight after stocking sampling of post-larvae may be done to observe the growth using cast net or fry net
- The feed quantity may be increased as the post larvae grow in size
- Nursery rearing may be done for 30-60 days
- During nursery rearing water temperature may be checked twice daily. *p*H, dissolved oxygen, transparency and depth may be checked once every week and to be maintained in optimum ranges

- Loss of water due to seepage and evaporation should be compensated by water addition at least once every fortnight
- At the end of the nursery rearing the juveniles (>1.0 g) can be collected by dewatering the pond

Grow-out culture

The nursed juveniles (~1 g) harvested from the nurseries are stocked in well prepared earthen production ponds @ 3/m^2. The prawns are fed daily with formulated pellet diet (2-3 mm size) @ 10% of the biomass initially and then reduced to 3% of the biomass at the end of the culture period. Daily monitoring of critical water quality parameters such as dissolved oxygen, *p*H, and temperature is essential to prevent any loss of stock due to poor water quality. Phytoplankton bloom and decaying waste material are the main reasons for dissolved oxygen depletion usually seen in prawn ponds. Regular monthly sampling with cast nets or small mesh seine nets is done to assess growth of the prawns. After four months prawns that achieved marketable size (>40 g) are removed by using a seine net of suitable mesh size. Selective harvesting should continue once every 3-4 weeks for another 3-4 months and finally the pond can be harvested by complete draining. The steps involved in culture operation are given here:

Pond management during grow-out culture operation

- The grow-out pond has to be prepared prior to stocking in the same way as done for nursery pond. Hide-outs in the form of earthen or other pipes, old tyres, bamboo pieces etc. should be provided in the pond (1,000-1,500 /ha).
- Once the pond is ready for stocking the juveniles collected from the nursery pond are stocked in grow-out pond for further growth. The preferred stocking density in grow-out pond is 30,000/ha.
- The prawns should be fed with a pellet diet @ 20% of biomass/day to start with and the rate should be reduced as the prawns grow.
- The feed should be broadcasted in the pond as mentioned above. Check trays 3-4 nos may be kept in different corners of the pond to check the consumption of food.
- During the course of culture the water quality need to be maintained at optimum levels for good growth by routine monitoring of temperature, *p*H, alkalinity, transparency and dissolved oxygen content. Pond depth should be preferably maintained at four feet.
- Major problems that may arise during culture are mortality of the stock due to low dissolved oxygen in the pond water.
- Heavy plankton bloom, very low water level and lack of water exchange leads to low dissolved oxygen levels. Continuous rainy/cloudy days precipitate this problem. Immediate water exchange or aeration of ponds during night hours may be done to prevent this problem.
- Development of bottom algae due to high transparency of water is another problem during monoculture of prawns. To avoid this problem always maintain transparency in 30-40 cm range by frequent fertilization.

Table 18.7. Economics of *Macrobrachium rosenbergii* hatchery (10 million post-larvae/annum)

Item	Amount (₹ in lakh)
Expenditure fixed capital	
Hatchery site (2,000 m^2 @ ₹ 75/m^2)	1.50
Hatchery building (20 m x 15 m)	15.00
Construction of office (80 m^2 for seed packing / laboratory/store)	2.40
Larval rearing tanks (RCC, 20 nos of 2.5 MT)	3.00
PL rearing tanks (RCC, 12 nos of 12MT)	2.90
Water storage tanks	
• Seawater tank (10 m x 2.5 m x 2 m)	1.50
• Freshwater tank (8 m x 2.5 m x 2 m)	1.20
• Mixed water tank (8 m x 2.5 m x 2 m, 2 nos)	2.60
Artemia hatching unit (200 litres, 6 nos)	0.10
Air blowers (2 nos, 5 HP)	1.00
Generator (15 KVA) with accessories	1.50
Water pumps (3 nos for freshwater, seawater and mixed water)	0.35
Water supply/aeration connection	0.50
Electrification	0.50
Bore-well	0.75
Miscellaneous expenditure	0.60
Sub-total	35.40
Variable cost (for five cycle)	
Cost of broodstock	0.50
Cost of transportation of seawater	1.00
Larval feed (*Artemia* cysts 200 kg @ ₹ 4,000/kg and formulated diets)	4.00
Chemicals/medicines	0.50
Electricity	2.00
Wages (1 manpower @ ₹ 8,000/month and 12 labourers @ ₹ 2,000/ month for 1 year)	3.84
Miscellaneous expenditure	1.00
Sub-total	12.84
Total costs	
Variable cost for five cycles	12.84
Depreciation of fixed capital at 15% level	5.31
Interest on fixed capital @ 15% per annum	5.31
Grand Total	23.46
Sale of PL 8 million seed at 80% of hatchery capacity @ of ₹500/1,000 nos)	40.00
Net income (gross income – total cost)	16.54

- Regular partial harvesting/cull harvesting of bigger size specimens using a large mesh cast net from the third month of culture will increase the yield and improve the growth of smaller prawns. It should continue once every 3-4 weeks till final harvesting.
- After six months of grow-out culture the ponds may be harvested by complete draining. Prior to harvesting arrangements for marketing the prawns should be made.
- Prawns after harvesting should be cleaned in freshwater and should be packed in ice layer by layer to avoid loss of quality.

Strategies for the development of freshwater prawn culture

Freshwater prawn farming is mostly restricted to maritime states even though it

could be taken up in many of the inland states. Lack of adequate seed availability is the major reason for the slow pace of development of freshwater prawn farming in inland states. Even among maritime states, Andhra Pradesh accounts for bulk of the production (>70%). Such concentration of culture areas in limited areas has its own problems. Any serious disease outbreak or any environmental problem restricted to those areas will seriously affect the overall production. Therefore horizontal expansion is essential for the bright future of the freshwater prawn farming. As India has vast resources to undertake freshwater prawn farming we need to establish this farming practice in new potential areas (Tables 18.7, 18.8). Gujarat, Maharashtra, Odisha, Bihar, Chhattisgarh, Jharkhand have very good potential for freshwater prawn culture. These states have the advantage of natural seed availability, suitable climate and plenty of natural resources. The following strategies will help in further development of freshwater prawn culture in these states.

- Strengthening of training and extension system to create awareness about the improved farming techniques to get good production
- Setting up of a seed bank in few of the major carp seed rearing units that are nearer to major airport for rearing post-larvae for 30-45 days prior to supplying to farmers
- Creation of infrastructure facilities such as cold chains and ice factories for the post-harvest storage
- Development of marketing channels to assure the farmers reasonable price for the produce
- Awareness campaign to increase the domestic demand of freshwater prawns
- Promotion of polyculture of scampi with IMC

Table 18. 8. Economics of giant freshwater prawn culture
[Unit economics for a production of 1.2 tonnes /ha/crop (8 months)]

Item	Cost (₹)
Expenditure variable cost	
Pond lease value	30,000
Prawn seed @30,000/ha @ ₹ 500 /1,000 nos	15,000
Fertilizer (cowdung) @ ₹ 500/tonnes @ 5 tonnes/ha/crop	2,500
Lime @ 600 kg/ha/crop@ ₹ 8/kg	4800
Feed (pellet form)@ 1.5 tonnes/crop @₹ 40/kg	60,000
Wages@ ₹ 3 000 /month for eight months	24,000
Energy (electricity/ fuel)	5,000
Harvesting charges	5,000
Miscellaneous expenses	2,000
Sub-total	148,300
Total cost	
Variable cost	148,300
Interest on variable cost @15% /eight months	14,830
Grand total	163,130
Gross income	
Total production (kg)	1,200 kg
Farm-gate price (head on)	200
Gross income	240,000
Net income	76,870

- Evaluation of the feasibility of establishing a freshwater prawn hatchery in the saline-affected areas
- Aquaculture to be provided status at par with agriculture by all concerned states so that the farmers would get the same facilities that are provided to agri-farmers
- Create awareness about the technology
- Provide training to farmers on scientific prawn farming techniques
- Set up hatcheries near the coastal areas

India has enormous freshwater and low saline brackish water resources that can be utilized for freshwater prawn farming. Three of the large cultivable freshwater prawns *M. rosenbergii, M. malcolmsonii* and *M. gangeticum* are native species and the first two are available in most of the river systems in the country. Already one million ha are under carp culture in the country and with little additional inputs these can be utilized for polyculture of freshwater prawns increasing income of farmers. Technology for both hatchery and grow-out culture of three large species of freshwater prawns *M. rosenbergii, M. malcolmsonii* and *M. gangeticum* is available and nearly 71 commercial hatcheries producing approximately 200 million seed of *M. rosenbergii* are in operation in the country. Feed mills producing quality feed for the freshwater prawns are also available. Majority of the freshwater prawn farms are away from coast lines and thus there is no threat of coastal pollution from this sector and it is relatively safe from the environmental issues. Freshwater prawn farming sector is not directly linked to CRZ Act and there is no hassles for licenses for initiating culture. Freshwater prawn farming is mostly carried out by small and marginal farmers who are employing a low input level operation and this indirectly helps in sustainable production. All these indicate the scope for further expansion of freshwater prawn farming in India.

However, there are some recent developments that are threatening to seriously affect this sector. These are: (*a*) serious disease outbreaks such as that caused by noda virus (white muscle disease) and appendage deformity disease affecting production in hatcheries and grow-out, (*b*) reduction in productivity in major production areas (Andhra Pradesh and Tamil Nadu) due to inbreeding/poor quality broodstock, (*c*) increase in the cost of essential inputs, (*d*) unpredictable export market, (*e*) fluctuating farm gate prices, and (*f*) natural calamities such as cyclones, flood and drought. Besides these there are other factors that are adversely affecting the spread of freshwater prawn farming such as: (*a*) remote location and scattered nature of farms adversely affecting distribution of seed and feed, (*b*) concentration of the culture in few states in spite of the potential in several inland states, (*c*) lack of awareness among the farming community about the scientific prawn farming techniques and its benefits, (*d*) relatively high cost of production, (*e*) size heterogeneity in the produce making it difficult to market, and (*f*) perishability of the produce.

In spite of all the above bottlenecks and threats, the outlook for the freshwater prawn farming sector is optimistic due to increased demand in urban domestic market, availability of subsidies from state and central agencies, ease of integration with agriculture, horticulture and animal husbandry and higher market price and existing export and domestic market demand.

19. Integrated Fish Farming

Integrated farming may be defined as sequential linkages between two or more agri-related farming activities with one farming as major component. When fish becomes the major commodity in the system it is termed as integrated fish farming (IFF). The integration of fish farming with agriculture and animal husbandry is considered as sustainable farming system, which offers greater efficiency in resource utilization, reduces risk by diversifying crop, provides additional income and food for small scale farming household. This system involves recycling of bio-resources (on farm and off farm) or byproducts and interconnected nutrient flows of one system as input for other, by maximizing the production from same unit areas. The IFF is well recognized in Asian countries like China, Malaysia, India, Vietnam, Indonesia, Philippines and Bangladesh having tropical climate, and later countries like Hungary, Germany, Ghana accepted IFF as an alternative land use, livelihood option and is also promoted as a strategy to improve nutritional standards. Freshwater aquaculture is organic based and derives inputs from agriculture and animal husbandry. India being an agrarian economy produces large quantities of plant and animal residues to the tune of over 322 and 1,000 million metric tonnes, respectively, on annual basis. Country supports largest bovine population of over 222 million cattle heads, along with 181 million sheep and goats, 16 million pigs and over 150 million poultry and other livestock. Other commodities like mushroom cultivation, rabbit, sericulture and apiculture provide huge quantities of organic matter for aquaculture. The agro-based industries (sugar industries, distilleries, breweries, food processing plants and dairy effluents) also produce biomaterials with nutrients which could be recycled for fish farming in addition to the huge quantities of domestic sewage generated from urban cities to the extent of 4,000 million litres per day.

Ecosystems of IFF

The integrated farming system encompasses processes of trapping of solar energy and production of organic material by primary producers, its utilization by phagotrophs, which is followed by decomposition of primary producers and phagotrophs by saprotrophs and finally release of nutrients for producers.

Food web in aquaculture pond: The byproducts obtained from agriculture crops, i.e rice polish, bran from paddy, flour from wheat, oil cakes, soybeans etc., are directly used in varied processed forms in aquaculture as feed input. The excreta, urine, dung, leftover feed obtained from livestock are used as source of fertilizer or directly consumed in aquaculture pond releasing nutrients to generate fish food organisms providing dual benefit. It is important to understand the pathways of animal waste application in ponds, nutrient accumulation in sediments, conversion of natural fish food organism and animal protein in the form of fish. Animal manure when applied in the pond stocked with fish, enters food web in several pathways: (*i*) as food, (*ii*) as source of minerals required for autotrophic production, and (*iii*) as organic substrate for heterotrophic microorganisms which are consumed directly by fish or by zooplankton.

Manures available in the form of animal or green manures help aquaculture ponds to improve the soil-water fertility by providing substantial amount of organic matter. These are applied to increase the essential nutrients, i.e nitrogen, phosphorus and potash. The nutrient content of manures and other organic materials is used to maintain humus content, and is decomposed by soil microorganism. The frequency of manure application is primarily determined by the fertilization rate of manure decomposed in the ponds. Organic manure from excreta, manure, fresh dung, droppings and urine triggers biological activities, which are responsible for production of natural food web. The decomposed nutrient of the manure provides microflora (autotrophs), while non-mineralized portion food base provides for bacteria and protozoa (heterotrophs). Temperature, light, micro and macro flora, inorganic nutrients, are major requirements for the process of photosynthesis.

Fish species in IFF

In traditional practices of IFF, polyculture fingerling stocking of six species combination of Indian major carp (rohu, mrigal and catla) and exotic carp (silver carps, grass carp and common carp) have been demonstrated by several workers. Looking at the compatibility for habitat preference and available natural fish food organisms, promotion of multi-species concept and diversified cultivable practices, with medium and minor carps (*Labeo calbasu, L. gonius, Puntius sarana* and *Labeo fimbriatus, L. bata*) are identified as important regional species introduction to IFF polyculture system. The carp species are also cultured under mixed system of freshwater prawn (*Macrobrachium rosenbergii, M.malcolmsonii*) or catfish magur (*Clarius batrachus*), singhi (*Heteropneustes fossillis*) or anabas (*Anabas testudinius*) and murrels (*Channa marulius, Channa striatus, Channa punctatus*), *Ompok* and *Mystus* species with proper composition and ratio for optimum utilization of the organic resources.

Types of IFF systems

There are basically two types of IFF followed by farmers in Indian context. The agri-aquaculture based system (one to one single systems approach) includes paddy-fish, horticulture-fish, mushroom-fish, seri-fish, vermicompost-fish system with aquaculture as major component whereas other agriculture practices taken as minor components. The livestock-fish system includes cattle-fish, pig-fish, goat or sheep-fish, poultry-fish, duck-fish, rabbit-fish, in one to one sequential approach with objective of increasing farm productivity and maximizing synergies between these components. Further, combining the agri-aqua-animal husbandry commodities (multi- systems approach) at one place such as pond water irrigation, fish and agriculture crops; pond dykes utilization, fish, apiculture; agri-byproduct, animal husbandry feed, fish, excreta

utilization and off seasons utilization of dried ponds for oil crops; biogas slurry, animal husbandry, aquaculture; duckweed or azolla, duck farming, agro-forestry-pond dyke and fish pond etc., are considered as the innovation for judicious recycling of nutrient linkages contributing to farming intensification, effective use of bio resources, optimum production of protein, agricultural diversification and environmental sustainability (Fig. 19.1). Thus IFF provides organic aquaculture management system that promotes and ensures biodiversity, biological cycle and integrated soil water fertility management (ISWFM).

Agri-aquaculture based system

Paddy-fish system: Rice is the major crop and staple food for over half the world's population. Over 90% of rice produced in Asian countries is the livelihood for rural farmers. Collection of wild and indigenous fish from paddy field for home consumption in small family is an age-old practice as the rice cultivation by itself. In fact, India has the distinction of incorporation of fish in rice fields for culture about 1,500 years ago. Planned rice-fish system ensures higher productivity, increase in farm income and employment with reduction of investment risk.

In paddy-fish integration, paddy fields retain water for 3-8 months in a year. The culture of selected species of fish in field which remains water logged even after the harvest of paddy crop provides an opportunity to grow fish and provide off-season occupation for farmer with additional income. The modern concept of paddy-fish integration with rice-fish plot, digging of peripheral trenches, construction of dykes, nutrient utilization of pond refuge and sowing of improved varieties of rice and release of fish in the trenches helped to harvest better yield of rice and fish. Fishponds receive the crop residues as pond input. The ecological benefits are weed control, consumption of some pests and molluscs and bioturbation of soil-water interface. Green leafy vegetables on the pond dyke in aerial system, cash crop such as banana and papaya provide a net income of ₹ 35,000-40,000/ha/year, which is higher than the tradition as rice cultivation. In this integration, product yields are, fish, rice, seasonal horticultural crop etc.

Horticulture-fish system: Fruits and vegetables popularly known as olericulture are rich in nutritive value and contain carbohydrates, fats, proteins, vitamins and minerals. Leafy vegetables, seasonal fruits etc., are usually grown on the pond dyke to utilize the areas under cultivation. The top, inner and outer dykes of pond are the best place to grow horticultural plants such as floriculture, agro-forestry, oil crops etc. Pond water is irrigated to the crop and the nutritive silt with manure value used as base manure. The success of a horticulture-fish system depends on the selection of plants. The plants under vegetable and fruit varieties should be of dwarf type, less shady, evergreen, seasonal and remunerative. Dwarf varieties of fruit bearing plants such as mango, banana, papaya, and citrus are suitable, as these plants do not obstruct sunlight to the pond. Pineapple, ginger, turmeric and chilly are used as intercropping plants. Seasonal varieties (summer) brinjal, tomato, gourd, cucumber, okra, watermelon, carrot, peas etc. and (winter) cabbage, cauliflower, carrot, beat, raddish, turnip and spinach are grown for better profitability. Plantation of flowers like tuberose, rose, jasmine, gladiolus, marigold, and chrysanthemum provides more remuneration to the farmers. Farming of oilcrops, black mustard, yellow mustard, sunflower, pigeonpea, soybean; green fodder *bajra*, berseem, *jowar* is also carried out on the broad middle portion of the dykes where the nutrient rich pond water irrigates these plants. The outer dyke areas are planted with agro-forestry, poplar, eucalyptus grown in some states of India fetch better utilization of land area. Residues of vegetables and green fodder are recycled into fishponds and herbivorous fish grass carp (monoculture) at stocking density of 5,000/ha has resulted in 3,500-5,000 kg/ha production. In mixed culture practice of grass carp, rohu, catla, mrigal, silver carp and common carp in 50:15:15:10:5:5 ratio at a density of 7,500/ha fish to the tune of 4,000-5,000 kg of fish fed with dyke grown green fodder. This yielded fish to the tune of 4,000-5,000 kg of fish fed with dyke grown green fodder. This integrated system not only provides 20-25% higher returns compared to aquaculture alone but also generates engagement opportunities round the year.

Mushroom-fish system: Mushrooms are fleshy fungi, priced and praised for its meaty biting texture and flavours. Four types of mushroom popular in India, belong to *Agaricus bisporus* (white button), *Volvoriella* sp. (paddy straw), *Pleurotus* sp.(oyster) and *Calocybe indica* (milky) respectively. Mushroom cultivation requires high degree of humidity, which is fulfilled from aquaculture environment.

The paddy straw after mushroom cultivation becomes rich in protein; organic nutrient along with other essential matter is utilized for cattle feeding. It has been observed that, feeding cattle this straw enhances milk production. Excreta of cattle are recycled in fishpond fertilization enhancing pond productivity through detritus food chain. Compost of mushroom bed known as spent mushroom substrate (SMS) contains 1.9, 0.4, and 2.4% (fresh) nitrogen, phosphorus and potash, respectively, which could be used in aquaculture and agriculture.

Sericulture-fish system: Sericulture in rural India is an agro-industry to produce silkworm and silk from cocoon. The process of cultivation starts with mulberry plants, which are planted in fishpond dykes for water irrigation to plant. In return, the waste product from sericulture practices like silkworm pupae, faeces and wastewater from processing facilities could be used as a nutrient input in aquaculture. In this integration, worm eats the mulberry plants leaves converting to cocoon releasing nutrient rich faeces ingested by fish directly. In seri-fish system energy passes through complex food web of the dyke-pond system and undergoes a series of exchanges among subsystem. In pond dyke-plant system absorption process converted energy into chemical energy by photosynthesis. Chemical energy stored in plant material and wastes are used as fish feed and pond fertilizer. The silkworm subsystem provides energy linkages between mulberry and pond sub-system. It absorbs stored energy in harvested mulberry leaves and the waste enters fishpond as a mixture of leftover mulberry leaves and silkworm excrement. In other words, 75% of mulberry leaves consumed by the silkworm will produce huge quantity of excreta. Remaining 25% unconsumed leaf debris with the generated excreta are dumped in fishpond consumed by fish. Mulberry planted dykes yield leaves at 30 tonnes/ha/year; when fed to silkworm, produced 16-20 tonnes of waste in which stored energy is 66% of that supplied to silk worm. The energy intake by fish accounts for only 32% of the total input. In 1 ha mulberry-fish project, 50% area is utilized for mulberry plantation with rest for fishpond. Of the former, 0.45 ha is planted with mulberry and remaining 0.05 ha is used for vegetable production. Vegetables are inter-planted giving additional production of 3-4 tonnes/ha/year. A production of 2-3 tonnes/ha/year of fish is expected from this IFF system.

Vermicompost-fish system: Compost that is prepared with the help of earthworm is called vermicomposting and the culture process or technique adopted termed as earthworm rearing. The process of composting is different in the sense that the traditional compost is prepared through decomposition process. In vermicomposting, the decomposable organic waste are eaten up by earthworm, digested in the body and material not required for its nutrition excreted. Some commonly used earthworms in India are *Eisenia foetida, Eudrillus euginea, Perionyx excavatus, Lumbricus rubellus, Pheretima elongata, Lampito maurita* etc. Owing to its high nutrient content N, P, K (1.6, 2.56, 0.8 %) and minerals Ca, Mg, Fe, Cu, Zn, this becomes fertilizers in fishponds. Fresh earthworms contain 8-10% protein and dry earthworm 56-66%. The earthworms multiply themselves during the process of culture become direct food for some of the ornamental fish. Earthworm with higher nutritive value and energy content is used in chopped condition as feed of carnivorous catfish like magur, singhi, murrels, *Anabas* sp. and freshwater prawn. It has been seen that 1 kg of earthworm produces 10 kg of compost in 60-70 days.

Aquatic weed-fish system: Aquatic weed-based fish system integrates various types of aquatic plants as feed source for herbivorous fish. Grass carp the exotic fish, directly consumes duckweed belonging to family Lemnaceae commonly known as *Lemna, Wolffia, Spirodela* and water fern *Azolla*. These floating plants with higher proteins (30-45 g/100 g), low fat (5.0-7.0 g/100 g), fibre (7.5-10.0 g/100 g), lower lignin (2-3%) and cellulose (10-12%) has beneficial impact on digestibility for livestock and fish available throughout India. In aquatic weed-fish polyculture system, herbivorous fish (grass carp; 50%) with other fish (rohu, catla, mrigal, silver carp, common carp; 10% each) in stocking density of 6,000-8,000 fry/ha, fetches production over 5-6 tonnes/ha/year of marketable size fish. The duckweed is consumed by grass carp *ad lib.*, whereas the excreta of the grass carp and decomposed weed work as pond fertilizer. *Azolla*, is a nitrogenous biofertilizer on the water surface in fishponds producing nitrogen, phosphorus and potassium by trapping the solar energy. In polyculture pond with water area of 1ha, the nutrient requirement met through application of 40 tonnes/ha/year *Azolla* provides over 100 kg of nitrogen, 25 kg of phosphorus and 90 kg of potassium in addition to 1,500 kg of organic matter. Due to high protein content (13.0-30.0%), use of *Azolla* as feed ingredients is of special interest in aquaculture system. *Spirulina*, is a blue green algae with high biomass production rate known as "wonder gift of nature" used as dietary supplement and therapeutant not only for animals but for human beings. It has crude protein content (62.5-71.0%) on dry weight basis. Being an aqua-product, *Spirulina* incorporated diets show higher growth and play important role in augmenting the pigmentation of ornamental fish.

Animal husbandry-fish based system

Cattle-fish system: Fish farming using raw cow manure is one of the common practices all over the world. Among all livestock excreta, cow dung is most abundant throughout rural India. A healthy cow weighing 400-450 kg excretes over 400-500 kg of dung and 3,500-4,000 litres of urine on annual basis. Due to its quick sinking ability, the nutrients available are responsible for increase in natural food organisms – detritus and beneficial bacteria in fishponds. Edible non-digested feed of cow dung is consumed directly by fish. Biological oxygen demand (BOD_5) of cow manure is lower than that of other livestock manures as it is already decomposed by microorganism in ruminant. Nutritive value of excreta of different animals is given in Table 19.1. The faeces and urine is extremely beneficial for filter feeding and omnivorous fish such as catla and silver carp. A unit of 5-6 cows can provide adequate quantity of dung and urine to

Table 19.1. Nutritive values of different animal excreta

Animal	Excreta	Moisture (%)	Organic matter (%)	Nitrogen (%)	Phosphorus (P_2O_5 %)	Potash (%)
Cattle	Faeces	80-85	14.0	0.3	0.2	0.1
	Urine	92-95	2.3	1.0	0.1	1.4
Pig	Faeces	85	15.0	0.6	0.5	0.4
	Urine	97	2.5	0.4	0.1	0.7
Chicken	Faeces	78	25.5	1.4	0.8	0.6
Duck	Faeces	81	26.2	0.9	0.4	0.6
Rabbit	Faeces	10	37.0	2.0	1.3	1.2
Goat	Faeces	10	-	2.7	1.7	2.9

Source: Integrated Fish Farming, NACA Technical Manual 7. The figures are subject to variations depending on the management practices.

produce 3,000-4,000 kg of fish per ha per year. With these types of integration, 9,000 litres of milk and fish harvested from the system became most popular among rural household. The shed of cattle, built on the dykes or near the pond helps in easy disposal of urine and dung into pond simplifying handling problem. The fresh dung and urine collected separately can be applied periodically @ 10 tonnes/ha/year to culture ponds.

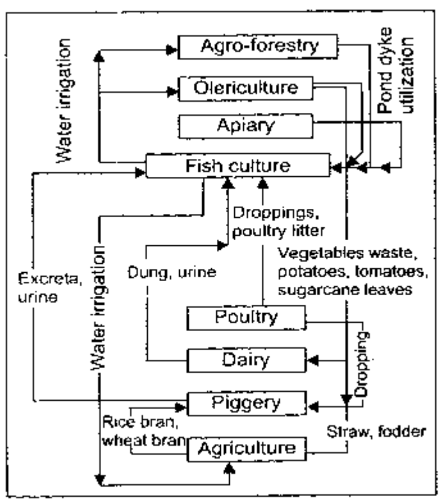


Fig 19.1. Multiuse aqua-agri-animal husbandry system

Biogas slurry-fish system: Biogas slurry is a byproduct from the biogas plant after digestion of dung or biomass to produce methane gas. The slurry produced during the operation contained 1.5-2.5% N_2, 0.82-1.5% P_2O_5 and 0.8-1.2% K_2O respectively. Direct use of bio-slurry in

liquid form mixes quickly in pond water to produce required fish food organism compared to solid wastes. Biogas slurry applied @ 30-45 tonnes/ha/year produces 3-4 tonnes/ha/year of fish without feed and fertilizer. Slurry application for fry to fingerling rearing is advantageous over the traditional methods as it keeps pond environment clean.

Pig-fish system: Pig-fish animal husbandry systems are better compared to other integration systems because of production of meat and fish at a cheaper feeding cost. A floor space of 3-4 m^2 is required for a pig weighing 70-90 kg. The popular exotic pig breeds that are preferred by farmers for rearing are White Yorkshire, Landrace and Hampshire. The pig dung and urine is utilized for fertilization of culture ponds which is either channelized directly or partially decomposed before application in ponds.

Scientifically prepared base feed-mixture offered to pigs comprise maize, groundnut, wheat-bran, fishmeal and mineral mixture. To reduce the cost of feed for pig, many farmers in the rural India use agro-industrial waste (press mud, poultry droppings, distillery waste), vegetables waste (rotten potatoes, tomatoes, pumpkin etc.) mixed with pig feed mash. A full-grown pig provides 500 to 600 kg of dung in a year and excreta of 40-45 pigs provides required quantity of manure to fertilize 1 ha pond. Pigs attain slaughter size (60-70 kg) within 6 months.

In fishpond, the application of pig dung enhances nutrient for dense bloom of phytoplankton and zooplankton. Stocking of bottom feeder mrigal in higher quantity with focus on filter feeding fish, silver carp is advantageous in this type of integration. In additions to this, production of detritus at pond bottom provides space for substrate development for colonization of microorganism and benthic fauna. Polyculture practice of fish with Indian major carp and exotic carps is undertaken in fish-pig farming ponds. Partial harvesting of marketable fish offers higher yield in this type of integration. Fish harvest results in 3-4 tonnes/ha without any feed and fertilization in 12 months culture period at the stocking rate of 8,000-8,500 fingerlings/ha.

Goat-fish system: Goat/sheep farming is an age-old practice by rural people for meat, milk and manure. India has 25% world goat population with 13 well known breeds, mainly categorized on the basis of fibre, meat and milk.

Goat housing should be dry, comfortable, safe and protected from excess heat. In a goat-fish IFF system, these are kept on elevated pond dyke under wide spread shady trees. Goat does not survive on marshy and swampy ground. For housing adequate space, proper ventilation, sanitation and drainage facilities should be planned while constructing a house. Kids are kept under large inverted bamboo basket until they run along with mother. Goats are selective feeders and relish on green fodder berseem, napier grass, cowpea, soybean, cabbage, cauliflower leaves, lettuce. Leaves of shrubs, *Acacia* (*babul*), *Azadirachta indica* (*neem*), *Ziziphus mauritiana* (*ber*), *Tamarindus indica* (tamarind), *Ficus religiosa* (*pipal*) and mulberry, are consumed by goats.

Goat excreta is a very good organic fertilizer and contains 60-70% organic carbon, 2-3% nitrogen, 1.5-1.8% phosphorus, 2.5-3% potassium with solid excreta applied directly in fish pond as manure. The droppings are about 1 cm in size coated with mucus and floats in semi-dried conditions. The bacterial activities accelerate formation of organic detritus consumed by fish biomass in food chain. For better result, the solid mass of droppings should be moistened in a container (15 days) and crushed to powder before application to fishponds. An adult goat weighing about 20 kg discharges 300-400 g excreta on daily basis. For manuring 1 ha water area, 50-60 goats herd are needed. This integration could produce 3.5-4 tonnes/ha/year of fish without supplementary feed or fertilizer in pond. These types of IFF produce fish and 750-900 kg goat/sheep meat.

Rabbit-fish system: A rabbit is considered a pet animal by hobbyists and is used as an experimental animal by professionals. It has emerged as an alternate meat source and is regarded as dietician's choice for health-conscious meat consumers, owing to low fat compared to other meat-producing animals. Small body size, high reproduction rate, potential for year round meat production and ability to utilize non competitive food are some of the attributes, which make rabbit a favourite meat supplying animal for human being.

As many as 60 varieties and breeds of rabbits are recognized throughout globe. Important meat producing breeds are Soviet Chinchilla, Grey Giant, White Giant, New Zealand White etc. whereas wool types breeds are Russian Angora and German Angora.

Rabbits are reared in cage, hutch and floor system. Rabbit excreta contains 50–60% organic matter, 2-3% nitrogen, 1-1.5% phosphorus and 0.8-1.2% potassium. The manurial potential of excreta with high nitrogenous content (10 times higher than cowdung) found releasing nutrient gradually and sustained high plankton production for a longer period. For these characteristics rabbit becomes a potential animal for integrated fish farm.

Poultry-fish system: Poultry fish system provides poultry droppings and litter into fishpond and acts as a fertilizer source for production of fish. In this system farmer's efficiency in management, experience, aptitude and ability helps to get better economics. The management includes good quality of chicks, housing, brooding equipments, feeder, water treys and prevention and control of diseases. In fish-poultry system, birds have to be housed in intensive, semi-intensive and extensive system. Poultry birds are kept in confinement with no assess to outside. The house of the birds is built on the pond dyke or inside the pond. Birds are reared in pens and about 0.3-0.4 m^2 space is provided for each bird. The floor is covered with litter prepared with chopped straw, dry leaves, sawdust or groundnut shells. Deep litter pens are made during dry weather. Selection of birds depends on the utility such as meat type (broilers), egg type (layers) or fancy type, and is integrated with fish. Egg production and weight gain and local breed are important criteria for selection. Proper vaccination and prophylactic measures against diseases are needed for better economic returns. Poultry feed industry is well-organized sector and feeds are available for various stages of poultry birds. Egg type birds are fed with starter 0-8 weeks, grower 8-20weeks and brooder feed 20 weeks onward, while broilers are fed 0-4 week with starter and 4-6 weeks with finisher feed. Hoppers are used for feeding to minimize feed wastage. Provision of clean water for drinking and hygienic condition in the poultry house are important aspects, which affect egg or growth of birds. Layer birds are discarded after eighteen months of rearing as egg production goes down. Marketing of broilers starts after 5-6 weeks of rearing when birds weigh 1.2-1.5 kg.

Recycling of poultry wastes such as leftover feed, droppings and litter are used to increase biological productivity of pond water. The deep poultry litter is applied to pond at 30-35 kg/ha on daily basis. One adult chicken produces about 25-30 kg of compost poultry manure in a year to provide sufficient manure. For 1 ha water-bodies, 1,000 birds produce sufficient manure with 90,000-100,000 eggs and over 1,500 kg of meat per year while broiler rearing provides over 1,500 kg meat/batch. At least 5-6 batches can be reared in a year. A production of 3,000-4,000 kg of multispecies fish could be harvested from such system.

Duck-fish system: Duck-fish integration is very common in countries like China, Hungary, Germany, Poland, Russia and some parts of Indian states like Andhra Pradesh, Odisha, West Bengal, Bihar, Kerala, Tamil Nadu, Karnataka and North-East states like Asom, Manipur, Tripura, Mizoram etc. Duck farming alone provides meat as well as eggs for the farmer. In aquatic environment, ducks roam freely during daytime and get several aquatic animals and plants as its food. Duck droppings and urine from the house used as nutrient source provide carbon, nitrogen and phosphorus, for production of natural food organism used by fish in duck-fish integration.

There are several varieties of duck reared on the basis of production performances by farmers either for meat or egg purpose. In duck-fish IFF system, pond provides semi-closed biological environment with aquatic animals and plants for ducks. They consume juvenile frogs, snails, dragonfly and tadpoles, thus making a safe environment for fish. The excreta goes directly to the ponds containing essential nutrients, nitrogen, and phosphorus stimulating natural fish food organism.

Housing for layer duck should have good ventilation, space area, laying boxes, egg trays with multi-door facility to remove washing, feeding and collection of eggs. In duck-fish integration, the houses are built in the middle of the pond or on the pond dykes or in a centralized system or in floating house. In pond dykes, the house is built with sufficient sunlight and protection from rain. In open water system, large number of ducks are left in large water-bodies like lakes and reservoirs during daytime while they are kept inside the sheds during night. In centralized system, relatively large sheds are made of bamboo in vicinity of the fishponds with cemented area of wet and dry run. Dry runs are cleaned on daily basis whereas wet runs are cleaned at an interval of 3-4 days and fertilized excreta is flushed directly to the ponds or collected in a container for phase fertilization.

Day-old ducks are available for rearing in duck shed. These weigh about 50-60 g and need brooder house with lighting, temperature, ventilation etc., with a brooding period of 1-3 weeks to be allowed to swim freely in water. During this period, the floor preparation is very much important such as dry litter materials like saw dust, paddy husk, chapped straw etc. Extra care is needed like portentous crumble starter feed and medicated water for their growing. Once the ducks attain a size of more than 150 g, they start searching food from the ponds. During growing period, apart from prepared compound feed consisting of wheat grain, broken rice, soyabean meal, fish meal, wheat bran, rice polish, mineral mixture and common salt, duck consumes snails, earthworm, aquatic insects, aquatic weeds and predatory fishes. Duckweed *Wolffia* is consumed by ducks during younger age whereas *Lemna, Spirodela* and *Azolla* are preferred during grown up stages. It has been advantageous that fish fry (1.5-2.0 inch or 3.8-5.04 cm size) may be stocked in pond when one-day-old ducklings are reared in the IFF by the time ducks start freely swimming in ponds, the fry also become fingerlings or bigger.

The duck starts laying eggs after 6 months of age and continues for 2-3 years depending on the duck species, nutrition, health and environment. Since egg laying is in the nighttime, there is no possibility of an egg laid when birds are in ponds.

Multi-species culture of fishes with rearing period of one-year yield fish ranging from 3,000-4,000 kg/ha/year is expected from this types of IFF in addition to 4,000-6,000 eggs and 500-750 kg duck meat on annual basis at the stocking rate of 200-300 ducks for 1 ha pond. The income generated from eggs and meat covers the rearing and feed cost of duck whereas the monetary value obtained from fish sale becomes profit in these types of IFF without any investment for fish.

Multi-utilization system

In multi-utilization system, in the pond area, more than two farming systems are planned to utilize the potential of pond water, peripheral areas etc. resulting in extra income from the land area. As the pond bottom is rich in organic nutrient it reduces the application of chemical fertilizer and also results in higher and good quality product yield. In some states like Punjab, Haryana, Uttar Pradesh, Himachal Pradesh etc. due to low temperature during winter, farmers evacuate their fishponds completely during the lean months. To utilize the dried pond area, some farmers grow short-term oil crops with low water irrigation that resulted in better utilization of land area with more crop yield. The excess nutrient in soil trap by these green plants resulted in better fish production next season. Pond dykes with free space of inner, outer and middle portion are utilized for agro-forestry, apiculture, horticulture, seasonal plantation and agro-forestry which provide additional income. Duckweed and *Azolla* pits could be planned with a small area near the pond areas to use these as feed for animals such as cow, pig, goat or duck reducing the feed cost of the animals.

The present types of IFF methods adopted by farmers are based on traditional knowledge and experience without proper planning, shortfall of latest technology and management techniques. With the practice of scientific IFF, the farmers need specialized training, introduction of high-yielding varieties, multi-cropping knowledge and innovation in farming to extract maximum output from the small land holding. In addition, marketing of produce, proper utilization of internal resources, mechanized farm machinery; climatic change and update knowledge of world trade criteria are some of the challenges faced by farmers. To overcome these constraints IFF is the only alternative to enhance production and productivity from existing agricultural land and water. Further, waterbodies such as seasonal or perennial should be targeted for IFF in dry areas with multi-cropping pattern, short-term crop and sustainable production for overall integrated development to farming community. Strategy should be developed to trap the potential of large water-bodies in rural areas for introduction of IFF so as to utilize these properly.

20. Wastewater Aquaculture

The production of fish in ponds fertilized with wastewater is a common practice in many parts of Asia and was also known in medieval Europe. Now-a-days the sewage-fed fishery is well established because it is economically more attractive than that of the intensive fish farming practices using prepared pelletted feed. This system includes sanitary engineering pond technology which can also be associated with significant energy savigs. Sewage-fed fishery was developed in Germany at the end of nineteenth century and independently in Kolkata in 1930.

Although, satisfactory as source of nutrients, sewage presents problems such as toxicity to fish, accumulation of heavy metals and toxic substances in fish muscles and it also contains various pathogenic microorganisms. Fishes from waste water-fed farms may sometimes act as a potential vectors for transmission of pathogens to fisherman and even to consumers. For sanitary aspects it is necessary that the wastewater to be used in fish ponds needs to be in appreciable quantity, should first undergo some treatment to decrease the number of pathogenic microorganisms. Therefore, it is essential to consider the treatment process by which bacterial flora changes from predominantly faecal character to suitable limit, facilitating fish culture. Utilization of treated sewage for fish culture has attracted the researchers not only for a vast possibility for fish production alone, but also to check the possible transmission of communicable diseases by pathogenic organisms such as bacteria discharged by human beings. Since the traditional treatment of sewage involves highly expensive installations, a second thrust was given to treat the sewage biologically, involving different ponds in the series.

With the launching of the Ganga Action Plan in 1985 there has been a renewed interest as also vigour among engineers, scientists, environmentalists, and town planners to restore this mighty river to its pristine purity. Overall environmental degradation and consequent precarious health of river system can be traced to fast pace of urbanization, industrialization and modernization of agricultural sector. Discharge of municipal waters is a major contributor to deterioration in water quality. According to official view of Central Board for Prevention and Control of Water Pollution, the stoppage of discharge of sewage/sullage into river Ganga would reduce pollution to the extent of 75%. Further, studies conducted by the Board reveal that most of the Indian cities do not have adequate sewerage and sewage treatment facilities.

In view of above, the appropriate waste handling system for most of the municipalities would be interception of untreated sewage flowing into rivers, treatment of sewage in low-cost treatment plants such as stabilization ponds which do not require high degree of skill and reuse of treated sewage and sludge for raising fish and vegetable crops. As far as human and animal wastes are concerned they are biodegradable. The biodegradability of human, animal and domestic wastes is the rational basis for sewage treatment converting waste into an economic resource for recycling.

Problems related to sewage-fed culture systems

- Accumulation of silt and high organic matter at pond bottom
- Incidence of parasites and fish diseases
- Possibilities of pathogens being transferred to humans
- Accumulation of heavy metals in the system

Solutions

- Regulate sewage intake into the ponds
- Provide freshwater for dilution and use of prophylactics
- Depuration of fish in freshwater before marketing

Because of the high biochemical oxygen demand (BOD) of the wastewater and the resulting de-oxygenation of the water during the night, fish usually cannot be cultured directly in the waste itself, hence steps must be taken to reduce the BOD. This usually is brought about by one of the following three methods: (*i*) treating the waste to such a degree that it does not create any hazard to fish – Moscow model, (*ii*) diluting the wastewater before its introduction into the fish pond. This method is adopted by the classical example of Munich's wastewater – fish ponds, and (*iii*) diluting the wastewater in the pond by the water contained by the pond itself. The pond water can be freshwater or aged and stabilized wastewater. The best example for this system is that of Calcutta Wastewater-fed aquaculture.

Treatment of raw sewage

In many parts of the world waste of community is disposed off in natural water courses like rivers, lakes and streams without any treatment. In some areas, particularly in arid and semi-arid zones, sewage is collected in ponds and ditches and used for various purposes, including sewage farming and fish farming etc. However, with the rapid growth of industries and population, the natural water bodies are unable to sustain the higher load of organic and inorganic pollutants and it becomes necessary to think of other methods of wastewater treatment rather than relying on natural process to purify them. Many methods of sewage treatment are applied in several urban centres of India.

Primary treatment: For physical removal of solids by mechanical means including screening of coarse solids, primary and secondary grit removal, sedimentation and other modern physical treatment.

Secondary treatment: Includes the biological removal of soluble materials. Three main basic methods are involved, i.e. activated sludge, trickling filter and waste stabilization pond.

Tertiary treatment: For biological or chemical removal of soluble products of partial or complete oxidation.

Grit removal

Grit removal is essential at sewage treatment works for two main reasons:

- to reduce blockage, erosion of pump bodies, bearings, stations and rotors, pipe work and environments where it will act in the manner of a fluidized grinding paste.
- to prevent the reduction in available operation capacity that occurs when grit is deposited in sludge tanks and digesters and in oxidation ditches which are surface aerated and where the flow velocity around the system is inadequate to keep inorganic material in suspension.

Sedimentation and dilution

For recycling sewage through fish culture, it is desirable to treat sewage at least primarily by sedimentation so that organic load of raw sewage is reduced considerably. BOD values of raw domestic sewage generally vary between 150 and 400 mg/litre and primary treatment by sedimentation is likely to reduce its value by about 33%. Primary sewage effluent contains less of organic matter than raw sewage but more of nutrients than secondary or tertiary sewage effluents and is generally more congenial for fish culture in ponds where no other supplementary fertilizer or feeds are given. For effective use of primary treated sewage effluent for fish culture, dilution with freshwater having normal oxygen concentration may be necessary to keep a positive dissolved oxygen balance and the concentration of toxic ingredients such as CO_2, NH_3, H_2S, etc., below lethal limits. The oxygen required for biochemical oxidation (BOD) of organic matter is obtained from freshwater used for dilution and through green algae and vegetation in the pond water. Photosynthetic activity of algae increases the oxygen balance of pond water and consequently, helps in lowering the BOD value of pond water rendering the pond more suitable for stocking fingerlings of Indian major carps and Chinese carps (Table 20.1).

Trickling filters

A trickling filter usually consists of a cylindrical tank 2-3 m in depth filled with rocks. The rocks typically have a diameter of 2-10 cm, and should be loosely packed and as nearly spherical in shape as possible to facilitate the downward flow of sewage and the upward flow of air through the system. The effluent from the primary clarifier is sprinkled over the surface of the bed of rocks by one or more rotating arms. Usually a given area of the bed is sprinkled approximately every 30 sec but faster application rates are possible and sometimes necessary. As the sewage trickles down through the bed of rocks, bacteria and fungi that grow on the surface of the rocks in a glutinous film ingest the dissolved and suspended organic substances in the water. The bacteria and fungi are, in turn, fed on by a variety of higher trophic level organisms, including protozoa, rotifers, nematodes, worms, and insects. Part of the trickling filter effluent is routed to the secondary clarifier, where settling of the sludge removes additional BOD from the water. However, part of the effluent is normally recycled back to the trickling filter to maintain the population of decomposer organisms in the filter and to further reduce the BOD.

Activated sludge

An activated sludge system usually consists of a long rectangular tank or series of tanks 3-5 m deep. The effluent from the primary clarifier is introduced at one end of the tank and exists at the other end. The residence time of water in the system is usually about four to eight hours. During its passage through the tank(s), the sewage is vigorously mixed from below with bubbles of air that keep the contents of the tank in a state of great turbulence. This vigorous mixing and aeration are necessary to prevent the O_2 concentration in the water from dropping below 2-3 mg/litre. Otherwise the respiratory activity of the organisms in the tank is likely to be slowed.

Table 20.1. Percent removal of BOD and suspended solids (SS) using various treatment methods

Process	BOD removal (%)	SS removal (%)
Septic tank	25-65	40-75
Primary treatment	30-40	40-75
Primary + trickling	80-90 or more	80-90 or more
Primary + activated sludge	85-96 or more	85-96 or more

Global scenario of wastewater aquaculture

The use of organic wastes in fish culture has been in vogue much before history. Silkworm wastes were used in fish ponds in China more than 4,000 years ago. The earliest published work on the use of wastes in fish culture was by Fan Lai in China around 460 BC this may be equally true for ancient civilizations like India and Egypt. Subsequently in recent years wastewater based fish culture gained momentum in China, Taiwan, Indonesia, Philippines, Hong Kong, Hungary, Malaysia, Israel, USA, Germany, Australia and Canada. Among these countries, only Germany, Israel and China are raising fish in wastewaters for human consumption, while other countries raise fish in the system for other uses.

Wastewater-fed aquaculture in India

Sewage-fed fish is not new as far as India is concerned. It is estimated that at present there are more than130 wastewater aquaculture units in India covering about 10,000 ha. Almost 80% of these are located in West Bengal. In West Bengal, sewage is extensively used as a fertilizer for fish pond. One of the major sewage irrigated fisheries is in Kolkata, popularly known as Vidyarathi Spill area, which is presently known as Salt Lake. Simultaneously sewage-fed fish culture started at four sites in India namely Nagpur, Bhilai, Madras and Bhopal. Domestic sewage and storm water within the city of Kolkata are mostly carried through combined sewers. However, outfall drainage channels are separately designed for dry weather flow termed as Dry Weather Flow (DWF) channel, and for storm water flow termed as Strom Water Flow (SWF) Channel. Population covered by the outfall channel capacity was 4 million Kolkatans over an area of 94.50 km^2. The DWF Channel starting from the Tapsia covers a length of 32 km to reach to the river Kulti Gong at Ghusighata. At Bantala 6.4 km away from Tapsia the outfall channels are connected with the sedimentation tanks.

The SWF Channel was constructed to carry the storm water of the city of Kolkata and a part of adjacent urban and rural areas, covering an area of about 150 km^3. The SWF begins from Ballygunj drainage pumping station and traverses about 34 km to reach to river Kulti Gong. The Capacity of the SWF at one stage was 2011 cusec. Subsequently, with the rise of city population and increase of impervious areas within the command area the capacity of the SWF was remodeled to accommodate a discharge of 4,966 cusec.

Sewage utilization in aquaculture

The tropical climate, encountered in India and some of the South-East Asian counties, is ideal for the conversion of human wastes into high protein micro-algae due to the presence of favourable temperature and light throughout the year. The sewage effluents in fish ponds act in the same manner as organic fertilizers and liberate nitrogen, phosphorus and trace elements which stimulates the production of fish food organisms in the culture system. Immediately after application of sewage effluents the BOD level of pond water rises considerably, the extent of increase depends on the amount of organic matter, enhances the primary productivity of the culture system through release of nutrients. Phytoplankton starts appearing within 3-5 days of sewage application and generally continues to grow upto 15-20 days, depending on the availability of nutrients, to maintain this nutrient status, it is imperative to supply sewage at regular intervals. This phenomenon is accompanied by a consequent increase in the amount of consumer food organisms like zooplankton, insects etc. Apart from releasing nutrients to the phytoplankton, the organic content of the effluents exhibits other ways of enhancing the productivity level of the system. The small particles the 'microfines' which are basically assemblage of bacterial colony, provide direct source of food to the zooplankton and benthos and thus, solar energy-dependent food cycle is bypassed.

Biotic community in wastewater aquaculture

Rich nutrient status of sewage fish ponds is reflected in the occurrence of high phyloplankton density since the nutrients released from the sewage effluents are directly utilized by these organisms. Phytoplankton consists mainly of Chlorophyceae with following predominated genera, *Ankistrodesmus, Scenedesmus, Chlorella* and *Closterium*, followed by Myxophyceae with predominated genera like *Oscillatoria, Spirulina* and *Nostoc*. Diatoms mainly represented by *Navicula, Nitzchia* and *Synedra*. Among zooplanktons, cladocerans are most dominant and chief genera usually found are *Moina* and *Daphnia*. Among Copepods, *Cyclops* and *Diaptomus* and among Rotifers, *Brachionus, Keratella, Filinia* and *Asplanchna* are common.

Fish production practice

For obtaining sustained production of fish from a wastewater pond and to maintain an ecological balance the highly variable nature of fish food organisms should be suitably utilized through judicious stocking of different fishes. Since one fish species cannot utilize all the natural food an imbalance of organisms may develop from indiscriminate selection of fishes. Unchecked proliferation of some of the organisms may not only drive down the oxygen level to a minimum hazardous level but also lead to considerable loss of nutrients through non productive use. The best combination of species mix is silver carp, a prolific phytoplankton feeder, rohu, mrigal, catla and common carp. One of the unique features of East Kolkata bheri system is that the peripheral zone (2-4 m) of each pond is covered by water hyacinth. Water-hyacinth plays an important role of removing heavy metals from the system and also minimizes poaching of fish. Before stocking, bheries are dried up and sewage is allowed to enter bheri. This effluent requires stabilization for a few days (5-7 days) and after observing the plankton population the bheries are stocked with advanced fingerlings at 7,000-10,000/ha. In some bheries, where scientific method is followed stocking density may go up to 15,000/ha. Normally, multiple stocking and multiple harvesting is adopted in these bheries and fishes are reared for 3-5 months, depending on the growth of the fishes to reach marketable size of 250-400 g.

Chemical properties of sewage-enriched fish pond

Sewage is a dark coloured foul-smelling fluid containing organic and inorganic solids in dissolved and suspended forms. It contains 90-99% water, 10-70 mg/litre nitrogen, 7-20 mg/litre phosphorus and 12-30 mg/litre potassium. One of the major changes that occurs in sewage-fed fish pond due to high BOD value of water is, reduction of DO level. Fluctuation of DO is reported during day and night time due to the presence of high density of phytoplankton in the system. Low value for DO during night hours support decomposition activities (Table 20.2).

Table 20.2. Diurnal variation in physico-chemical characteristics of running waste treatment ponds

Time(hr)	pH	Temperature (°C)		Dissolved oxygen		Free CO_2	Total alkalinity	Chloride (ppm)	NO_2-N (ppm)	NH_4-N (ppm)
		Surface water	Bottom water	Surface water	Bottom water					
4 PM	7.53	31.50	31.25	5.72	2.56	9.12	118.0	117.37	0.11	6.79
8 PM	7.48	30.65	30.65	2.83	1.71	11.37	122.0	118.21	0.225	8.51
12 PM	7.45	30.35	30.40	1.24	0.39	13.47	127.0	119.17	0.325	8.96
4 AM	7.46	29.65	29.85	0.92	0.24	16.87	129.0	118.46	0.352	9.09
8 AM	7.47	30.35	30.25	1.43	0.67	14.65	133.0	117.0	0.267	8.12
12 AM	7.50	33.15	31.30	5.12	1.93	10.46	134.0	116.8	0.21	7.11

In spite of that the spread of this fish farming system remains basically as a 'Kolkata affair' mainly because of two major reasons: (*i*) fear psychosis of transmission of pathogens from the system to handlers and consumers through fish, and (*ii*) presence of heavy metals in the system.

Public health consideration of sewage-fed aquaculture

Detailed studies have been conducted in Kolkata sewage-fed aquaculture system related to epidemiological aspects of persons involved in the system in particular with

Table 20.3. Average microbial loads in different sewage-fed systems

Bacterial type		Kalyani	Rahara	Bandipur	Salt Lake
Total coliforms	A	180.0×10^6	$1{,}125.0\times10^6$	125.0×10^6	30.0×10^6
(CFU/100 ml)	B	75.0×10^5	41.6×10^5	53.0×10^5	14.5×10^5
	C	47.4×10^4	16.28×10^4	36.0×10^4	28.84×10^4
Faecal coliforms	A	52.0×10^6	59.0×10^6	59.0×10^6	6.2×10^6
(CFU/100 ml)	B	39.0×10^5	43.0×10^5	59.0×10^5	6.63×10^5
	C	5.6×10^4	6.5×10^4	51.3×10^4	10.29×10^4
Faecal/streptococci	A	95.8×10^6	110.0×10^6	110.0×10^6	61.0×10^6
(CFU/100 ml)	B	80.0×10^5	90.6×10^5	120.0×10^5	75.0×10^5
	C	3.0×10^4	3.0×10^4	9.3×10^4	7.8×10^4
Total pseudomonads	A	75.0×10^6	120.0×10^6	120.0×10^6	35.0×10^6
(CFU/100 ml)	B	53.0×10^5	125.6×10^5	100.0×10^5	32.8×10^5
	C	67.8×10^4	92.0×10^4	68.8×10^4	49.7×10^4
Heterotrophic	A	13.1×10^5	15.4×10^5	5.4×10^5	16.0×10^5
(CFU/ml)	B	30.7×10^4	50.1×10^4	52.6×10^4	49.3×10^4
	C	24.0×10^3	14.4×10^3	7.8×10^3	7.8×10^3

A, Raw sewage; B, stabilization pond; C, fish pond; CFU, colony forming units.

Source: Bhowmik M L, Chakraborty P P and Chattopadhyay A. 2000. Microflora present in sewage-fed systems and possibilities of their transmission. *Waste Recycling and Resource Management in Developing World*. Jana B B, Banerjee R D, Guterstan B and Heeb J (Eds), pp-71-77.

Table 20.4. Average rate of reduction in percentage of microbial load in different sewage-fed system during 1995-98

Bacterial type		Kalyani	Rahara	Bandipur	Salt Lake
Total coliforms100/ml	A	93.97	96.54	93.43	91.69
	B	99.50	99.31	99.03	98.31
Faecal coliforms100/ml	A	94.01	92.15	90.05	87.77
	B	99.03	99.05	98.88	96.78
Faecal streptococci100/ml	A	91.57	91.77	89.85	86.60
	B	98.60	98.13	97.86	95.36
Total pseudomonads100/ml	A	92.19	90.65	89.65	91.88
	B	88.37	85.51	83.183	80.27
Heterotrophic bacteria/ml	A	74.025	69.275	64.64	63.86
	B	94.125	92.266	92.91	94.09

A, Raw sewage; B, stabilization pond.

Source: Bhowmik M L, Chakraborty P P and Chattopadhyay A. 2000. Microflora present in sewage-fed systems and possibilities of their transmission. *Waste Recycling and Resource Management in Developing World*. Jana B B, Banerjee R D, Guterstan B and Heeb J (Eds), pp 71-77.

collaboration with All India Institute of Hygiene and Public Health, Kolkata with reference to quality of fish raised from sewage-fed system along with keeping quality and shelf-life of fishes raised in fresh and wastewater-fed system. From the comparative study of average microbial loads in four sewage-fed farms it was observed that the average bacterial loads (colony forming units – CFU) in respect to faecal coliforms, faecal streptococci and total pseudomonads 100/ml of raw sewage were highest at Rahara and Bandipore farms whereas total colifoirms 100 /ml of raw sewage was highest in Kalyani farm (Table 20.3). Average value of heterotrophic bacteria/ml of raw sewage was highest at Salt Lake farm. The population of total coliforms, faecal coliforms and faecal streptococci reduced appreciably during biological treatment (Table 20.4). The reduction of bacterial load in stabilization and facultative ponds may be due to intense microbial activity that brings about a change in nature from pathogenic enteric bacteria to the bacterial populations, very active in the degradation of organic matters. This biological process facilitates the growth of different phytoplankton and consequently oxygenation takes place from their photosynthesis.

After analysis of fish samples for pathogenic bacteria present in sewage-fed aquaculture ponds into various body parts, it was observed that digestive tract always contained a larger number of bacteria than the organs and this is due to phagocytic activity of the cells present in the membrane of the digestive tract. Different pathogenic bacteria, e.g. *Staphylococcus* sp., *Streptococcus* sp., *Pseudomonas* sp., are also recovered from fish organs like kidney, liver, spleen etc. (Table 20.5). Another significant finding of this study is the absence of *E. coli* in fish muscle.

Table 20.5. Average microbial load in fish samples collected from four sewage-fed fish farms

Bacterial type*	Tissue	Kalyani	Rahara	Bandipur	Salt Lake
Total coliforms100/ml	Slime/cm^2	26.1×10^4	8.2×10^4	16.0×10^4	3.5×10^4
	Gills/g	18.0×10^4	9.0×10^4	17.2×10^4	2.0×10^4
	Gut/g	6.4×10^5	17.4×10^4	32.0×10^5	5.0×10^5
	Muscle/g	4.0×10^2	1.8×10^2	2.5×10^2	5.4×10^2
Faecal coliforms 100/ml	Slime/cm^2	5.5×10^4	1.0×10^4	1.0×10^4	1.5×10^4
	Gills/g	4.0×10^4	2.3×10^4	1.1×10^4	1.2×10^4
	Gut/g	1.5	7.3×10^5	1.0×10^4	1.5×10^4
	Muscle/g	Nil	Nil	Nil	Nil
Faecal streptococci 100/ml	Slime/cm^2	5.8×10^4	2.5×10^4	8.2×10^4	4.8×10^4
	Gills/g	8.7×10^4	2.3×10^4	8.5×10^4	5.2×10^4
	Gut/g	4.4×10^5	4.2×10^4	10.2×10^4	5.5×10^5
	Muscle/g	1.7×10^2	1.0×10^2	2.0×10^2	9.3×10^3
Total pseudomonads 100/ml	Slime/cm^2	3.6×10^4	3.6×10^4	4.5×10^4	5.8×10^4
	Gills/g	1.3×10^4	3.5×10^4	4.0×10^4	4.6×10^4
	Gut/g	7.1×10^5	6.2×10^5	8.8×10^4	3.2×10^5
	Muscle/g	4.1×10^2	2.6×10^2	3.2×10^2	3.8×10^2
Heterotrophic bacteria/ml	Slime/cm^2	13.8×10^3	9.0×10^3	12.0×10^3	10.7×10^3
	Gills/g	8.0×10^3	9.2×10^3	7.5×10^3	8.5×10^3
	Gut/g	6.8×10^4	7.9×10^3	8.6×10^4	8.8×10^4
	Muscle/g	4.4×10^3	2.4×10^3	3.8×10^3	4.4×10^3

Human health

There is a moderately high prevalence of diarrhoea, fever and cough and cold among fishermen in the study areas and also high in the control area and there is no significant difference. Regarding the prevalence of itchy skin lesions, it is significantly higher among the fishermen of Salt Lake fish farm than those of Rahara fish farm. The fishermen of the control area also have higher prevalence of itchy skin lesions than those at Rahara fish farm, but it was not statistically significant. The yearly prevalence of helminthiasis was moderately high in the study areas as well as in the control area. Hemoglobin estimation have showed that only a minority of fishermen in all the areas are anaemic (i.e. Hb concentration less than 80%). Most of the fishermen have, on an average, more than 80% of Hb in their blood.

Hookworm and *Trichuris trichura* infections were virtually absent in all the areas. Prevalence of round worm was also absent in the control area and it was 14.29% in the fishermen of Rahara fish farm and was 24.73% in Salt Lake. Poor personal hygiene and use of untreated sewage-may contribute to the high degree of round worm infection especially in Salt Lake area. *Enterobius vermicularis* was present only in 10% of stool samples of kalyani fishermen but it was significantly higher in the stool samples of Salt lake fishermen (37.93%). Interestingly, when the prevalence of *Enterobius* sp. was compared amongst the fishermen of Rahara and Salt Lake, a significant difference was observed (at Rahara it was only 17.85%), suggesting that there must be some other contributory factors responsible other than sewage. Infection of *Giardia lamblia* was significantly higher among the fishermen of Rahara and Salt Lake than Kalyani suggesting that use of sewage for aquaculture may be the primary contributing factor. Clinical examination reveals that at Salt Lake the prevalence of skin disease was remarkably higher in comparison to that of Rahara and Kalyani. Poor standard of hygiene along with poor economic condition may be responsible for it. However, handling of untreated sewage may also have a contribution. Glossitis and angular stomatitis were slightly higher in fishermen of Salt Lake than those of Rahara and Kalyani. Prevalence of caries teeth was more in fishermen of Rahara in comparision to that of Kalyani and Salt Lake, though statically insignificant. A peculiar finding of pedal oedema (19%) in the fishermen of Kalyani could not be interpreted with available limited data. This symptom was virtually absent in the fishermen of Rahara and Salt Lake. It can be concluded that there is no risk of transmission of any disease from sewage-fed systems to human being provided that the persons involved maintain good standard of personal hygiene and eat well cooked fish raised in sewage water-fed system.

Heavy metals in sewage-fed system

Wastewater as a source of rich nutrient has been recognized world over. The next problem associated with the use of wastewater for productive purpose of raising fish is the presence of heavy metals in the system and chance of accumulation and magnification in fish body and muscle (Table 20.6). In general, the values of iron (Fe) were higher than the values of copper (Cu), zinc (Zn) and chromium (Cr) in all the samples. The concentrations were lower for chromium in all the samples.

Copper and its compounds are ubiquitous in the environment and are frequently found in surface water. Copper ion precipitate gill secretions, causing death by asphyxiation. The average value of copper was higher (0.049 mg/g) in soil than water (0.034 ppm), similarly its value was higher (0.053 ppm) in raw sewage than the treated sewage (0.032 ppm). Intermediate value (0.035 mg/g) was recorded in aquatic weed

Table 20.6. Estimation of heavy metals copper (Cu), iron (Fe), zinc (Zn) and chromium (Cr) in sewage, soil water and their bioaccumulation in fish and aquatic weeds in sewage-fed ponds

Heavy metal	Sewage (ppm)		Samples				Standard (ISI) for drinking water (ppm)
	Raw	Treated	Soil (mg/g)	Water (ppm)	Fish (mg/g)	Aquatic weeds (mg/g)	
Cu	0.053 (0.046-0.06)	0.032 (0.029-0.04)	0.049 (0.045-0.055)	0.034 (0.028-0.04)	0.015 (0.006-0.026)	0.035 (0.028-0.046)	0.05
Fe	16.96 (12.65-28.50)	2.22 (1.10-3.335)	12.72 (9.66-18.54)	0.124 (0.011-0.257)	0.189 (0.109-0.252)	0.376 (0.[illegible]0-0.492)	0.03
Zn	0.067 (0.055-0.071)	0.025 (0.035-0.052)	0.064 (0.12-0.032)	0.041 (0.035-0.052)	0.022 (0.020-0.030)	0.03 (0.022-0.04)	5.00
Cr	0.027 (0.025-0.039)	0.01 (0.008-0.022)	0.031 (0.006-0.015	0.016 (0.025-0.036)	0.01 (0.003-0.015)	0.018 (0.011-0.027)	0.05

Values in parentheses indicate range values.

Wolffia arrhiza, whereas the lowest value (0.015 mg/g) was recorded in fish. Iron is the fourth most abundant element by weight in the earth's crust. In water it occurs mainly in ferric state. An appreciable difference in concentration of iron was noticed in between pond soil and water. Highest average value of 16.96 ppm was found in raw sewage and lowest average value (0.124 ppm) was observed in pond water, pond soil indicated 12.72 mg/g. The average value of iron (Fe) was 2.22 ppm in treated sewage, whereas it was 0.376 mg/g in aquatic weed. The accumulation of iron (Fe) in fish samples showed very low degree (0.189 mg/m) in comparison to aquatic weed, soil and sewage.

Zinc is an abundant element and contributes approximately 0.04 g/kg of the earth's crust. Its occurrence in sewage is expected because of its extensive use in making household appliances and by leaching from galvanized pipes. The concentration of zinc was quite low in all the samples. The average values of zinc were 0.067 ppm in raw sewage, 0.025 ppm in treated sewage and 0.03 mg/g in aquatic weed and 0.022 ppm for fish. The accumulation of chromium in all the samples was very low which might be due to its low solubility and availability in water. The average values of chromium were 0.031 mg/g in soil, 0.016 ppm in water, 0.027 ppm in raw sewage, 0.01 ppm in treated sewage, 0.018 mg/g in aquatic weed and 0.01 mg/g in fish samples.The levels of accumulation of Cu, Zn, Fe and Cr in soil, water, aquatic weed and fish (especially in muscle) samples were well below the permissible limits as per BIS for drinking water and within the permissible limits prescribed by WHO and do not pose any serious threat to consumer of fish themselves.

Shelf-life and keeping quality of fish raised in sewage-fed system

Presently, with increase in consumption of fish raised in freshwater and wastewater

by keeping in ice, the information about variation of keeping qualities and organoleptic properties, if any, during storage in conditions maintained normally by the retailers. Acceptability of catla and mrigal from both environments was very good up to seventh day of storage from organoleptic properties of raw whole fish. Study of indicators of spoilage, as above, in catla of freshwater environment remained good up to 28th day of storage and more than 50% rejection started from 36th day of storage, which indicated that catla and mrigal raised in freshwater can be accepted for human consumption up to 36th day of storage. On the other hand, catla from wastewater can be accepted up to 33rd day of storage and mrigal up to 30th day for human consumption. This indicates not much difference with regard to both shelf-life and acceptability for human consumption between fish cultured in freshwater and wastewater. It has been noticed that microbial load increases during ice-storage in conditions maintained normally by the retailers. To know their exact proliferation with different days of storage linear second degree polynomial equations were calculated for the fish raised in both fresh and wastewater environments. Though the study reveals that there is slight difference in spoilage time for catla raised in wastewater and freshwater environments, so far acceptability for human consumption is concerned, there is no difference. Similar trend was also observed in case of mrigal.

Aquaculture and sewage water treatment

Aquaculture-based sewage treatment plant

An aquaculture-based sewage treatment plant (ASTP) designed in India has incorporated cultivation of duckweeds prior to application of fish ponds,and post-fish culture depuration, with the objectives of refinement of sewage-fed fish culture and

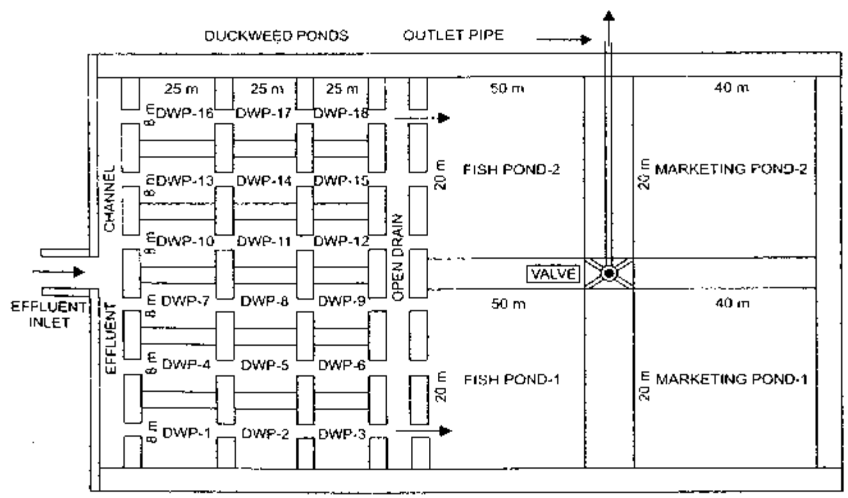


Fig 20.1. Plan of aquaculture treatment system for domestic sewage.

sewage treatment through aquaculture practices. The ASTP consists of a set of duckweed ponds, fish ponds and depuration ponds, located at a place 250 m away from the residential area and bore-wells. Gravitational flow of sewage wherever feasible for sewage intake into the treatment complex will be advantageous.

Design and construction of a model to treat 1 mld sewage: A model (Fig. 20.1) for treating one million liters per day of sewage, from a population of about 20,000 is described here.

Source: A receiving chamber for sewage feeds the effluent to the ASTP.

Duckweed culture complex: It comprises 18 ponds with brick lining (25 m × 8 m × 1 m), with three series of six ponds in a row. The sewage is retained here for a period of two days, with free passage between the series.

Fish ponds: Two fish ponds (50 m × 20 m × 2 m) receive the treated sewage from the duckweed ponds and retain it for three days.

Depuration ponds: Two depuration ponds (40 m × 20 m × 2 m) with freshwater, also used as marketing ponds, provide for depuration of fish for a week before marketing. As the fish harvest is occasional, these ponds are also used for the culture of grass carp, fed with duckweeds from the system.

Outlet: Sewage outlet drains are provided from the fish and depuration ponds for drainage into natural waters.

Candidate fish species for sewage-fed fish culture: Depending on the area of operation, different fish species could be used. Tilapia (*Oreochromis* spp.) and Mandarin fish (*Siniperca chautsi*) are some of the species that are cultured in sewage-fed waters in China and other countries. The ASTP provides for retention of sewage for two days in duckweed ponds and three days in fish ponds. This achieves the desired reduction in nutrient concentrations, BOD, COD and the bacterial populations to meet the standards for discharge into natural waters. The fish produced from the system enables recovery of about 40 % of the working costs

The model as shown in Fig. 20.2 has been used in several Indian villages for community sanitation and aquaculture, with modifications. Typically, one-third of the pond of the size of 0.2 – 0.4 ha. at the inlet end serves as the receptor of sewage from solid wastes from community latrines. This portion is stocked with duckweeds that

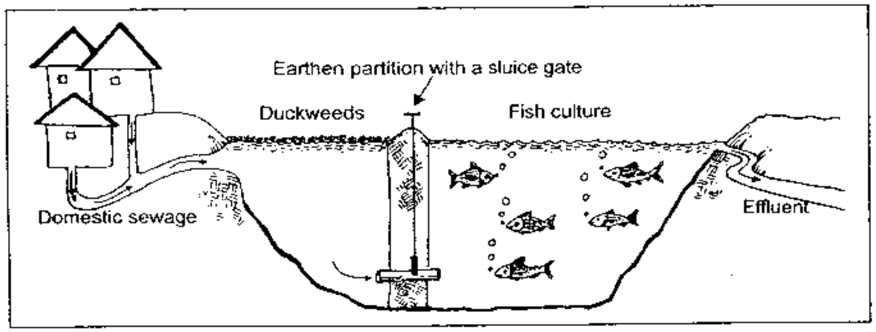


Fig 20.2. Sewage treatment in rural ponds

multiply in the presence of organic matter and effluents are then passed into the adjacent portion of the pond stocked with fish, with a continuous flow the organic loading is regulated in different sessions.

Ganga Action Plan Sewage Treatment – Kalyani Model

Kalyani sewage-fed fish farm (Fig.20.3) represents a small model of sewage treatment through aquaculture. The entire system involved two stabilization ponds of 0.5 ha each two facultative or oxidation ponds of 1.00 ha each and series of four maturation ponds (fish ponds) of 1.0 ha each, located in such a way that inlets and outlets of ponds placed diagonally facilitating the water course in zig-zag way leading to the river Hooghly. A total of 6 MLD raw-sewage is being passed though this system. Observations revealed that considerable amount of reduction in nutrient level and bacterial load has been effected within periods of 1 day, 5 days and 5 days retention time in stabilization, oxidation and maturation pond respectively. The biological system demonstrates a low-cost technology for fish production without much infrastructural installations. The maturation ponds are utilized for fish culture.

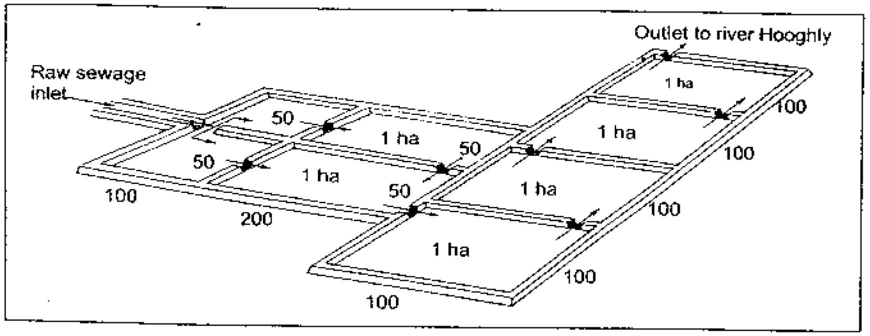


Fig. 20.3. Kalyani sewage-fed fish farm lay out

Duckweed fish-based treatment system at CIFA

The Central Institute of Freshwater Aquaculture (CIFA), Bhubaneshwar, India has developed and evaluated an aquaculture-based sewage treatment system integrating duckweed and fish as biological components. This integrated system where wastewater passes through a series of duckweed ponds, followed by fish ponds was developed at Matagajpur, Cuttack, Odisha under a Project funded by the Ministry of Environment and Forests, New Delhi during 1992-97. The pilot plant has a capacity of treating sewage of 1 million litre/day (MLD). The duckweed-fish based treatment system is an integrated system where wastewater passes through a series of duckweed ponds, followed by fish ponds. It is an innovative biological wastewater treatment systems possessing unique advantage of resource recovery in the form of fish and protein rich duckweeds utilizing nutrients from wastewaters. The system developed by CIFA mainly comprised three component systems, viz. (*i*) duckweed ponds, (*ii*) fish ponds, and (*iii*) depuration ponds.

The treatment strategy included initial treatment of sewage in duckweed ponds in a retention time of two days, followed by second stage treatment in fish ponds in retention period for three days before release into the natural water bodies. The duckweed species, viz. *Lemna, Spirodela* and *Wolffia*, act as the nutrient sink absorbing nutrients from wastewater, thereby ensuring their permanent removal from the system through harvested weeds. Fish production levels of 3-4 tonnes/ha/year are achieved in fish ponds with utilization of sewage as the only input. The technology is being replicated at two strategic point of the Bhubaneshwar city, viz. Vanivihar and Niccopark, under a collaborative project, the details of which are as follows. This one MLD treatment plant covering 0.76 ha area comprised 18 duckweed ponds (0.36 ha) of 25 m × 8 m × 1 m each and two fish culture ponds (0.2 ha) of 50 m × 20 m × 2 m each. In addition, two marketing reservoirs (0.16 ha) of 40 m × 20 m × 2 m were also provided for the depuration before marketing fish produced in the system. The treatment strategy included allowing the initial retention time of two days in duckweed ponds, followed by three days in fish ponds at the second stage of treatment before release into the natural water bodies.

The weeds, grown in ponds of the duckweed-fish based treatment system, act as nutrient pump, primarily absorbing nitrogen, phosphorus, calcium, sodium, potassium, magnesium, carbon and chloride from the wastewater. The rapidly growing plants act as a nutrient sink, absorbing various nutrients from wastewater which are removed permanently from the system as the plants are harvested. The duckweed mat covering the pond in association with the bacterial flora jointly works for purification of the wastewater. There are about more than 2,000 species of bacteria and fungi present in the root zone bed. Degradation of organic matter takes place around the root. Most of the organic content in the wastewater is decomposed in the oxidized zones around root to carbon dioxide and water. Further, ammonia is oxidized to nitrate by nitrifying bacteria in these zones. Free oxygen is depleted in regions away from the root surface, thus the denitrifying bacteria present in the zone convert nitrate present in this anoxic zone to free nitrogen. Organic matter is decomposed anaerobically to CO_2 and methane by fermentative process. Simultaneous interactions between different kinds of microbial degradation process in aerobic and reduced zones decompose organic matter and efficiently remove the nutrients by the plant root systems. The second component of the duckweed-fish based treatment system, i.e. fish pond further helps in purifying the semi-treated water received from the duckweed ponds. The microbial population in the fish ponds helps in treatment of water through both aerobic and anaerobic processes. Higher nutrient availability in the semi-treated water also ensures rich growth of plankton which is grazed continuously by the fish. Such simultaneous production of plankton and their grazing result in removal of nutrient load from the system on a continuous basis. The high protein and fat contents make duckweed plants an attractive food source for animals and poultry.

Five types of carp species, namely catla *(Catla catla)*, rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*), silver carp (*Hypophthalmichthys molitrix*) and common carp (*Cyprinus carpio*), were evaluated in the fish ponds at a stocking density of 10,000 fingerlings/ha. Without provision of any supplementary feed and fertilizers, fish production levels of 3-4 tonnes/ha/year could be achieved with utilization sewage as the only input. The fishes harvested from these ponds are kept in depuration ponds for at least one week before marketing for reducing the possible risks due to microbial contaminations. Such depuration process, since does not form an essential component of the treatment process, are not necessarily be located at the treatment site.

Application of duckweed-fish-based treatment method in 'Project WATER': The conspicuous potential of duckweed-fish-based systems has prompted CIFA and Xavier Institute of Management, Bhubaneshwar (XIM-B) to come together for demonstration and refinement of this technology for large-scale treatment of the sewage arising from Bhubaneshwar city. With financial assistance of India-Canada Environment Facility (ICEF), New Delhi, a project named as 'Project WATER' was initiated during October 2000 in Bhubaneshwar city. Under this project, the duckweed-fish-based sewage treatment plant was established at two strategic sewage receiving points of the city, viz. Vanivihar and Niccopark. The detailed specification of the treatment plant with 4.5 MLD sewage treatment capacity are as follows:

Catchment area	:	9.40 km^2
Land area	:	3.6 ha
Maximum storm water discharge	:	2,613 MLD
Dry weather inflow of wastewater	:	6.0 MLD
Designed wastewater treatment capacity	:	4.5 MLD
Primary treatment through	:	Sedimentation pond
Secondary treatment through	:	Duckweed and fish ponds
Duckweed pond	:	3 nos. (11,342 m^2)
Fish pond	:	2 nos. (8,085 m^2)
Marketing pond	:	1 no. (1,387 m^2)
Main diversion weir	:	21 m
Main channel	:	40 m × 400 m
Retention time	:	0.8 day in sedimentation pond, 3 days in duckweed ponds and 2 days in fish ponds
Species of duckweeds used	:	*Lemna* and *Spirodela*

The treatment systems begin with settlement tanks constructed before the diversion weir for minimizing the suspended solids. The raw sewage after short retention in sedimentation tank is allowed to pass through the three duckweed ponds, one after another. Each of the duckweed ponds were provided with intermittent staggering walls in order to allow longer traverse distance and retention time for the sewage within the ponds itself. The semi-treated sewage water is further allowed to enter into the two fish ponds one after the other. The treated water is finally released to the main channel. Fingerlings of six carp species, namely catla, rohu, mrigal, silver carp, common carp and silver barb (*Puntius gonionotus*) were stocked in the fish ponds at a combined density of 10,000/ha. The water samples were analyzed for different physicochemical and microbiological parameters following the standard procedures The typical

Table 20.7. Water quality characteristics at different points of the duckweed-fish based sewage treatment system of Vanivihar, Bhubaneshwar at 7.45 AM on 28 October 2004 showing the efficiency of the system

Parameters	Drainage channel at upstream	Source I (sedimentation pond)	DWP 1 (exit point)	DWP 2 (exit point)	DWP 3 (exit point)	Fish pond	Outlet	Per cent reduction (source to outlet)
Temperature (°C)	28.3	28.2	28.2	28.3	28.3	28.4	28.4	-
*p*H	6.7	6.8	6.9	6.9	6.9	7.3	7.3	-
DO (mg/litre)	0	0.2	1.4	2.8	2.8	3.5	3.5	-
Total ammoniacal N (mg/litre)	6.50	5.66	3.76	2.61	1.85	0.88	0.83	87.21
Nitrite-N (mg/litre)	0.33	0.26	0.16	0.1	0.1	0.037	0.04	87.87
Nitrate-N (mg/litre)	0.334	0.228	0.465	0.417	0.41	0.292	0.20	54.54
Total inorganic nitrogen (mg/litre)	7.164	6.148	4.385	3.127	2.36	1.209	1.07	85.06
Phosphate-P (mg/litre)	2.30	1.88	1.25	0.86	0.59	0.33	0.36	84.34
BOD (mg/litre)	100.00	84	70	56	48	36	32	69.23
COD (mg/litre)	212.00	196	156	124	100	80	72.0	66.03
DOM (mg/litre)	18.8	18	16.2	12.8	10	8.8	6.4	-
Total suspended solids (mg/litre)	150.00	128	100	88	72	64	56	62.66
Total dissolved solids (mg/litre)	200	189	155	149	134	107	90	55.0
Total solids (mg/litre)	350	317	255	237	206	171	150	-
Aerobic heterotrophs (CFUs × 10^5/ml)	67	65	30	20	20	5.5	5	92.53
Total coliform (CFUs × 10^4/100 ml)	80	63	2	0	0	0.5	0.6	99.20
Faecal coliform (CFUs × 10^4/100 ml)	45	36	15	0	0	0.5	0.2	99.55
Faecal streptococci (CFUs × 10^4/100 ml)	40	25	4	1	0	0	0	100.00

characteristics of sewage during one sampling (28 October 2004) at different points of the treatment systems are presented in Table 20.7, which depicts the overall efficiency of the system. The duckweed-fish-based treatment system being an innovative, low cost, low tech and biological in nature is an ideal alternative treatment system that can be suitably replicated in many of the Indian towns and cities.

Advantages of duckweed-fish based system

- Resource recovery: Besides treatment of sewage, the system helps in conversion of nutrients from sewage to protein in the form of fish flesh and duckweed biomass. The revenue generated can support more than 30% of the recurring expenditure of the system.

- Less sophisticated technology with easy adaptability.
- Flexibility of establishment as decentralized treatment system depending on land availability and sewage volume, thus making it suitable for small towns and cities.
- Environment-friendly system utilizing minimum energy input.
- Cost-effective biological treatment system.

Limitations of duckweed-fish-based system

- Fish being one of the components of the system, it is suitable only for treating domestic sewage. The system may not be applicable for wastewater containing industrial effluents.
- Effective only in tropical region. Further, the temperature dependency of the system makes it less efficient in colder months.
- Relatively larger land requirement.
- Applicable only for weak sewage with maximum BOD levels of 140-150 mg/litre, thus require a separate pre-treatment system for treatment of strong sewage.
- Possible problem of pests for duckweeds.
- The retention time dependant on sewage concentration and temperature.

Economic and financial Implications of wastewater treatment

Although the responsibility for collecting, treating and disposing of urban wastewater will normally lie with a local water or sewerage authority or municipality, farmers wishing to take advantage of the effluent are often able and willing to pay for what they use but are not prepared to subsidize general disposal costs. They will base their decision on whether or not they will be better off paying for the effluent rather than doing without it, taking into account the quantity, timing, quality and cost of the treated effluent. The local sewerage authority should acknowledge their financial responsibility for the basic system to achieve environmental protection objectives and only charge farmers for any incremental costs associated with additional treatment or distribution required specifically for effluent use in agriculture or aquaculture. In practice, if the effluent use scheme is considered at the time the sewerage project is being planned, treatment costs might well be reduced over those normally required for environmental protection.

Since wastewater treatment is a major cost in effluent use systems, accepting that local authorities are fully responsible for wastewater collection, it is essential that treatment process selection is made in conjunction with decisions on crop and irrigation system selection. Only this way a minimal investment in treatment can be achieved without compromising the health risks of an effluent use scheme. Once a decision on effluent quality has been taken, the required standard must be achieved consistently and the effluent treatment and conveyance system must be operated with complete reliability. Fluctuating production and demand for effluent created by seasonal and diurnal patters of water use, cropping and crop water needs must be accommodated at all times, even if the price of the effluent is varied, to be higher in the hot season.

Policy issues

The legislative framework for effluent use in agriculture can have a significant influence on project feasibility. A coherent national policy for wastewater use in agriculture is essential. This must define the division of responsibilities among involved ministries and authorities and provide for their collaboration. Institutional mechanisms for implementation of the national policy must be established and legal backing provided for enforcement of regulations. Realistic standards must be adopted to safeguard public health and protect against adverse environmental impacts. Environmental issues associated with wastewater use are the main subject of a UNEP (1991) document. Provisions should be made to adequately staff and resource organizations charged with the responsibility for assessing implementing, operating and monitoring effluent use schemes and enforcing compliance with regulations.

A national and or regional consultative committee will often be of value in developing policy guidelines. Serving on this committee should be a representative of all the main interest groups, including water resources planning, public health, public works (municipalities), agriculture and forestry, environmental protection, trade and commercial interests (including farmers' representatives). Policies emanating from such a committee should be free of local or partisan influences but, nevertheless, should be pragmatic. In particular, enforcement legislation must be unequivocal, unambiguous and addressed to the main problem areas. The committee should also be charged with assessing the epidemiological and agricultural impacts of effluent use schemes.

The management of India's water resources falls under the jurisdiction of a number of government agencies although the primary responsibility for the development of water belongs to the individual states. The Central Government oversees the implementation of the national policy on resource development and exploitation as well as manages inter-state and international rivers and river valleys. It also provides technical advice to individual states on development, flood control, navigation, coastal erosion, dam safety, navigation and hydropower if required. The Ministry of Water Resources is the principal agency responsible for water in India and, as such, oversees the planning and development of the resource from policy formulation to infrastructure support.

The National Water Policy (NWP) is the primary document stating the position of the Government of India on water resource issues ranging from drought and flood management to drinking water provision. The NWP, 2002 calls for intensifying research through recycling and re-use of water. It calls for better water management practices and improvements in operational technologies. The policy also calls for adopting participatory approach to water resources management. Specifically it calls for involving not only the various governmental agencies but also the users and other stakeholders, in an effective and decisive manner, in various aspects of planning, design, development and management of the water resources schemes.

The document specifically mentions that "practice of focusing on water supply to the exclusion of sanitation and wastewater treatment, should be given up". This plan establishes the need for further research and development on technologies for the treatment of sewage and the health effects of sewage water used in agriculture and horticulture. However, field analyses throw up multiple issues regarding proper implementation of such guidelines. Lack of clarity regarding areas of operation often leads to overlapping of different departments. Since wastewater use in agriculture shows benefits in the form of livelihoods and income generated, there is a need to define a legislative framework for large-scale implementation of the same. A coherent national policy for wastewater use in agriculture and various other sectors is bottlenecks/ key issues in institutional handling of wastewater.

The previous discussion raises the fundamental question of who is responsible for wastewater aquaculture, providing support and technical advice, ensuring the safety of products and informing the consumer and other stakeholders about such activities? From a regional or local government perspective, such responsibilities might be integrated into existing organizational structures. Considering organization within many local governments, it has been noted, for example in cases of Bihar, Uttar Pradesh and West Bengal, that their centralized and hierarchical structures, and absence of any over-arching thematic or strategic forces, makes it extremely difficult to identify effective mechanisms to support, extend and control wastewater aquaculture in spite of local interest and enthusiasm among some institutional sectors. A primary responsibility for institutions dealing with wastewater aquaculture, or other farming practices exploiting waste resources, will be to protect the health of consumers, and this may involve implementing standards, guidelines and regulatory safeguards. However, if defined better, the benefits generated directly and indirectly by wastewater aquaculture could potentially justify an increase in spending. One way to achieve this would be to conduct a comprehensive cost benefit analysis considering alternative waste disposal options.

The status of indirect approaches to wastewater aquaculture has been described to a limited extent and a number of health risks and other negative impacts have been reported. However, the possible impacts of such policy developments should not be underestimated; indirect approaches to waste reuse, especially wastewater aquaculture, are widespread in many developing countries and changes in the acceptability or value of products from such practices may have serious consequences for the livelihoods of many poor people. Although bringing indirect and uncontrolled waste reuse practices into a regulatory framework may influence consumer perception of products cultured, safeguarding the health of workers and consumers in the long-term should be a priority.

Relevant problems

There are three fundamental problems with the wastewater aquaculture. First, most of the potential benefits as specified are in the nature of public goods and hence are subject to free rider's problem. The benefits flow to the country as a whole or even to the humanity at large-in fact, both present and future generations. The second major problem is that the current yield rate of most wastewater resource in this region, whether in crops or in fisheries, is awfully small so that they tend to be easily attracted to alternative uses other than aquaculture. Third, the weak economics of aquaculture on wetland and the consequent lack of economic strength of the traditional dwellers on wetland make them very susceptible to various negative externality effects from non-aquaculture activities, which they cannot resist.

The legal framework governing use of wetlands in West Bengal that although the government had initially started protecting the private property rights in wetlands and water bodies so as to promote aquaculture, later on the thrust shifted towards development under active government ownership and control, so much so that the private or even common property rights earlier extended to promote fisheries were severely cut back and put at the disposal of various Government departments. In the process, the property rights regime on wetlands seems to have shifted from one extreme to the other, as if private or common property management of these resources were invariably 'bad'.

There is no doubt that the sewage is a readily available biodegradable nutrient rich resource and aquaculture provides an opportunity for not only converting this waste into valued protein food but also a biological means for wastewater treatment. With the recent emphasis on environmental up keep and standards for discharge of wastewaters into natural water course, aquaculture, in fact offers high potential as resource recovery-based treatment system.

21. Cage and Pen Culture

Rearing of finfish and shellfish in cages and pens in water-based confinements is an aquaculture technique which is gaining importance world-wide for intensive exploitation of existing, especially large, fresh or brackish water and marine resources. The confined aquaculture system as cages, pens or enclosures consists of growing of young fry of finfish or shellfish to a large size, within netting or screening, which allows free circulation of water. Enclosure is a confined bay, where shoreline is typically closed-off by a net or a screen barrier on all but one side. The rearing facility in pen is almost man-made, the sides being covered by bamboo-matting, netting or screening. The bottom in both, enclosures and pens, however, is bound by lake bed. Cage, on the other hand, is enclosed on all sides leaving a small portion at the top for cage operations. However, the terms 'enclosure', 'pen' and 'cage' are virtually synonymous and therefore they are often together referred to as enclosures.

Cage culture possibly first originated nearly 200 years ago in Cambodia where fishermen used to keep *Clarias* sp. and some other fishes in bamboo-made cages in the basements of floating dwellings, primarily for holding and marketing them later. This gradually became a system of culture, since fish could withstand crowded conditions inside cages and grows with kitchen-scrap, leftover rice and other similar waste materials.

The system gained popularity throughout lower Mekong basin. Cage culture is traditional in parts of Indonesia also, where cages are anchored in streams which are practically open sewers. Common carp culture in bamboo-cages is practised in west Java, since early 1940. This type of traditional fish culture, distinguished by its reliance on natural construction materials and waste feeds is still practised in many parts of Indonesia and Indo-China region. However, although moderately successful, these methods of rearing fish have been largely localized and not directly given rise to current cage fish farming industry. Modern cages utilize synthetic mesh or netting and have collars largely fabricated from synthetic polymers and metals, although wood is still widely used in many designs. Modern cage culture in open water-bodies, probably originated in Japan in early 1950s. However, it was only during the past 40 years since 1970, that aquaculture in enclosures has spread to other countries. According to Food and Agriculture. Organization, cage culture is now practised in over 62 countries and has become a high-tech business in developed countries such as floating and/or submerged cage-culture of salmonids in Norway, Canada, and Scotland; tuna and yellowtails in Japan; Chinese carps in China; and catfish in the southern USA. Currently 80 species of finfish are being cultured in cages. The dominant being Salmonids followed by Japanese amberjack, Red sea bream, Yellow croaker, European seabass, Chinese carps etc.

In India, cage culture was initially attempted for the first time in air-breathing fishes in swamp for raising major carps in running water in the rivers: Yamuna and

Ganga at Allahabad and for raising common carp, catla, silver carp, rohu, snakeheads and tilapia in still water-body of Karnataka. Thereafter the cages are mostly used for rearing fry in many reservoirs and floodplain wetlands to produce advance fingerlings for stocking in the main water-body. Sea cage culture although a recent phenomena is already being done by many developed countries, amongst which the nine leading countries are: Norway, Chilie, China, Japan, United Kingdom, Canada, Greece, Turkey and Republic of Korea. In India, it was initiated in 2007 only with the culture of Asian seabass in cages along Vishakhapatnam coast by Central Marine Fisheries Research Institute (CMFRI). The other fishes currently cultured in cages are grey mullet, *Mugil cephalus*; pearl spot, *Etroplus suratensis*; and also shrimps, lobsters and mud crab as their seeds are available in nature, cobia *(Rachycentron canadum)* whose breeding in captivity has been standardized is also being experimented for same. Cage culture in open sea got impetus with the initiation of the financial support from the National Fisheries Development Board, Hyderabad. The board sanctioned 14 open sea floating cages for open sea farming across the country along almost all maritime states in India.

Compared to cage culture, pen culture has a more recent history. It possibly started in inland sea area in Japan in early 1920s and later spread to China in early 1950s for rearing carps in freshwater lakes. Pen culture was taken up on a commercial scale in Laguna de Bay and San Pablo lakes in the Philippines from 1968 for rearing milkfish, *Chanos chanos*. Presently, commercial pen culture of fish is in vogue in the Philippines, Indonesia and China. The main species cultured in pens in these countries are tilapia and milkfish, grass, bighead and silver carp and tilapia.

In India, *in-situ* carp seed rearing was attempted in Bhavanisagar and Tungabhadra reservoirs in pens for rearing spawn and fry of carps and in Pillaimadom Lagoon in Mandapam, near Rameswaram to culture mullets and milkfish. Pens are still constructed by and large in the same way that of older days, excepting in some cases where nylon or polyethylene mesh nets have replaced traditional split bamboo fences. In Chilka lake, traditional *Jano* fishery used enclosures made of bamboo strips to culture-prized mullets. Now, it is replaced with *Gheri*, where enclosures made of nets are used for prawn culture.

Scope of cage and pen culture

Indian reservoirs with water spread of 3.15 m ha, and yield potential of 50, 20 and 8 kg/ha/year only from small, medium and large reservoirs, respectively, leave enough scope of enhancing fish yield from such resources through culture-based capture fisheries. Same is true of floodplain wetlands (*beels*), with 0.79 million ha of resource and yield potential of above 1,000 kg/ha/year. To bridge the gap in production and potential, stocking of fingerlings of fast growing fish species at 10 to 15 g or 100 to 120 mm size is being advocated. Availability of quality seeds of desired species at desired size is often scarce, expensive and becomes a critical requirement for successful fish production ventures, both in stocking of open water-bodies and aquaculture in ponds. Thus stocking with right kind of fish seeds, species, size (>100 mm) at right time is essential to optimize fish yield from such open waters. Though 24 billion fish fries are produced every year, there is acute shortage of fish fingerlings to be stocked in the reservoirs/wetlands all over India. The fish seeds, if at all available in some distant places, it is difficult to transport them up to the reservoir/wetland site due to high mortality during transport. Therefore, cage and pen culture offers ample scope in *in-situ* production of stocking materials, provides a vital input towards production enhancement programme for Indian open waters.

Fish production from marine resources presents more or less a stagnating trend all over the world. According to Food and Agriculture Organisation (2007), 2% of fish stock is underexploited, 18% moderately exploited and 52% fully exploited, therefore producing catches at or close to their maximum sustainable limits. India also adopt the same where fish production from marine sector over the last 10 years presents more or less a stagnating trend with an average production of 2.9 million tonnes. In this context there is no scope for further increase in production from inshore marine fisheries by putting more fishing effort. However, the sector provides great scope for increasing fish production through coastal and offshore mariculture, including open water cage culture of potential species. Cage culture in sea offers the fishers a chance for optimally utilizing the existing water resource which in most cases has limited use for other purposes. It is a low impact farming practice with high economic returns. The importance of sea cage culture can be gauged by the fact that production of Atlantic salmon increased from 294 tonnes in 1970 to 1,235,972 tonnes in 2005. India with a vast continental shelf-area of 530,000 km^2 and Exclusive Economic Zone of 2.02 million km^2 has ample scope for mariculture which can be taken only in cages. The yield from the resource will not only add to the fish basket but will also add to export earnings as shrimp, crab and lobster are excellent export earners.

Pen and cage culture can be practised at various management levels such as extensive, semi-intensive and intensive methods. In extensive culture, no supplementary feed is given and cultured species solely depend on naturally available food in the water-body such as plankton, detritus, periphytic community and benthos. In semi-intensive culture, low protein (<20%) feed is given to supplement natural food. Extensive and semi-intensive cultures can be practised in pens and cages in fairly productive water-bodies. In intensive culture, species are reared almost exclusively on high-quality supplementary feeds (> 30% crude protein). This type of culture can be more conveniently practised in cages rather than in pens.

Advantages and some considerations

The major advantages of enclosure aquaculture are resource ranching and technology benefit. In resource ranching: (*i*) there is a possibility of making maximum use of all available water-bodies, (*ii*) it helps in reducing pressure on land use, and (*iii*) permits more intensive use of existing waters. From the technology point of view, the advantages are: (*i*) a rapid, easy, sure and complete harvest of fish with very little effort; (*ii*) scope to raise different species of fishes inside enclosures and in open-waters; and (*iii*) direct

Feed is supplied to grow-out fishes at 5% body weight at which highest growth rates have been observed in many of the cultured species. Feeding more than twice a day and supplying food in excess of 5% of body weight result in wastage of feed and proves uneconomical. Feed is best supplied *ad lib.* based on quantity of feed consumed by fish within 10 min. of its supply. Feed formulations are fortified with adequate quantities of vitamins, minerals and growth-promoting substances, together to an extent of 0.1%. Broodstock may be provided with vitamin E (200 mg/kg feed) and vitamin-C (50 mg/kg feed) and fed @ 3% body weight for about 5 to 6 months commencing from February or earlier depending on the commencement of breeding season. Veterinary brands of preservatives, drugs and antibiotics, may be added to prevent/cure fish disease and as a prophylactic measure.

Enclosure structure

Cage: Four types of cages are being used for cage aquaculture: fixed, floating, submersible and submerged. Fixed cage, though very primitive in origin, still in vogue, is used in shallow water with water depth 1 to 3 m in those reservoirs where water depth does not fluctuate too much. Fixed cages are comparatively inexpensive, simpler, and smaller in size and shape and their use is also restricted. Floating cage, on the other hand, is basically supported by a floating frame, where from net bags are kept hanging in water without touching the basin. It is generally practised in water-bodies with depth of water more than 5 m in reservoirs, 3 m in wetlands and 2 m in canals. Enormous diversity of types, size, shape and design, of this cage has been developed to suit the wide purpose of the fish growers in open waters. Submersible cages have net bags suspended from surface and with adjustable buoyancy may be rigid or flexible, The submerged cages have net bags fitted in a solid and rugged frame and submerged under water, operational mainly in marine environment.

Ideally, cages used for aquaculture should be inexpensive, durable and easy to handle. Various shapes and sizes are being used successfully depending on: *(i)* culture operation, be it for rearing seed or for grow-out culture, *(ii)* on the type of resource, wherein these are installed, reservoir/wetland or sea, and *(iii)* availability of support infrastructure. In most of the cases, they have a collapsible frame structure and screen is of nylon or other synthetic webbing of various mesh sizes.

Pens: Pens are fenced enclosures created along the margins of watersheds. Pen culture has considerable potential in situations where large and suitable watersheds exist. Flat or mildly sloping bottom with muddy clayey loamy soil substratum with not less than 50 cm and not exceeding 1.2 m water depth during growing period of 4 to 6 months, without sharp draw-downs, are most suitable sites for installation of pens. The method of erection of pens can be two types, viz. on wet ground where already water exists and on dry surface where submersion up to 1.2 m is expected. The individual pen segments may be of any shape and of varying sizes, as dictated by area and contour of water-body. The supporting structure is constructed by driving stakes (length: 2.5 m; diameter : 30 to 40 mm) into bottom, fixed 1.5 m apart, and braced with long and straight split-bamboo horizontally at every 30 cm height from ground level. In a dry pen, a trench 30 cm wide and deep may be dug, having 50 cm pits at every 1.5 m distance, for firmly driving poles into bottom soil, well before onset of monsoons. And, in wet pens, water area has to be demarcated using a guide rope and corner posts. The structural framework is prepared using 2.5 m long bamboo poles (fixed in bottom-mud vertically along the guide rope at 1.5 m intervals) with upper and middle bamboo bracing. The pen screen (12 mesh/cm) is lined inside the pen structure. Joining running length of material by stitching makes screen of desired width (approximately 1.8 m). In wet pen bottom portion of the screen (30 cm) is kept folded inside and pushed down with the help of brick lying all along, and in dry pens 30 cm portion is buried in trench and filled with soil. The top screen is raised and tied to upper horizontal bracing with ties (at the bracing points on top, middle and bottom) at each vertical post. Net cover for pens may have to be provided to ward-off any possible bird menace. Provision may have to be made for ladders or other perches for attending to feeding and harvesting fish.

Materials: The materials used for constructing enclosures should be strong and durable enough to hold collective weight of fish stock and yet allow relatively unrestricted exchange of water. Ideally materials used for screen and other accessories should be: (*i*) strong, (*ii*) light, (*iii*) rot, corrosion and weather resistant, (*iv*) fouling resistant, (*v*) easily worked and repairable, (*vi*) smooth textured and thus non-abrasive to fish, (*vii*) inexpensive, and (*viii*) easily available.

Collar and flotation system for cages: The frame of the cage (collar) is for providing support to cage bag in water column. Many cage collars also serve as work platforms with flotation system. The simplest is constructed almost entirely from bamboo and wood. Other examples include galvanised iron– G.I pipes with 6.09 m length, 6.5 to 7.5 cm diameter and 4 to 5 mm thickness normally used in bore well can be fruitfully utilized for cage framing or conduit iron tube or rigid PVC or Oriplast make HDPE pipes (6.5 cm and 6 mm thickness can also be utilized, although latter are costly but have high durability, thus cost effective in long run.

Empty barrels/drums with tightened lids having 22 kg weight, 88 cm length, 180 cm circumference, 58 cm diameter are suitable as floats. The HDPE drums, fibreglass or Styrofoam are used as buoys to keep cages afloat. Sinkers, made up of locally available stones each of 3 to 4 kg size tying from the bamboo frame with nylon ropes along the corners and central sides are needed to keep the cage straight and in proper shape, withstanding wave action. A total of eight sinkers are needed per cage.

Pen screen structure: The materials required for pen construction are: (*i*) fencing screen of suitable material, (*ii*) bamboo or wooden poles to support and hold pen screen in position against water current, wind and wave actions, (*iii*) 3 to 5 mm diameter foot and head ropes of durable quality, and (*iv*) tying or lacing twine of about 1 mm thickness.

The screen materials used for making pens should be: (*i*) having small mesh size to retain fish fry or fingerlings; (*ii*) resistant to long exposure to sun and water; (*iii*) sturdy enough to withstand stretching tension and current, wind and wave action;

and easy observation of feeding activity and general health of fish and elimination of fish losses due to predatory animals in open ecosystems. These may be considerable indirect employment opportunities.

However, enclosures have their limitations – strong water current, turbulence, wind and wave actions are not congenial, as they may damage or dislocate enclosure structures. Therefore, their location is restricted to sheltered areas. Backup feed store, hatchery and marketing places are called for and therefore strategic location is necessary. An adequate water exchange through enclosure walls is needed to remove metabolites and to maintain high dissolved oxygen (D.O.) levels. Rapid fouling of screen requires frequent cleaning. There is absolute dependence on artificial feeding, unless highly eutrophic water-bodies are utilized, especially with regard to cage culture. High quality balanced rations are essential for fish stock, and feed losses are possible through walls unless dispensed appropriately, using innovative methods. Sometimes interference from natural populations, i.e. small fish entering into enclosures and competing for food can occur. Security at times is a problem, since fish in enclosures may be easily poached or structures damaged by vandals. Intensive cage culture practice may lead to environmental perturbation with the release of unused feeds and faecal matters rendering eutrophication especially in small reservoirs/wetlands while growing table fish years together in the same water-body.

Site for location of enclosures selection

The selection of site for cage culture is very important and success depends on selection of proper site. Factors that must be taken into account include: *(i)* depth of water column, it should be at least 5 m or more in case of reservoirs/creeks and coastal areas and 3 m in case of wetlands and canals; *(ii)* water quality, and *(iii)* fish seed availability. In large and medium reservoirs, site should be in protected bays to evade strong wind action while in wetlands it is in the deepest portion. In small reservoirs, the cage should be anchored in the deeper lentic sector avoiding direction of current flow through sluice gates and irrigation channel. Site should be devoid of local and industrial pollution, devoid of algal blooms and macrophytes and have good water circulation. Should have access to land and water transportation but away from frequent disturbance of local's. It should not hinder the navigation, if being practised in the reservoir or sea.

Fish species for enclosure aquaculture

Fish culture in enclosures is practised by 62 countries all over the world and currently 80 species of finfish are being cultured in cages. The dominant being Salmonids, followed by Japanese amberjack, Red sea bream, yellow croaker, European seabass, Chinese carps, perches, tilapia etc.

The choice of species depends to a large extent on availability of fish seed and market demand. However, the main desirable characteristics of the candidate species for enclosure aquaculture are their potential for fast growth in fingerlings and grow-out phases, high survival, capacity to withstand overcrowding, rapid adaptation to artificial feeds, high-feed conversion rate, quality flesh and resistance to diseases and bacterial infections. The Indian and Chinese carps (*Catla catla, Labeo rohita, L. calbasu, L. bata, Cirrhinus mrigala, Cyprinus carpio, Hypophthalmichthys molitrix* and *Ctenopharyngodon idella*), air-breathing catfishes (*Clarias batrachus* and *Heteropneustes fossilis*), climbing perch (*Anabas testudineus*), tilapia (*Oreochromis mossambicus*), snakeheads (*Channa striatus* and *C. marulius*) and freshwater prawns (*Macrobrachium rosenbergii* and *M. malcolmsonii*) are cultured in freshwaters in India. However, there are many other cultivable species, the most important being, other catfishes (*Ompok* spp., *Mystus* spp., and *Pangasius* spp.), perches and feather backs. Certain brackishwater fishes like *Etroplus suratensis*, *Lates calcarifer*, *Mugil cephalus* and *Chanos chanos*, and marine species,viz. cobia (*Rachycentron canadum)*, mud-crab *(Soylla tranquebarica)* and lobester *(Panulirus homarus)*, are being cultured in marine ecosystem currently. However, other fishes like groupers (*Epinephelus malabaricus*, *E. tauvina*, and *Cephalopholis* spp.); rabbit fishes like *Siganus* spp., snappers, viz. *Lutjanus argentimaculatus* and *L. lutjanus*, could be acclimatized and adopted for their culture in enclosures.

Stocking density

The number of fishes that can be stocked in cage or pen is variable and depends on carrying capacity of the water (water-spread area, depth and water quality), water exchange, species of fishes and quantity and quality of supplemental feed input. To get optimum fish production from cages and pens, the stock needs to be provided with such conditions which minimize losses and promote growth. This involves (*i*) stocking at densities appropriate to the site/size of the fish and methods of rearing, (*ii*) feeding fish in the most cost effective manner, (*iii*) ensuring best possible water quality within cages, (*iv*) maintaining cages, anchors and auxiliary gear in proper condition, and (*v*) regular checking of stock for disease, removal of dead fish and treatment of infected fishes. Samples of fish should be taken at regular intervals and weighed so that growth of stocks can be monitored.

Food and feeding requirements

The feed should contain a full complement of proteins (including essential amino acids), fats and carbohydrates as energy sources as well as non-energy sources, like vitamins, minerals, etc. Compounded diets may be prepared by balancing feed ingredients so that they would yield desired level of proteins, carbohydrates and fats. About 70% of the energy is used for metabolism and 30% is converted to fish flesh. Protein is the costly factor in feed formulations. The requirement of protein may vary from 24 to 50% of diet according to species and stage of its life-cycle. Excessive amount of protein supplied to fish is used more as energy source than growth. Adequate supply of digestible carbohydrates and liquid fats (with long chain fatty acid-poly unsaturated fatty acids-PUFA) would reduce cost of feed and at the same time carbohydrates would supply up to 20% of the available calories in the ration and fat up to 30%. This will spare protein since less protein would be used for energy and would be converted into fish flesh. Fats may be added at 5 to 10% and carbohydrates at 15 to 25% to diet.

(*iv*) resistant to cuts by crabs and other animals; (*v*) relatively low-priced and easily available; and (*vi*) easy to handle and support.

The HDPE mono-filament webbing material is commonly used, being low-priced and is lighter and resistant to damages by crabs. The material is also quite resistant to sunlight, saline water and stretching tension. However, in an environment where filamentous algae grows in abundance, the netting material tends to get clogged. Weekly brushing of pen-wall reduces this problem. The material usually comes in rolls of 0.75 to 1.2 m in width, varying from closely woven (40 mesh/cm) to 10 to 20 mesh/cm. Approximately, 40 meshes/cm fabric is ideal for rearing spawn to fry and 12 to 15 mesh/cm webbing, from fry to fingerlings. Knotted nylon webbing (stretched mesh of 20 to 400 mm) may be used for making a top-cover, whenever necessary. Matured and well-seasoned bamboo or casuarina poles (50 to 70 mm diameter) are best materials for supporting stake structures, particularly in relatively shallow water areas. Pressurized treatment with preservative chemicals and tar can prolong life of posts. Side bracing is done either with thin round or split bamboos.

Cage design and construction

Shape and sizes: Cage shape does not make significant difference in fish production. It is important that cage volume remains relatively resistant to deformation by external forces, which could cause crowding, stress and mortality of stock. Static force is vertical which includes weight of bag and fouling. Static loads can be estimated from the area and density of netting or rigid mesh materials used, the extent of fouling, fish biomass and amount of ropes and weight of frame components used to strengthen and stiffen structure. It is important to quantify static loads for design of flotation and mooring systems, which are less critical in determining design of cage. Dynamic force caused by currents act horizontally, although wind induced surface waves acting on the collar will induce some degree of vertical dynamic loading. Quantification of currents and response of materials can help in predicting how a particular design will perform in terms of water exchange and deformation of cage and can aid in design of frame for rigid mesh materials and in rigging system for netting.

The size of fish cages depends on the scale of operation, species and stage of fish reared and infrastructure, financial and managerial resources. The cages used in India in reservoirs/wetlands are small, in the range of 1 to 36 m^2 and both cylindrical and rectangular ones being suitable for manual operation. Cage (bag) depths between 0.9 m and 1.6 m are generally considered ideal for most freshwater fishes and give stocks sufficient shelter from surface effects, whilst providing adequate water volume for exercises and feeding. Preferred cage size and shape for raising fingerlings is, 5 m × 3 m × 3 m dimension and for table size, it is, 5 m × 5 m×3 m or 4 m ×4 m × 3 m for Inland waters. The height of freeboard is determined on the basis of the species cultured. However, the influence of wind forces in exposed netting should be considered. A compromise is to use a top-net, which deters entry of predators as well.

Sea cage structure and size is still under investigation, generally circular type cages

are used in sea. Initially the cage used in sea had outer cage net of 7 m diameter and 4 m depth and the inner cage net of 6 m diameter and 3 m depth. At Karwar, a low cost round (6 m diameter) metal cage was designed using GI pipes and floated on 10 HDPE barrels filled with 30 pounds of air. It appears to be cost-effective than HDPE cages. At Mangalore, cages of netlon material were designed with inner nylon net to grow the juveniles. At Kochi, 2 m dia. HDPE cages were used for farming trials. The frame was provided with two nets – an inner grow out and an outer predator net. The nets are suspended as two separate pieces, overlapping at the floating pipe level. HDPE ballast pipe (2 1/2" or 6.25 cm dia.) with 5 mm holes at regular intervals, having three 16 mm steel wires inserted into it is used as sink weight for stabilizing the column structure of the outer cage. Polished marble stones (1 to 1.5 ft × 0.5 ft or 30 cm to 45 cm×15 cm) each weighing approximately 15 to 20 kg, 1 gabion (3 m × 1m × 1 m) and PP ropes (12 mm and 32 mm) are used for mooring. Indigenous sealed, PUF-filled Sintex milk cans used as buoyancy.

An innovation in sea cage mooring system: Dyneema (ultra-high-molecular-weight polyethelene-UHMWPE-fibre) mooring is introduced for cage mooring in open sea. It needs no metal shackles and rings for connection of floats. It comes with the entire mooring set attached with a gabion box.The Dyneema fibre is 15-fold stronger than steel, 4 to 5-fold stronger than polyamide,whereas lighter than water and extremely durable. It has longer life time and reduced maintenance. It is bite resistant and can even pull oil tankers. The Dyneema is not affected by seawater, whereas, up to 15% strength of nylon is lost in seawater. Now the sea cage structure and size has been standardized and a cage of 6 m dia and 5 m depth costs approximately 0.150 million.

Mesh size is critical and depends on the initial size of stock. For rearing fry, it is desirable to have 1 to 2 mm mesh size to raise fingerlings from fish fries of 10 to 25 mm size, and if objective is to raise table fish from fingerlings.The mesh size would be 4 to 6 mm with knotless nets (HDPE Plasto nets). Unless pre-fabricated bags are ordered from a commercial company, netting must be cut and assembled into cage-bags at farm itself. The shape of floats requires some consideration. The dynamic forces acting on a floating framework are principally horizontal, produced by wind, current and waves, although latter does have a vertical component as well. Wind forces act on freeboard netting and other parts of the structural frame, which are above the water line. Based on meteorological data of the region, the wind forces are to be assessed and superstructures need to be designed. Some of the cages fabricated with frame or collar and flotation system are discussed here.

Bamboo cage: The cage frames (6 m × 6 m × 1.5 m) are constructed using straight green-bamboo sticks (40 mm in dia.) for holding net bag in shape. The nylon net of 12 mm mesh is stitched like a bag of the size of the cage and hung within the frame. The top, on one side is provided with a slit, which can be closed, for feeding and for handling stockfish. Eight empty and sealed jerry cans (high density polypropylene, HDPP); capacity: 35 litres, each) are tied at 1.5 m height from the bottom to the corner and side bamboo sticks are floated in wind protected deep-water, after anchoring with two stones on either side of cage. The cage when floated would have an underwater volume of 36 m^3 with a freeboard of 0.5 m above water.

PVC floating cages: A rectangular cage (4 m × 2 m × 2 m size) with knotted netting bag is tied to a HDPP/PVC pipe auto-floating framework. The frame is constructed from 70 or 90 mm diameter (6 kg) rigid PVC pipe with appropriate right angle elbow at each corner. The pipe and elbow are glued with PVC cement and joined airtight. The top of the cage bag is attached to the frame, which also serves as a flotation device. Twelve, 100 g lead weights may be attached equidistantly to netting at the bottom-line of the cage-bag to help retain its rectangular shape. The top of the cage net is raised above water level to have a freeboard (about 30 cm), by a light, additional supporting PVC frame or any other device.

Basket cage: A small basket or shuttlecock-shaped floating net cage with a volume of 0.5 m^3 were fabricated and used in feed-testing operations, bioassay of waters using fishes as experimental animals and for rearing air-breathing catfishes. The cage consists of a frame made of galvanized iron rod of 8 mm thickness. It has a lower ring of 50 cm dia and an upper ring of 75 cm dia connected (by welding) by 6 supporting rods, each of 60 cm long. A perforated plastic basin (diameter 50 cm; depth 10 cm) is fastened with nylon twine to lower ring. The frame is covered with a nylon net (mesh 3 to 8 mm^2) well stretched and stitched in between the top and the bottom rings. An opening with a flap is provided on the top for handling fish and feeds. The cage is floated with Rexene floats (dia. 15 cm), one fixed on each supporting rod, 25 cm below the upper ring. This ensures enough freeboard above water level. A number of such cages can be floated and held in an anchored floating framework. The cage is ideal for culture of magur (*C. batrachus*) and singhi (*H. fossilis*) in any type of protected water-body, including open-wells.

Metallic frame cages: Metallic cages can be of circular or square type. The square cage is constructed using conduit pipes as a box-type frame (3.35 m × 3.35 m × 2 m; area 10 m^2) to which a net bag is attached and floated with the help of a floating-bamboo catwalk. The iron-conduit pipe is available in electrical shops with a diameter of 20 mm (gauge 16), which are light in weight. Clamps and nut-and-bolt arrangement can assemble frame. The catwalk is buoyed up with 4-sealed-oil drums (200 litres capacity). Similar cages were fabricated with minor changes for easy transportation for Odisha, Andhra Pradesh, Chhattisgarh and Meghalaya.

The circular cages have been designed and fabricated of 1 m^2 (radius, 0.56 m; circumference: 3.52 m), 5 m^2 (radius ,1.26 m; circumference: 7.92 m) and 10 m^2 (radius, 1.78 m; circumference: 11.209 m). The cage frame for a 10 m^2 consists of four arc pieces (each, 2.802 m long) with nut-and-bolt arrangement for assembling to form frame of a cylindrical cage. The frame is made of iron conduit pipe. Each arc unit has uniformly arched top and bottom pipe pieces (chord length 2.523 m) which are joined vertically by welding 3 similar, straight 1.5 m long pieces. Each vertical pipe has a float ring welded at a height of 1 or 1.5 m from the bottom. The cage can be floated in water, using four polyethylene jerry-cans of suitable buoyancy (35 kg, each) tied to float ring on alternate vertical pipes with nylon ropes. The cage size can be

enlarged or reduced both in area and depth; the former by increasing or reducing number of arcs and adjusting curvature to make it a perfect circle, and the latter by increasing or decreasing length of vertical pipes. The frame is given two or three coatings of waterproof paint to prevent its corrosion in water. The net material (knotted or knotless) of suitable mesh size is stitched like a cylindrical bag with a circular bottom, hung and fastened (hanging coefficient 0.5 to 0.7) to frame The net cage is enclosed at the top, providing a slit for handling stocked fish.

Cage linkages and groupings: The number and arrangement of cages should depend on: (*i*) size of farm, (*ii*) area and nature of site, (*iii*) shape and design of cage and linking system, (*iv*) mooring constraints, and (*v*) environmental considerations. Square and rectangular cages can be assembled in a variety of configurations. It is recommended that for most sites, although cage groupings may be 8 to 10 cages long, they should be no more than two cages wide. Their groupings together markedly reduce forces acting on individual cages. Linkages between cages should be so designed that the pitching motion is only moderately damped, while rolling, surge and sway are kept to a minimum. If linkages are rigid, forces that are concentrated are greater at these points. It is best to construct either smaller cages with linkages, which permit some degree of pitching and bearing or large cages with flexible collars. The simplest type of linkage is with rope or chain, which is secured sufficiently tight, to reduce all motion, except in vertical plane, to a minimum. Rubber tires are often lashed or bolted between cages to act as fenders.

Anchoring and access: The lines and anchors together form mooring system to secure cages in a desired position. The moorings also influence stress acting on individual cage and its behaviour in rough weather and can affect fish production. The mooring system can be: (*i*) multiple, or (*ii*) single point. The former is more common and involves securing cages in one particular orientation, while the latter allows them to move in a complete circle. Cages moored from a single point distribute wastes over a considerably larger area than those secured at multiple points. Most methods of moorings involve use of rope and chain to connect cage or group of cages to anchors or pegs. However, an alternate method is to drive long posts into substrate and to attach cage raft directly, either with ropes or tire strips, which permit tidal and wave induced vertical movements of cages. Mooring lines must both withstand and transform forces. The tidal length of mooring line to bear anchors should be at least 3-times the maximum depth of water at the site. Block anchors are more efficient as they tend to bed down into substrate for inland waters. Access to cages is normally by boat. Daily feeding and other routine management activities are done by boat, rigidly fixed pier walkways or solid-bank attachment.

Feeding rings, troughs or feeders: In design and construction of cages, consideration should be given to type of feeding arrangement inside cages for sinking or floating pellets, as the case may be. Part of the surface area of the cage or entire perimeter is enclosed in feeding ring with 1 to 3 mm close meshes net for feeding floating pellets. The sides of the feeding ring should extend 10 cm into water. A trough is submerged below the water surface for sinking pellets and feed is led into it, with some suitable device. The feeder for sinking pellets comprises an intake funnel on the top, a delivery pipe in the middle and feed drop trough (receptacle) at the base. The rigid HDPP/PVC funnel serves as the mouth for introducing feed, dovetailing into delivery pipe. The lower end of the delivery pipe opens above the receptacle of 60 cm height, made of monofilament HDPP fabric. This is modified for handling floating pellets with lower end of the delivery pipe opening into feeding ring, instead of receptacle in the former design. The feeder (both designs) is fixed onto the cage frame. Both methods reduce feed losses, especially if the water is rough and strong currents pass through cage.

Pen design and erection

As in cages, the strength and stiffness criteria must be considered in design of a composite pen structure, the components of which react to the given load. Fish-pen designing and construction is easy and simple when compared to that of cages. No amount of structural analysis is satisfactory in designing unless forces which act on them are not properly determined, such as effects of winds, waves and drifting weeds or other objects. The ideal site for installing pen is the marginal area of wetlands with 1.5 to 2.5 m water depth.

The size of net pens depends on a number of parameters such as location, depth of water and species of fishes reared. However, for effective control, it is recommended not to increase individual area to more than 500 m^2. For commercial operations, the sizes, however, may be large, ranging from 1 to 5 ha. Height of pen-wall depends on the maximum water level during culture period. There should be a reasonable freeboard (50 cm or more, depending on wave action, jumping behaviour of cultured and predator fish species outside the pen) over the maximum water level. A portion (about 30 cm) of the wall should also go into bottom mud to keep pen wall secure.

The shape of the pen may be polygonal/rectangular/square or circular. The standardization work on the suitable shape of the pen module that best fits the culture of fish is still under investigation. However, the circular-shaped pen is well appreciated as circular configuration becomes most suitable for facing wind direction from all angles as well as multi-directional water circulation. While preparing a square-shaped pen, care should be taken so that it's diagonal remain parallel to the prevalent/most dominant wind directions in the area. However, rectangular-shaped pens are widely used in India.

Construction of pen walls: The design of pens, their configuration and duration of culture, may vary according to water-body. Water-bodies for pen construction may be divided into category–1, which will include narrow rivers, irrigation canals, oxbow lakes, etc; and category–2, will be shallow reservoir margins or tanks or lagoons. A part of the former can be divided into a number of convenient sections by erecting partition fences across the narrow water-bodies. Thus, there can be one to several pens in a series. Each pen will have two walls but two contiguous pens will have a common partition. The other two sides of the pen will be the river or canal banks. In some creeks and oxbow lakes there may be a fence at least on three sides, shore being

the fourth side. In latter type of water-body, depending on the draw down situations, pens are four-walled, constructed away from shores, taking into account onsite depth contours. This category of water can be used for installing pens for rearing fish fry, as culture operation cannot be continued for a long period due to wide fluctuation in water level.

Bamboo screen fence: The simplest pen is made of bamboo screens, which are interspersed through vertical poles alternately and secured by coir rope or nylon twine. A trench is excavated and lower part of the screen is partially buried inside and filled, to prevent entry or escape of fishes from bottom. Now-a-days a nylon netting or velon screen of suitable mesh size is provided inside bamboo screen for additional safety of stock. Bamboo screen fencing is suitable in narrow and shallow rivers, roadside canals, flooded fields and other similar water-bodies. The fence is best installed when there is little or no water in the impoundment.

Monofilament cloth pen: Two or three running lengths of mono-filament fabric are attached length-wise to get required width. Selvedge meshes may be attached on either side of the screen. A 5 mm dia. rope may be inter-woven into selvedge meshes along the head and foot-line. Loops at an interval of 3-4 m in the foot rope are needed for tying with bamboo groove which is driven into the mud. This arrangement is made to ensure tucking of about 30 cm of the net into the mud. The screen wall is prepared just like a fry net. The HDPE knotless webbing is best for net pen wall, considering the durability and ease of handling. If material of appropriate height is not available, stitching of two or more width of material will be required. The mesh size of netting should not be more than 10 mm. Steps for installation of the net pen are more or less similar to bamboo screen fencing.

Pen erection in waterlogged conditions: Demarcation of exact position of pen must be first decided to facilitate construction of structural framework. The following procedure may be followed: (*i*) place screens of pen and lightly stake bamboo marker in each corner, verify the distance between corners; (*ii*) drive corner posts deeper (about 1 m) into mud after they are correctly located; (*iii*) on a 5 mm dia. PE rope (5 m more in length than the distance between the corner posts) mark at 1.5 m intervals by tying pieces of coloured cloth; (*iv*) tie ends of the marked rope to posts at opposite corners a little above water line and stake posts at 1.5 m intervals, following markings in guide rope; (*v*) repeat procedure on the other three sides; (*vi*) fix horizontal bamboo struts on braces, about 1 m above the average depth of water during dry season and another row about 1 m above highest water level during monsoon; and (*vii*) fix diagonal support post or bracing to protect from water current, wave action and pushing effect caused by drifting masses of aquatic weeds; two obliquely staked bamboo, one on each side of the pen at 5 m interval would provide adequate strength to framework.

Installation of net enclosures includes hanging of pre-fabricated screen on the upper row of horizontal bracing, weighing down bottom rope and insertion of lower portion of the net into the mud, as follows: (*i*) hang the upper portion by tying its head rope with the upper horizontal bracing; and (*ii*) weigh down a part of the bottom net which is folded inside by about 30 cm width, preferably by laying bricks in a row along the entire length of bottom rope into mud to a depth of 30 to 50 cm, appropriate alignment and insertion of bricks into bottom mud should be ensured, and vertically the screen is tied securely to vertical posts in one or two points. Generally practised in shallow and perennial water body.

Pen erection on dry bed: The supporting structure of a pen is constructed on even, exposed sites during summer by driving 2 to 3 m long wooden stakes, approximately 70 mm in dia into bottom, fixed about 1.5 m apart, and braced with long and straight split bamboo, horizontally at every 30 cm height, from ground level. To start with, a trench of about 30 cm width and depth has to be excavated between 50 cm deep pits for firmly driving wooden posts into soil. The HDPE monofilament fabric (12 mesh/cm) of the desired width is used as screen. The top and bottom edges of the assembled screen are reinforced with nylon rope (3.5 mm diameter). The bottom of the screen (30 cm) with footrope is embedded in trench and filled up. Installation of this type of pen is easy and simple compared to previously described one.

Care may be taken to provide net cover for pens to ward-off predating birds from attacking captive stock, wherever necessary. It would be economical to install pens in clusters with common partition walls. Ladders may be provided to pens to facilitate feeding and sampling. This method is followed during dry season, generally in reservoir when water level is drastically reduced and vast area is available for pen construction.

Stocking and management

Seed rearing in enclosures: According to National Fisheries Development Board, Hyderabad, current production of fish fry is 31,688 million fry, to achieve the fish production of 10 million tonnes in near future, country needs an additional production of 16,312 million fry which is possible by establishing 1,630 new hatcheries with 10 million capacity/ hatchery. This in addition to usual investments requires huge resource both in terms of land and water, which are very scarce. As such there is an urgent need to diversify fry-rearing systems from traditional farm-pond practice to other alternative means to overcome present-seed supply crisis deterring aquaculture expansion.

Production of seed of commercially exploited fish species in enclosures reduces pressure on land for fish nurseries and maximum use of available water-bodies; Rapid, easy, sure harvest of product with little handling mortality and also elimination of loss due to predation; Considerable savings in packaging and transport of seed, if the seed is reared for *in-situ* stocking; With successful breeding captivity of many marine fishes and possible scenario of large-scale mariculture The scope for increase of fish production from offshore waters up to 12 nautical miles lies in enhancement of fish stocks through sea ranching programmes and adoption of region specific, resource specific and species specific mariculture activities. For all this, sure supply of seed is needed which can be reared in enclosures.

The season for rearing seed of Indian carps such as catla, rohu, mrigal, calbasu, fimbriatus, and Chinese carps, such as silver and grass carp in cages and pens is from July to September. Rearing of common carp and freshwater prawn seeds can be planned for the rest of the year, excepting for winter (December and January).

Rearing in cages: The purpose of nursery phase of cage-culture is to rear spawn and fry to fingerling size within 2 to 3 months (like in nursery ponds) for stocking in grow-out cages or other systems for fattening. The biomass being less, because of small individual size of young fish-stock, high-density rearing is resorted to in this phase, with intensive high protein feeding.

Stocking: A stocking density of 250 to 300 numbers carp fry (15 to 25 mm size)/ m^2 is most suitable for cages installed in reservoirs with netlon cage with depth of 3-3.5 m, and 150 to 200 nos. fry of the said size in cages installed in wetlands with netlon cage depth of 1.5 to 2.0 m. The acclimatization for fry is essential at the site of release in cages so as to provide balanced environment for the fry, especially adjusting temperature variation. The oxygen packets with fry (1,000 no's in 4 litres water in polyethylene bags having filled with two-thirds oxygen) are kept inside cages as such for 1 hr the fry are released in to cage water. Prior to release the fry from oxygen packets into cages they are subjected to some prophylactic measures to prevent them from disease infection. They are dipped in 2-3% salt solution as well as potassium permanganate (2 to 3%) for 1 to 2 min and then released in cage water.

In sea cage farming rate of stocking depends upon the type of fish, carnivorous or other. For seabass 12,000 no of fry/cage (6 m, dia. ×5 m, depth) is preferred stocking density.

Supplementary feeding: Feeding is essential for carp fry in captivity as the natural food in many Indian wetlands and reservoirs may not be sufficient enough for their growth even up to fingerlings. Usual formulated feeds as used in land nurseries/hatcheries can be applied in cages, but most suited are floating feeds. In inland open waters, feed @ 4 to 5% of body weight should be broadcast on the surface water twice a day at a fixed time, whereas once in a day during winter. Tray feeding is not feasible in cages installed in reservoirs, while it works well to some extent in cages installed in wetlands.

Feeding is also essential for sea cage farming. In seabass cage, feed given is either as dry pelleted feed @ 20% of body weight initially bringing down to 10% of body weight after 30 days of rearing or wet feed in the form of chopped trash fish 1,00% of body weight bringing down to 30% later on. In sea cages, feed could be provided through perforated bags in four or five places at different depths inside cages as to avoid feed loss with wave action.

Cage and stock maintenance

To rear healthy seed in cages certain precautions are necessary like: *(i)* monitoring of water quality especially in inland open water systems, *(ii)* cleaning of cages from bio-fouling–cages should be cleaned with soft coir brush fortnightly to erase bio-fouling organisms like algae, sponges, debris, etc. At times floating macrophytes surround the cages due to wave action which also needs to be removed. Dead fishes, if any, should be removed immediately, *(iii)* routine checking – loose twine, torn meshes by predators, anchor, sinkers etc. are to checked in routine manner and immediately need based management is applied. Torn meshes are repaired with patches to save fish fries from escaping. With onset of bad weather, anchors are to be checked and fastened tightly, and *(iv)* fish stock monitoring – a routine check up of fish health is mandatory to overcome any untoward incident relating to mass mortality of fries. Due prophylactic measures should be followed at least fortnightly and as and when necessary by uplifting fries inside the cages – soaking in salt solution (3 to 4%), followed by permanganate solution (3 to 4%) for 1 min to eradicate ectoparasites and make the fries and aquatic environment more healthy. Even, potassium permanganate solution (15 to 20%) may be spread on water surface inside the cages. At times, liming solution may be spread inside the cages to clear. On an average, at least 80% retrieval of fingerlings could be achieved following the procedure mentioned above.

Case studies on cage culture

Several experiments were conducted at Central Inland Fisheries Research Institute (CIFRI), Barrackpore, to study feasibility of raising of carp-seed in floating cages in tanks and reservoirs. Floating cages of bamboo-frame and nylon cloth bag, measuring 2.20 m × 1.60 m × 1.45 m (later standardized to 2.0 m × 1.5 m × 1.5 m) were used in a 1.0 ha tank at Juri in Uttar Pradesh for rearing hatchlings, fry and fingerlings, with appropriate mesh of cage wall. The stocking in cages was done with 30,000 hatchlings (8,500/m^2) of 6.5 to 7.8 mm size. In 21 to 28 days, they grew to 30.2 to 45.6 mm with a survival of 26%. In fry-rearing, the mesh size of the cage bag was 3 mm. The stocking rate was 700 to 2,500 fry/m^2 in each cage and within 90 days, they attained sizes ranging from 103.6 to 121.8 mm. In these experiments, the feed used was soybean powder, groundnut oil-cake and rice bran mixed in equal proportions. The stocking rate was standardized at 10,000/m^2 for rearing spawn to fry, 2,800/m^2 for fry to fingerlings and 300/m^2 for further rearing to advanced fingerlings.

In Getalsud Reservoir, carps were reared in 2.4 m× 1.5m × 1.5 m cages, stocked at 300 to 700 fry/m^2 of 10 to 31 mm size. The monthly growth rate was 17, 25 and 20 mm in mrigal, catla and rohu. The spawns were fed with powdered mustard oil-cake and groundnut oil-cake and rice bran in 3 : 1 : 1 at 30% body weight /day for four days, which was reduced thereafter to 20% body weight /day, for rest of the period. In another experiment, floating cages were used of 10 m × 4 m × 1 m made of velon screen installed with 4-gallon empty kerosene tins, in Vellore Fort, Tamil Nadu, to rear 10-day-old Indian and exotic carp fry (10 mm) to 50 to 60 mm size in 40 days. The stocking density was 500 fry/m^2 and survival ranged from 28.9 to 85.8% in different species, under supplemental feeding. With this success, the Fisheries Department in Tamil Nadu has been raising stock-seed in cages in some of the Fort moat ponds during September to February, every year.

Under Central Institute of Fisheries Education (CIFE), Mumbai, experimental rearing of fry and fingerlings of carps and mahseer was conducted using HDPE Cloth cages (knotless webbing of 4 to 15 mm mesh) of 3 m × 3 m × 3 m. The rearing of fry to fingerlings and thereafter to juvenile size in *Tor khudree* and *T. putitora* were undertaken in Volvan Reservoir in Maharashtra and similar other experiments were conducted in Powai-lake near Mumbai, in Halali reservoir in Madhya Pradesh with catla (*C. catla*), rohu (*L. rohita*) and common carp (*C. carpio*) and in Gobindsagar reservoir in Himachal Pradesh (Table 21.1).

Table 21.1. Cage culture experimentations carried out at different places by Central Institute of Fisheries Education

Fish species (no. of cages)	Duration (days)	Number stocked	Initial stocking (average)		Final harvesting (average)		Number harvested	Survival (%)
			Length (mm)	Weight (g)	Length (mm)	Weight (g)		
Walvan Reservoir, Lonavla, Maharashtra								
Fry to fingerling stage (mahseer)								
Tor putitora (2)	159	3,600	28.3	0.132	118.54	13.57	2,600	72.33
Tor khudree (2)	159	3,600	27.8	0.132	117.87	15.27	3,228	89.67
Total		7,200					5,828	80.94
Fingerling to advanced fingerling (mahseer)								
Tor putitora (2)	391	900	80.53	[illegible]	179.50	71.22	641	71.22
Tor khudree (2)	391	1,800	73.10	6.33	145.60	50.84	1,600	88.89
Tor putitora (2)	371	1,350	161.38	35.20	288.06	285.16	625	46.30
Tor khudree (2)	356	450	120.71	14.60	223.85	206.45	310	68.89
Total		4,500					3,176	70.57
Powai Lake, Maharashtra								
Fingerling to advanced fingerling (Indian major carps and exotic carps)								
L. rohita (2)	43	1,800	65.62	3.24	152.11	54.72	913	50.72
C. carpio (2)	43	2,700	24.45	0.293	105.66	31.34	2,032	75.25
C. carpio (2)	43	5,400	24.93	0.349	97.26	20.93	3,098	57.37
Total		9,900					6,043	81.04
Fry to fingerling (Indian major carps)								
C. catla (8)	65	18,000	27.50	0.226	105.15	18.20	9,545	53.03
L. rohita (12)	65	32,400	27.50	0.258	101.68	13.43	18,574	57.33
C. catla (1)	99	450	49.40	1.510	114.67	14.87	420	93.33
L. rohita (8)	92	7,200	51.73	1.510	117.55	19.16	5,700	79.17
IMC (8)	92	10,800	48.84	1.270	110.13	15.40	9,021	83.53
Halali Reservoir, Madhya Pradesh								
Fry to fingerling (Indian major carps)								
C. catla (6)	62	27,000	43.67	0.690	110.89	20.72	23,820	88.22
L. rohita (6)	62	27,000	33.87	0.570	109.59	14.79	23,920	88.59
C. catla (6)	45	7,500	50.93	1.130	110.24	16.78	5,825	77.67
L. rohita (6)	45	18,000	35.67	0.685	109.57	13.33	14,635	81.31
Total		148,350					111,460	75.13
Fingerling to advanced fingerling (Indian major carps)								
C. catla (2)	102	410	114.67	14.87	265.04	264.00	378	92.20
L. rohita (8)	102	1,600	117.54	19.17	226.59	152.73	1,480	92.50
IMC (6)	102	2,400	110.11	15.18	243.72	205.03	2,264	94.33
C. catla and	89	3,240	112.93	18.20	153.31	52.95	3,076	94.94
L. rohita (12)		3,240	109.60	14.13	149.18	34.71	3,109	95.96
Total		10,890					10,307	94.65
Gobindsagar Reservoir, Himachal Pradesh								
Fry to advanced fingerling (Indian major carps and exotic carps)								
C. catla (2)	132	3,600	32.60	0.326	120.60	13.10	3,213	89.25
L. rohita (8)	132	7,200	33.55	0.349	116.34	11.62	5,845	81.18
L. rohita (8)	132	7,200	31.55	0.308	136.32	13.52	6,195	86.04
C. carpio (2)	101	3,600	34.50	0.684	73.03	4.50	3,312	92.00
Total		21,600					18,565	85.95
Fingerling to Advanced Fingerling (Indian major carps and exotic carps)								
C. catla (2)	167	The experiments were continued with the same harvested number of fingerlings in each cage	120.60	13.10	165.00	172.05	3,069	95.52
L. rohita (8)	167		116.34	11.62	152.75	59.55	5,272	90.20
L. rohita (8)	167		136.32	13.52	214.63	110.30	6,058	97.79
C. carpio (2)	167		73.03	4.50	172.00	162.00	2,905	87.71
Total		18,565					17,304	93.21

Amongst the four, two, Walvan and Powai lake were in same agro-climatic conditions while as Halali and Gobindagar reservoir are from different agro-climatic conditions latter being from temperate climate. Out of the four, Powai lake exhibited highest production due to its very rich nutrient status. Powai lake and Halali reservoir both receives city sewage from Mumbai Suburb and from Bhopal (MadhyaPradesh) respectively. Walvan reservoir was observed to be least productive among all these four aquatic bodies as it practically has a lotic habitat because it supplies its water throughout the year to Tata Hydroelectric Plant through a feeder canal and secondly its water is sometimes slightly acidic to neutral unlike Walvan reservoir, whereas the Gobindsagar although in temperate climate was observed to have the highest *p*H range (8.5 to 8.6) and thus most conducive for fish culture practices due to its favourable ranges of water quality parameters throughout the year.

The results although depicted success in all but the final impact regarding enhancement of production in the reservoirs could not be ascertained as the experiments were confined up to fingerling stage only. The Central Inland Fisheries Research Institute (CIFRI), Barrackpore during 2006-08 conducted experiments in a comprehensive manner from production of *in-situ* seed in cages to final harvesting of produce from reservoirs. The results of same are reproduced below (Table 21.2). Two reservoirs Dahod in Bhopal (Madhya Pradesh) and Pahuj in Jhansi (Uttar Pradesh) were studied from two agro-climatic zones. In Pahuj, the fish yield was 18 kg/ha before CIFRI's intervention. With proper management measures the production was raised to 105 kg/ha against the estimated potential of 300 kg/ha/year.

First phase: In the first phase, 0.1 milllion fish fry, 20 to 22 mm in size (grass carp : common carp, 6 : 4) was stocked in eight cages (5 m × 3 m × 3 m size) made-up of netlon screen (1 mm mesh size). The reared seed had a recovery of 45.82% fingerlings of grass carp possessing 70 to 96 mm length/weight ranging from 5.0 to 11.0 g and common carp 85 to 112 mm/19 to 26 g (Table 21.2).

Table 21.2. Cage culture experimentations carried out at Dahod Reservoir, Bhopal, Madhya Pradesh by CIFRI, Barrackpore

Fish species (no. of cages)	Duration (days)	Number stocked	Initial stocking (average)		Final harvesting (average)		Number harvested	Survival (%)
			Length (mm)	Weight (g)	Length (mm)	Weight (g)		
Fry to advanced fingerling (Indian major carps)								
Common carp (4)	161	54,000	21	0.18	83	8	24,743	45.82
Grass carp (4)	161	36,000	20	0.07	98.5	22.5	16,495	45.82
Total		90,000					41,238	45.82

Source: CIFRI-CGIAR Challenge Programme.

Second phase: In the second phase, 36,000 Indian major carp fry of 30 to 34 mm size (rohu: catla: mrigal, 5: 2: 3) were released in three cages. Two batteries of 8 cages each (total 16 cages) were installed and a recovery of 64.78% fingerlings could be achieved possessing length/weight, catla: 90 to150 mm/19.24 to 31.58 g, rohu: 88 to 160 mm/15.32 to 28.26 g and mrigal: 82 to 130 mm/11.64 to 23.12 g. (Table 21.2a). The other 13 cages were stocked with 1,40,000 fry of grass carp (56,000 nos.) and common carp (84,000 nos.) with a recovery of 80.97% fingerlings (Table 21.2a). Size of the fishes ranged, grass carp: 98 to 98 mm/3.42 to 9.89 g and common carp: 72 to 110 mm/9.85 to 20.5g

Table 21.2a. Cage culture experiment: second phase

Fish species (no. of cages)	Duration (days)	Number stocked	Initial stocking (average)		Final harvesting (average)		Number harvested	Survival (%)
			Length (mm)	Weight (g)	Length (mm)	Weight (g)		
Fry to advanced fingerling (Indian major carps)								
C. catla,	120	7,200	30	0.1	120	24.25	4,664	64.78
L. rohita and		18,000	32	0.06	124	21.79	11,660	
C. mrigal (3)		10,800	32	0.05	114	17.38	6,996	
Common carp and	120	84,000	17	0.15	92	11.28	64,806	77.15
Grass carp (13)	120	56,000	24	0.14	98	7.26	50,943	80.97
Total		176,000					139,069	79.01

Source: CIFRI-CGIAR Challenge Programme.

Table 21.2b. Cageculture experiment: third phase

Fish species (no. of cages)	Duration (days)	Number stocked	Initial stocking (average)		Final harvesting (average)		Number harvested	Survival (%)
			Length (mm)	Weight (g)	Length (mm)	Weight (g)		
Fry to advanced fingerling (Indian major carps)								
C. catla (8)	120	92,000	13.5	0.10	90.0	14.78	66,500	72.28
L. rohita (7)	120	83,000	13.5	0.06	96	11.65	65,500	77.71
C. mrigal (1)	120	13,000	14.5	0.05	86	9.08	9,400	72.30
Total		188,000					141,400	75.21

Source: CIFRI-CGIAR Challenge Programme.

Third phase: In third phase, 200,000 fry (11 to 17 mm size) of Indian major carps (catla:rohu:mrigal, 10 : 8.6 : 1.4), was released in 16 cages(each cage size: 5 m ×3 m × 3 m)..The reared fish seed were fed with rice polish: mustard oil cake: Agrimin (1: 1: 0.02) @ 4 to 5% body weight barring two cages where the seed were fed with floating feed: Agrimin (1: 0.01) at the mentioned rate. Recovery rate being 70%, possessing length/weight ranging from catla: 72 to108 mm/ 6.06 to 23.50 g, rohu: 68 to 124 mm/ 4.10 to 19.20 g and mrigal: 62 to 110 mm/3.89 to 14.26 g (Table 21.2b).

At Pahuj reservoir, Jhansi, Uttar Pradesh

In Pahuj, in the first phase, one battery of eight cages same as that of Dahod reservoir were stocked with one lakh fish fry of 22 to 24 mm size (grass carp: common carp,75 :25). Recovery rate of fingerlings being of 63%. Size attained by grass carp was 65 to 96 mm/3.89 to 11.87 g and by common carp 74 to 115 mm/12.48 to 22.09 g.

Table 21.2c. Cage culture in Pahuj Reservoir, Jhansi, Uttar Pradesh

Fish species (no. of cages)	Duration (days)	Number stocked	Initial stocking (average)		Final harvesting (average)		Number harvested	Survival (%)
			Length (mm)	Weight (g)	Length (mm)	Weight (g)		
			Fry to advanced fingerlings (Indian major carps)					
C. catla (4)	60	45,000	12.5	0.11	130	68	29,870	66.38
C. catla and	60	27,000	12.5	0.11	130	68	23,550	87.22
L. rohita (4)		18,000	13	0.06	93.5	9.17	14,760	32.00
Total		90,000					68,180	86.6

Source: CIFRI-CGIAR Challenge Programme.

In the second phase, 90,000 nos. fry (10 to 15 mm) of IMC (catla: rohu , 8 : 2) were stocked in one battery of eight cages same as above. A recovery of 86.6 % fingerlings (catla: 80-180 mm/6.12-74.88 g, and rohu: 79-108 mm/4.95-13.39 g) was achieved (Table 21.2c).

Economics of cage production: The fingerling production of carps in cages in freshwater open systems by now has been standardized and economics worked out. The same is depicted in Table 21.3. The production cost of each fingerling comes around ₹ 0.36 to 0.40, whereas the market price of each fingerling is around ₹ 2.00 to 3.00 in India. All three crops per year – two IMCs and one exotic, especially grass carp and common carp could be raised depending on the availability of food niches where cages were installed.

Table 21.3 Economics of fish seed raising in cages in Indian reservoirs (cost/crop)

Items /particulars	Three crops/year [cost/crop (₹)]
Total fixed cost	4,800.00 (17.13)
Total variable cost	23,213.00 (82.86)
Total cost	28,013.00
Number of fingerlings produced	70,000.00
Cost of production/fingerling	0.40
Value of fingerlings @ ₹ 1/fingerling	70,000.00
B:C ratio	2.20

Source: CIFRI-CGIAR Challenge Programme.
Figures in parentheses represent per cent of total cost.

Therefore, it is evident from the above studies that raising fingerlings from cages is profit worthy, and if practised on a large-scale, can solve the problem of stocking materials for which most of the water-bodies are starving.

Seed rearing in pens: Production of seed in pens is easier than in cages, as former are installed in peripheral, littoral habitats with natural productivity. Rearing of young stages of fin and shellfish in pens erected maily in beels and wetlands represent a new and relatively simple approach with a potential to become an important seed raising system in India in the near future. Species with potential for rearing pens are Indian and Chinese carps, eels, catfishes, milkfish, mullets, tilapia and both fresh and brackish water prawns.

Measures: Unwanted organisms inside the pen are to be eradicated by repeated netting, using dragnets and cast nets. The pen area is then fertilized with cattledung (up to 10 tonnes/ha and limed, using quick lime, with dose @ 200 to 300 kg/ha). Manures can be placed directly on the bottom of dry pen bed or in water in small, scattered heaps or in loose mesh bags. It must be applied repeatedly in small quantities, never in large amounts. Spawn/fry would be stocked 10–15 days after flooding to allow cattle dung to compost and be consumed by micro-organisms, Supplementary feeding, rice polish and mustard oil-cake can be given at a ratio of 1:1 @ 2% of the total body weight of stocked fish in the morning hours of the day. The feed may be applied in the surface water in broadcast method.

If the seeds are to be stocked in the same water body, no special harvesting method needs to be carried out. Openings can be made on the sides of the pen through which the fish fingerlings will move out into the open water. If the seed are to be harvested and transported elsewhere, drag nets of 0.5 cm mesh can be used. Harvesting may be done early in the morning.

Reservoirs

Spawns of carps are being reared every year, since 1982 in pens in Tungabhadra reservoir. The total area under pen rearing ranged from 4,000 m^2 in 1982 to 33,000 m^2 in 1989, with a stocking rate varying between 320 and 815 spawn/m^2 and survival was estimated at 10.7 to 63.1%. The species reared are mrigal and rohu. The enclosure screen is made of 12 meshes/cm monofilament cloth. On receipt of water, the pens will be manured with cow dung at 10 tonnes/ha and a mild dose of urea, super-phosphate and groundnut cake, for encouraging growth of natural food. Besides spawn was fed daily at 5 kg/l million spawn with powdered groundnut-cake and ricebran in 1: 1 ratio. The water retention in pens varies from 30 to 45 days, and the fry will be harvested when water level starts receding. The growth of fry generally varies from 25 to 50 mm, and they would be released into reservoir.

A split-bamboo enclosure of 247.5 m^2, lined with nylon-netting was stocked with *C. mrigala* (size: 7 mm) and *L. fimbriatus* (5 mm) spawn (ratio 13 : 10) in Pungar swamp, Bhavanisagar, at 4.6 million/ha (460/m^2) to raise fry. The pen was manured with fresh cowdung and super-phosphate at 10 tonnes and 400 kg/ha respectively. The spawn was fed with a powdered mixture of groundnut oil-cake and ricebran (1: 1) at 1 kg/day for the first 5 days, 2 kg/day during sixth to tenth day and 3 kg/day during 11th to 15th day. From 16th to 20th day, feed was supplied at 3.5 kg/day and thereafter at 4 kg till 30th day. The feed was broadcast over water surface during first 15 days and from 16th day; it was supplied in feeding plates, fixed at 3 m intervals along the perimeter of the pen. On the sixth day of stocking, the pen was manured for the second time at 15 tonnes/ha. Although, the survival of fry was not assessed, after 30 days rearing, size attained by *C. mrigala* was 38 mm and by *L. fimbriatus* was 28 mm.

Pen culture of carp seed was carried out by the CIFRI in a 75 ha at Odadurai village in Erode district of Tamil Nadu. Six pens with an area of 200 m^2. each were erected and fry of *Catla catla, Labeo rohita, Cirrhinus mrigala, Cyprinus carpio* and *Ctenopharyngodon idella* at a combined density of 324,000 nos/ ha was stocked.

Periodic manuring was done with cowdung in the pens to enhance plankton production. A mixture of soymeal (10%), groundnut-cake (30%) and rice polish (60%) was given as feed. Aquatic plants collected from the tank are provided as feed for grass carp. Four varieties of fish seed other than common carp attained fingerling size exceeding 100 mm in a culture period of 30 to 75 days. However, a minor percentage of common carp were smaller in size. The grown up seed were harvested using dragnet.

Table 21.4. Fish stock, yield and growth at the Goruchora and 46-Morakollang Wetlands of Asom

Parameters	Goruchora			46-Morakollang		
	C. catla	*L. rohita*	*C. mrigala*	*C. catla*	*L. rohita*	*C. mrigala*
No. of fish released	250.00	150.00	100.00	625.00	375.00	250.00
Days of rearing	145.00	145.00	145.00	145.00	145.00	145.00
Av. initial weight (g)	1.81	1.15	1.12	1.81	1.15	1.12
Av. final weight (g)	85.05	52.80	42.93	63.80	55.90	41.53
Av. initial length (cm)	5.46	4.51	4.65	5.46	4.51	4.65
Av. final length (cm)	18.99	15.80	15.80	17.02	15.38	14.03
Net weight gain (g)	83.24	51.65	41.81	62.00	54.75	40.41
Production (kg/ha)	2,106.00	1,780.00				

Table 21.5. Economics of carp seed raising in pens

Items	Amount (₹)
Expenditure	
A. Fixed capital	
Bamboo (140 nos @ ₹ 50/bamboo)	7,000
Velon screen net (600 m @ ₹ 9/m)	5,400
Coal tar (80 litres@ ₹19/litre)	1,520
Tyre cord (20 kg @₹ 55/kg)	1,100
Wages for pen construction and installation (52 man-days @ ₹ 50/man-day)	2,600
Miscellaneous	2,140
Sub-total	19,760
B. Variable costs (for one crop)	
Seed (60,000 fry@ ₹ 70/1000 fry for fingerlings rearing)	4,200
Feed	3,000
Miscellaneous including wages	2,000
Sub-total	9,200
Total cost	
Variable cost (two crops/year)	18,400
Depreciation on fixed capital @ 33% per year	6,587
Interest on fixed capital @ 15% per year	2,964
Grand total	27,951
Gross income	
Sale of produce in two crops (48,000 nos @ ₹ 1/fingerling)	48,000
Gross returns	48,000
Net income (gross income - total costs)	20,049
B: C ratio	1.71

Source: CIFRI, Barrackpore.

Wetlands

Fry of Indian major carps, catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) were stocked in a series of five pens which were installed at the Goruchora and 46-Morakollang wetlands of Asom covering an effective pen area of 750 m^2 and 1,875 m^2 respectively. It is evident from the results, in respect to both the wetlands, that the raising of required quantity of stocking materials within the same system by installing pens can be a viable option to address the cause of rational stocking in floodplain wetlands so as to convert them into culture-based systems for better economic returns (Table 21.4).

Economics: The production economics of carp seed raising in a pen of 0.1 ha/year with two crops has been standardized in Table 21.5.

Grow-out culture in enclosures

Stocking density: The number of fishes that can be stocked in cage or pen is variable and depend on carrying capacity of the water (water-spread area, depth and water quality), water exchange, species of fishes and quantity and quality of supplemental feed input. To get optimum fish production from cages and pens, the stock needs to be provided conditions, which minimize losses and promote growth. This involves: (*i*) stocking at densities appropriate to the site/size of the fish and methods of rearing, (*ii*) feeding fish in the most cost effective manner, (*iii*) ensuring best possible water quality within cages, (*iv*) maintaining cages, anchors and auxiliary gear in proper condition, and (*v*) regular checking of stock for disease, removal of dead fish and treatment of infected fishes. Samples of fish should be taken at regular intervals and weighed so that growth of stocks can be monitored.

Fish production in cages

Air-breathing fishes: The early experiments conducted in cages in India were by using air-breathing fishes, as they are hardy and tolerate crowding. Culture of *Anabus testudineus* and *Heteropneustes fossilis* were undertaken in bamboo split woven cages. Later, *Clarias magur, Channa striatus, C. marulius* and *C. punctatus* were also cultured in Bihar and Karnataka Centres under All India Coordinated Research Project for Air-Breathing Fish Culture at Central Inland Fisheries Research Institute. Stocking densities ranging from 50 to 300 fingerlings/m^2 were tried and optimum densities were found to be 150, 200, 200, 100, 125 and 150 fingerlings/m^2 for *A. testudineus, C. magur, H. fossilis, C. striatus, C. marulius* and *C. punctatus* respectively. The former three species accepted artificial feeds, compounded with protein-rich items such as fishmeal, de-fatted silkworm pupae, chick-feed, soybean meal, groundnut-cake and ricebran, using wheat flour or sodium alginate as binder. Addition of yeast, vitamins and mineral mixtures to feed at 1% level has enhanced growth in fishes. Whereas, murrels were trained to feed on soaked and chopped-dried trash fish. The net productions obtained were 0.3, 0.7, 1.0, 1.5 and 1.3 kg/m^3/month in the above species in their respective order.

Similarly, growth of *H. fossilis* in a bamboo cage of 1 m × 1 m × 1 m and a net cage of 2 m × 1 m × 1 m size adopting equal stocking density at 50 juveniles/m^2 for 112 days was 23.1 g in bamboo cage, and in net cage it was 21.5 g. The survival rate ranged from 72 to 84%. The growth of the species was better in bamboo cage as the periphytic community accumulated inside the cage would have helped in more growth than the other in the net cage. Cage culture of *Channa striatus* was undertaken by stocking 16.2-20.7 g fishes in round bamboo cages (60 cm dia, and 120 cm height) lined inside with velon screen. The stocking density was 15, 30, 60 and 90 fish/m^3. The stock was fed separately with live minnows and young tilapia. Though average monthly weight increment in lower densities (15 and 30 fish/cage) was found high, the net production was invariably more in cages of higher densities. The food conversion of snakehead fishes was observed better when fed with minnows than with tilapia. As far as stocking densities are concerned, better conversion ratios (8.5 and 4.1) were noted in cages stocked with 60 snakeheads, fed with tilapia and minnows, respectively. The net production was found varying from 3.38 to 10.65 kg/m^3. The giant murrel, *C. marulius* cultured under low density at 40 fish/m^3 in cages with trash fish as feed grew to an average size of 200 g in 6 months, giving a net production of 0.8 kg/m^3/month.

Carps: Employing a stocking density of 30 to 38 fingerlings/m^3, gross production of 1.5 to 2.2 kg/m^3/month was obtained in a grow-out period of six months with common carp. The fish attained a size of 325 to 350 g during culture period. The feed comprised a mixture of powdered silkworm pupae (de-fatted), groundnut oil-cake and rice bran (8: 9: 3 ratio), and was fed daily at 10 to 20% of the bodyweight of stock. The feed was given in dough ball forms in trays suspended in cages. The food quotient ranged from 8.3 to 10.4. The survival of the stock was 100%. Catla, stocked @ 13 fishes/m^2 and fed with rice bran and groundnut oilcake (1 : 1 ratio) @ 5 to 10% bodyweight attained 772 g in six months, yielding a production of 1.41 kg/m/month and a food quotient of 6.6. Rearing catla at a higher density of 49 fingerlings/m^2, the average size attained by the fish was 544 g in 8 months. The feed given was again conventional groundnut cake and rice bran mixture (1 : 1 ratio). The production obtained was 2.7 kg/m^2/month (1.8 kg/m^3/month) in cage culture of catla conducted during 1996–97 by the CIFA at Bengaluru, resulted in 100% survival, with a net production of 213.667 kg (16.03 kg/m^3/year), from the cage. The cage culture of rohu was conducted in 1 m^3 cubed cages in an irrigation tank (56 ha) at Medchal near Hyderabad, during 1993–95 and studied on aspects related to varying stocking densities and feeding rates. They were stocked at 10, 30, 50 and 70 fish per cage and uniformly fed daily with a feed containing 30.2% (crude protein) at 4% of fresh body weight. Maximum net production of 4.986 kg/cage in 89 days (49.86 tonnes/ha) was obtained at a stocking density of 70 fish/m^3, while the average individual growth rate was higher for lowest density. The fish growth exhibited inverse relationship with stocking density; the growth rates for 10, 30, 50 and 70 fish m^{-3} densities were 1.221, 1.111, 0.989 and 0.902 g/day respectively. The results showed that average growth of fish declined and yield increased as density increased. The growth and production of fishes in cages are dependent on operational and management functions. One of the important aspects of operational functions is regulating quantity of feed required for best growth. This can be determined from intake of feed and observation of feeding habits of fish. Extraneous feeding is a must, particularly in intensive culture operations, as natural food spectrum in the water-body would be limited and not enough for healthy growth of fish.

Experiments conducted with grass carp (size range: 76 to 103 mm in length and 7 to 10 g in weight) in three circular floating cages (3 m^3) made of hollow aluminium frame enclosed with nylon-net at stocking densities of 33, 50 and 67 m^3 in different cages with regular feeding with aquatic duckweed (*Lemna* spp) at 8% of fresh body weight for first three months and then with *Hydrilla* sp. a 70 to 80% bw for next three months, yielded average weight of 400g.

Mahseers: Experiments were conducted in cages of 1 m^2 (under water volume 1 m^3) installed in a large pond by stocking with mahseer (*T. khudree*) at 30 fish/cage (30/m^2) and fishes have grown to an average weight of 216 ± 23.3 with a weight gain of 171 g during culture period. Mahseer species, *T. putitora* and *T. khudree* were reared in cages in Valvan lake in Maharashtra, grew from 120.71 mm (14.60 g) to 223.85 mm (201.45 g) with a survival of 68.89% in 365 days in former and 161.38 mm (35.20 g) to 288.85 mm (285.168 g) with a survival of 46.3% in 371 days in the latter.

Freshwater prawns: Freshwater prawns (*Macrobrachium malcolmsonii* and *M. idae*) were stocked in net cages of 1 m^3, installed in a seasonal canal at 15, 30, 45 and 60 nos/m^2 in different cages with 42 to 48 mm, weighing 1.9 to 2.3 g. The prawns were fed with a mixture of groundnut oil-cake, pila meat and tilapia flesh, daily at 7% fresh body weight and survival in 60/m^2 to density cage was only 28.3%, whereas there was no mortality recorded in other densities. During grow-out period of six months, *M. idae* attained a size of 70 mm, weighing 8.37 g, as against growth in natural environment of 100 mm (9.25 g) in year. The growth of *M. malcolmsonii* was 70.9 g in weight within five months. Freshwater prawn, *M. rosenbergii* juvenile (mean size: 69.30 ± 3.59 mm long, from telson to rostrum; 3.55 g fresh body weight) were stocked in 1 m^3 square-net cages, installed in an irrigation tank near Hyderabad in a 120-day grow-out period. Final feed conversion ratio ranged between 2.8 and 3.2. The data indicated that 40 prawn stock/m^2 cage area coupled with a feeding rate at 4% fresh body weight appear to increase mean individual size and total production, with better feed conversion.

Open sea cage farming

The sea cage culture of different fishes, mud crab and lobsters at different locations in India was initiated by Central Marine Fisheries Research, Institute in a big way since 2007. Although there is whole lot of marine fishes suitable for cage culture but only those fishes whose captive breeding technology has been standardized or whose seed can be extracted from nature and is available in plenty are taken for this activity. The results of cage farming of such species are discussed here.

Cage farming of Asian seabass: The Asian seabass, Lates calcarifer, juveniles 17 to 22 cm (60-100 g) reared in the cage having size, outer cage net 7 m dia and 4 m depth and the inner cage net 6 m dia and 3 m depth for six months attained the size of 0.8 kg to 1.8 kg weight (25 to 49 cm total length) with an average weight of 1.3 kg.

More than 90% of the fishes were in the weight range of 1.1 to 1.5 kg. The survival rate was about 70% at the stocking density of 7,000 numbers. The cage was moored in the sea off- Chemmencherry at 12°46.815'N; 080 15.521'E in February 2010, about 1 km from the shoreline. The site being shallow (8 m depth) and with rocky substrates, the cage was modified to have a reduced column height. The nets were suspended as two separate pieces, overlapping at the floating pipe level. The high density polyethylene (HDPE) ballast pipe (2 1/2" or 6.25 cm dia.) with 5 mm holes at regular intervals, having three 16 mm steel wires inserted into it is used as sink weight for stabilizing the column structure of the outer cage. Polished marble stones (1-1.5 ft × 0.5 ft or 30-45 cm × 15 cm) each weighing approximately 15 to 20 kg, 1 gabion (3m ×1m ×1 m) and PP ropes (12 mm and 32 mm) were used for mooring. Indigenous sealed, PUF-filled Sintex milk cans were used as buoys. The juveniles (125 to 150 nos.) per trip were transported in a mildly anaesthetized condition in 200 litres. The HDPE barrels with a window cut along the side (20 cm × 20 cm), 100 litres of filtered seawater pre-treated with one ppm AQUIS/clove oil was filled in the barrels. Transportation of the fish was carried out with aeration provided by diffusing free oxygen gas through sandstones from compressed oxygen cylinder. The total time for transportation and transfer to cage was 1 hr and was completed with 100% survival. Regular net cleaning and net exchange during the culture period were imperative to avert the impact of fouling by other organisms. The cage withstood rough sea conditions, including Cyclone Laila in May 2010.

Feed was given twice a day. A combination of different feeds including commercial pellet feeds, fresh shrimp meat and fresh fish meat were given at different stages of the culture phase. The ration size increased as the biomass of the fish inside the cage increased. Periodical sampling was also done to monitor growth and survival of the fish. The harvest was conducted on 3 August 2010.

Cobia: The hatchery production of cobia, *Rachycentron canadum,* fingerlings developed by Mandapam Regional Centre of the CMFRI can pave the way for large-scale sea-cage farming of the species in the country. Cobia is an ideal species for aquaculture because it grows quickly, is highly adaptable to spawning in captivity, has a high meat quality, enjoys a great market demand and it can be bred at a low cost.

Mullet and pearl spot: Natural seed of grey mullet, *Mugil cephalus*, and pearl spot, *Etroplus suratensis* is available along south-west coast of Kerala in abundance, former during south-west monsoon (June - August) and latter throughout the year. The same is being exploited and the first ever attempt on cage culture of mullet and pearl spot was carried out at Kochi which resulted in good production and feed conversion with low inputs. The grow-out culture of both these fishes in cages has been standardized to some extent by the CMFRI. In case of mullet, *Mugil cephalus* a production of 2.5 tonnes with a survival rate of 90% can be achieved with the stocking density of 7,000/cage, size range of 10-12 g / fingerling for a rearing period of 6 to 8 months with artificial feeding. In pearl spot, *Etroplus suratensis*, a production of 4.32 tonnes with a survival rate of 90% can be achieved with the stocking density of 6,000

to 8,000/cage/ per batch,size range of 10 to 15 g/ fingerling for a rearing of 12 months at an interval of 4 to 12 months with artificial feeding.

Cage culture of *Etroplus suratensis* in Vembanad Lake, Kerala: Small-volume, high density farming of pearl spot (*Etroplus suratensis*) in floating net cages (1.0 to 2.0 m^3) in open waters (Vembanad lake) in Kerala, developed by the Regional Agricultural Research Station, Kumarakom and adopted by the self-help groups and local panchayath was found to be highly rewarding; seeds of *E. suratensis* (30 g size) with a stocking density of 200 nos/cage reached the marketable size of 300g in 6 months with locally blended compounded feed. The average cost of production was ₹ 62/kg against the market value of ₹ 300/kg. Being a scraping species, *E. suratensis* was found to be the most ideal candidate species for cage farming as the net cages stocked with pearl spot were almost devoid of fouling and mesh clogging algae. Being a brand cuisine of the backwater tourism and with high market demand, cage culture of pearl spot offers great promise in Kerala.

Spiny lobster: At Vizhinjam, 1,200 juvenile lobsters (*P. homarus*) weighing between 70 and 95 g were stocked in the middle of January 2009 in 5 m dia. floating cage with 6 m cylindrical high density polyethylene netting below the sea surface and was protected outside by another net. The cage was moored at a depth of 8 m in Vizhinjam Bay. Lobsters were fed daily *ad lib.* with live mussels collected from nearby rocks. Growth of lobsters and environmental parameters around the cage were regularly monitored to ensure good growing conditions. The nets were regularly cleaned to remove fouling organisms. Frequent observations were made on the growth of lobsters to adjust the feeding. Lobsters at harvest weighed 260 g on an average after 135 days of growing and 85% of lobsters stocked were retrieved. The cage also withstood the impact of rough sea of Kerala and proved to be sea worthy. The harvested lobsters were as healthy as wild caught lobsters and have good colouration. With a price tag of ₹ 1,000/kg, the farming operation has turned out to be an economically successful venture with a net profit of ₹ 0. 15 million. A cage of this size can be stocked with 1,500 young lobsters and therefore depending on the market price, the value of the harvest could be ₹ 0.34 million.

The open sea floating cage culture of lobsters is new to the country and will definitely help in augmenting production, besides attracting private entrepreneurs to take up this mariculture enterprise. This farming practice not only helps to utilize the under-size lobsters, which otherwise would have been sold at a low price in local market, but also helps to sustain the local population by breeding during the culture period. The local fishers will also be benefited as this will generate employment opportunities. Lobster farming at this stage is promoted on a small-scale venture as the seed resource is limited. Lobster culture in floating sea cages at Vizhinjam, has successfully demonstrated the viability of such promising mariculture.

Grow-out culture in pens

Pen culture is extensively practised in Japan, Peru and Philippines. Fish farmers in Laguna de Bay in Philippines stock milkfish fingerlings at 30,000/ha in pens where they are grown to a marketable size (200 g and more). In pens, continuous incursion of other fishes and shrimps is inevitable and some of the former group may be predators. It is, therefore, important to stock larger fingerlings (over 30 g) to ensure better survival. It will be desirable to have a nursery facility near a pen complex when culture is taken up on a large-scale. Species selection, composition and stocking rates in pens will depend largely on natural food supply, supplemental feeding strategy, water depth and duration of water availability in any particular site. However, for raising table-size carp, pen should be erected where the depth of water in the pen remains at least 1 m thought the year. Preferable size of the pen ranges between 0.02 and 0.04 ha. Carp fingerlings of 80 to 150 mm size at a stocking density varying between 10,000 and 15,000 are preferred. Supplementary feeding need be done with locally available conventional feeds to reduce the cost of production. The technology is also suitable in weed-choked areas where fishing is difficult.

Carps in wetlands: The pen culture experiments were undertaken in six wetlands of West Bengal namely Mathura beel, Kujerbagi beel, Jaleswar beel, Chumurdaha beel, Mustafapur beel and Kola beel having area of 0.04 ha each. Carp fingerlings were stocked in the pens at a stocking density of 15,000 ha at a ratio of 40:30:30. Average initial weight of *Catla* varied between 65.3 and 79.5 g, rohu 23.4 and 29.2 g, and mrigal 22.0 and 24.3 g. The fishes were fed with pelleted feed containing 30% protein @ 2% of the body weight/day. In 120 days of culture, average crop of 550 kg fish from each of the pens was harvested. The growth of the fishes ranged between 375 and 750 g for catla, 250 and 550 g for rohu and 300 and 500 g for mrigal. A total of three pens each of 0.1 ha of different shapes were designed and installed in Gomokpota wetland in West Bengal. Reducing the use of bamboo solely, HDPE nets having mesh size of 3 mm were used as pen wall. Bamboo poles and splits were used to hold the pen walls vertically in its position. The experiment was laid to test the pen material and different sizes. The shapes were circular, one rectangular pen with 50 m length, and another rectangular pen with 100 m length. The pens were stocked with major carp seed at a uniform density (7,500/ ha). The experimental fishes in all the pens were fed with a mixture of mustard oil-cake and rice bran *ad lib.* in a porous bag suspended from a pole. Variable growth performance was recorded during 60 days of experimental trial in different shapes of pen despite being fed with similar ration and occupying same area. Among the three major carps, *Labeo rohita* indicated better growth performance, while *C. catla* showed very poor performance in all the three shapes of pen. Highest growth was recorded with *L. rohita* in circular pen. Growth performance of all the three carp species was found better in circular pen when compared with other two shapes. Differential growth performance exhibited by different species in various shapes of pen was very distinct.

Demonstration of fish farming in pens in floodplain wetlands (*Maun*) of Bihar were undertaken by the CIFRI. The Indian major carp fingerlings were stocked in three *mauns* namely Koithkola, Rajoura and Bahuara in Begusari at a density of 20,000/ha in first two *mauns* and @ 15,000/ha in third one respectively. The growth

Table 21.6. Demonstration of pen culture in Bihar

Species	Stocking: Initial length (mm)	Initial weight (g)	Minimum length (mm)	Maximum length (mm)	Average length (mm)	Harvesting: Minimum length (mm)	Maximum length (mm)	Average length (mm)	Total weight (kg)	Production kg/0.1 ha/day
					Koithkola maun : 0.1 ha					
Catla	170.2	62.5	205.3	280.5	253.4	310	625	400	145	290 kg/
Rohu	200.1	66.6	232.4	300.7	270.1	250	455	350	80	0.1 ha /
Mrigal	179.1	55.5	225.2	275.2	257.4	275	370	300	65	220 days
					Rajoura maun : 0.1 ha					
Catla	188.3	71.42	208.1	282.1	247.3	300	650	400	150	342 kg/
Rohu	145.1	55.5	215.5	302.5	283.9	250	450	300	72	0.1 ha /
Mrigal	159.4	66.7	222.7	312.7	269.5	200	400	275	50	219 days
Grass carp	252.6	142.8	305.1	325.9	317.5	400	750	600	40	
Common Carp	230.5	250.0	235.9	285.5	263.7	300	700	450	30	
					Bahuara maun : 0.1 ha					
Catla	206.9	90.9	305.7	327.1	315.2	450	800	700	295	505 kg/
Rohu	146.0	62.5	261.1	302.4	295.4	250	525	400	123	0.1 ha/ /
Mrigal	134.8	55.4	262.3	305.5	287.5	250	450	350	87	220 days

performance of fishes in *mauns* of Bihar is depicted in Table 21.6.

Prawns in wetlands: Studies conducted by the Central Inland Fisheries Research Institute demonstrated that the pens can be utilized to hold freshwater prawn, *Macrobrachium rosenbergii,* as captive stock in wetlands, and reared up to marketable size to augment fish production. The technology was successful in the wetlands of Bihar, West Bengal and Asom and released package of practices for adoption. The technology has been adopted by fishers in several wetlands of West Bengal and Asom including parts of Bihar.

A detailed survey should be conducted before constructing pens, with special emphasis on the type of terrain and the nature of catchment. Areas having 1.5 to 2.5 m depth, in shallow, marginal areas of wetlands are ideal for installation of pens. Water depth should be at least 1 m with for about 4 to 8 months in an year. The shoreline may be of gentle slope. The bottom should be reasonably firm and smooth preferably sandy.

The pen may be of any convenient shape depending on the nature of shoreline, sediment type and depth of water-body. However, square or rectangular pens are found to be more convenient for rearing table size prawn. For better management and easy operation, pens of 0.1 to 0.2 ha preferred for growing table size prawn. The area where the pen is to be erected should be cleared of all kind of aquatic weeds. Unwanted organisms from the pen should be eradicated by repeated netting, using dragnets and cast nets. The pen area is limed, with quick lime, at an initial dose @ 200 to 300 kg/ha, followed by monthly instalments of 50 kg/ha.

Stocking: In the case of *M. rosenbergii* of 60-80 mm in size, the recommended stocking density is 20,000-30,000 individuals/ha. Prawn seeds of higher size always give better survival.

Supplementary feeding: Prawns need high protein diet for fast growth. The supplementary feeding may be done with commercially available pelletized feed or locally made feed mixture. Chopped and boiled molluscan meat also can be fed for better growth. As a general guideline for 1 kg of farm made feed, the ingredients as given in the Table 21.7 can be utilized. Feed can be prepared by grinding all the ingredients, except vitamin-mineral mixture, into powder form and mixed thoroughly. Boil water in a vessel and slowly pour the feed powder into it with stirring. After cooling, add the vitamin-mineral mixture and mix thoroughly. Mix the ingredients into uniformly and pellets can be made. The feed can be kept at the bottom of the pen, in feeding trays or bamboo baskets. The prawns can be fed once in the evening @ 2 to 5% of their body weight. Chopped and boiled molluscan meat also can be fed for better growth.

Table 21.7. Feed composition

Ingredients	Quantity/kg of feed (g)
Mustard/groundnut oil-cake	200
Soybean oil-cake	250
Silkworm pupae	150
Rice bran	200
Fish meal/prawn meal	100
Wheat flour	75
Vitamin-mineral mixture	25

Prawns possess the characteristics of cannibalism. During every moulting due to loss of exoskeleton soft body is exposed and the prawn becomes week. The stronger prawns take advantage of the same and start eating the flesh of the affected prawn resulting in increase of mortality rate. To overcome such situation, pens stocked with prawns, should be facilitated with placing palm/date palm leaves, PVC/cemented pipes where the prawns may take shelter during moulting.

Harvesting may be done early in the morning. Repeated netting by 6 to 8 persons, using dragnets and cast nets, can harvest the stock of 0.1 ha pen area within 1to 2 hr . Approximately 60 to 80 kg/0.1ha/ in 4 months of *Macrobrachium rosenbergii* can be achieved by adopting such methods.

***Prawn in* beel *of West Bengal (Garapota, Mathura)*:** Seed of *Macrobrachium rosenbergii* weighing 6 to 8 g (40 to 50 mm) was stocked in pens of 0.04 ha area, @ 20,000 to 25,000/ ha density in beel of West Bengal (Garapota). The harvested size of prawn varied between 195 and 250 mm weighing 60 and 105 g respectively. The prawns were fed with chopped and boiled molluscan meat which was available in the wetland. Production of 675 to 840 kg/ha was obtained in 130 days of culture period.

Risk and uncertainty

Risk in enclosure aquaculture is moderate to high. A small change in prices or survival rate of fish can alter profits significantly. Risk can be divided into several categories, such as risk associated with variation in water quality, disease and parasites; poor quality fingerlings; vandalism and theft are perhaps the most serious ones. Production risk can be partially offset through approved management practices and good husbandry. Nevertheless, problems sometimes occur that are not easily controlled.

The primary aim of aquaculture in developing countries should be to produce maximum quantity of fish for available feed input. Thus there is a need for a comparative

study of the food-conversion efficiency of various potential candidates and most efficient species with hardiness, should be selected for cage culture.

It may be desirable to develop two streams of technology transfer in India, a low-cost one for easy adoption by villagers residing near large water-bodies, with minimum capital investment under the National Rural Employment Programme (NREP), District Rural Development Agency/Integrated Rural Development Programmes, somewhat like a small-scale industry and another high-tech type that can be taken up by the Government agencies and large private sector companies for meeting demands of fish for export or niche markets like open sea-cage farming which is capital intensive activity, but also command very high prices in the international market. The species selection, feeding and value-addition and marketing are important to realize the best returns from this business. Cage and pen culture of fishes holds a great promise as a future potential system for a large-scale fish production, employment generation and foreign exchange earnings.

22. Ornamental Fish Breeding and Culture

Ornamental fishes form an important commercial component of aquaculture, providing for aesthetic requirements and upkeep of environment. Aquarium keeping of fish began n 1805 with the first public display aquarium at Regent's Park in England in 1853. Development of aquaria picked up, and by 1928, there were 45 display aquaria open o public, and at present, there are over 500 aquaria functioning worldwide. However, he market for ornamental fish in the world for public aquaria is less than 1%; 99% of he market for ornamental fish is still confined to the hobbyist. Availability of modern naterials, equipment and air transport have made it possible for hobbyists to obtain vide variety of fishes from all over the world, display in aquaria and maintain them vith a high degree of success.

In India, hobby of ornamental fish-keeping is nearly 70 years old. It began with the *British raj*, and is continuing till date. As the days passed by, ornamental-fish keeping has become an interesting activity for the many, and in the process generates income or unemployed youth and farmers. The concept of entrepreneurship development hrough ornamental-fish farming is gaining popularity day-by-day. And more and more eople are entering into this lucrative business of culturing and breeding of these ishes through farming. As a result, many ancillaries as also pet shops are coming up n the cities and even small towns.

World trade of ornamental fish: The trade has increased since the eighties. n 1995, the world trade of ornamental fish was estimated at US$ 4.5 billion with an nnual growth rate of 10% per year. Currently, the worldwide aquarium fishes and quipment trade is valued at $8 billion (retail), with estimates of 10 to 15% growth er year. Global export of ornamental fishes (both freshwater and marine) was roughly 319 million in 2007 as per the FAO statistics with a wholesale value close to 1 billion nd retail value close to 3 billion. In terms of value, freshwater species represent bout 80%, against 20% of marine species. The USA is the largest market of ornamental ishes, importing fish worth over US$ 500 million every year, followed by the European Jnion and Japan.

As per the statistics of the Marine Products Export Development Authority MPEDA), Kochi, India exported ornamental fishes worth about ₹554 lakh during 009-10 to South-East Asian Countries (45%), European Union (16.7%), Japan 11.9%), China (11.2%), USA (9.4%), Middle-eastern countries (3.8%) and other ations (2.0%) (Table 22.1).

reshwater ornamental fish culture

Common freshwater ornamental fishes

Indian waters possess a rich aquatic biodiversity with 2,319 finfishes distributed in ifferent ecosystems. Out of which, 640 species are found in Inland waters. It is

Table 22.1. Market-wise export details of live aquarium fishes from India

Country		1999-2000	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
Japan	Q:	1	2	2	2	1	2	2	3	3	2	2
	V:	0.42	0.58	0.53	0.47	0.43	0.49	0.45	0.68	0.56	0.62	0.66
	$:	0.10	0.13	0.11	0.10	0.09	0.11	0.10	0.15	0.14	0.14	0.14
USA	Q:	2	2	7	9	3	3	2	3	3	3	2
	V:	0.49	0.45	0.71	0.52	0.57	0.72	0.52	0.50	0.45	0.57	0.52
	$:	0.11	0.10	0.15	0.11	0.12	0.16	0.12	0.11	0.11	0.13	0.11
European	Q:	2	27	8	33	6	9	4	5	6	5	4
Union	V:	0.29	0.31	0.46	0.68	0.59	0.83	0.60	0.86	0.94	0.92	0.92
	$:	0.07	0.07	0.10	0.14	0.13	0.19	0.14	0.19	0.23	0.20	0.19
China	Q:	0	73	2	0	3	0	1	4	4	4	10
	V:	0.01	0.29	0.13	0.04	0.04	0.08	0.16	0.31	0.27	0.32	0.62
	$:	0.00	0.06	0.03	0.01	0.01	0.02	0.04	0.07	0.07	0.07	0.13
South-	Q:	13	57	113	12	136	40	48	45	48	47	30
east	V:	0.35	0.60	1.01	0.71	1.38	2.24	2.89	2.97	3.03	2.78	2.49
Asia	$:	0.08	0.13	0.21	0.15	0.30	0.50	0.66	0.66	0.75	0.64	0.52
	Q:	26	0	0	0	0	1	21	13	24	6	7
Middle	V:	0.11	0.00	0.02	0.00	0.00	0.01	0.49	0.19	0.53	0.16	0.21
East	$:	0.02	0.00	0.00	0.00	0.00	0.00	0.11	0.04	0.13	0.04	0.05
Others	Q:	1	6	15	3	3	4	2	2	2	2	2
	V:	0.08	0.07	0.28	0.13	0.06	0.07	0.06	0.05	0.06	0.06	0.11
	$:	0.02	0.02	0.06	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.02
Total	Q:	44	167	147	59	152	60	81	75	88.89	69.15	56.31
	V:	1.74	2.29	3.14	2.55	3.08	4.44	5.17	5.56	5.85	5.43	5.54
	$:	0.40	0.50	0.66	0.53	0.67	0.99	1.18	1.23	1.45	1.23	1.17

Source: MPEDA, Kochi
Q, Quantity in tonnes; V, value ₹ in crore; $, US dollar (M)

estimated that more than 100 varieties of indigenous ornamental fishes are available in our freshwater mainly within the north-eastern states and the Western Ghats (Table 22.2).

Table 22.2. Important native ornamental fish varieties and their distribution

Common name	Scientific name	Distribution
Black knife fish	*Notopterus notopterus*	All-over India
Scaly barb	*Gonoproktopterus lithopidos*	Western Ghats
Red tailed silver shark	*Gonoproktopterus curmuca*	Western Ghats
Nilgiri shark	*Gonoproktopterus thomassi*	Western Ghats
Black labeo	*Labeo nigriscens*	Western Ghats
Red gilled violet shark	*Labeo boga*	Ganga river
All black shark	*Labeo calbasu*	Northern India
Pencil gold labeo	*Labeo nandina*	Asom
Hi fin barb	*Oreichthys cosuatis*	Eastern India
Hi fin variable	*Oreichthys umangii*	Upper Asom
Black border tail orange cap	*Osteochilichthys nashii*	Western Ghats
Malabar barb	*Osteobrama bakeri*	Western Ghats
Four spot barb	*Puntius arulius tambraparniei*	Western Ghats
Indian rosy barb	*Puntius conchonius*	Eastern India

(Continued)

(Table 22.2. continued)

Common name	Scientific name	Distribution
Red line torpedo	*Puntius denisonii*	Western Ghats, Kerala
Red line torpedo	*Puntius chalakkudiensis*	Western Ghats, Kerala
Jerdon's carp	*Puntius jerdoni*	Western Ghats
Long snouted barb	*Puntius dorsalis*	Krishna River System
Melon barb	*Puntius faciatus faciatus*	Western Ghats
Black spot Barb	*Puntius filamentosus*	Karnataka, Kerala
Filament barb	*Puntius assimillis*	South Kerala
Malini's barb	*Puntius mahecola*	Western Ghats
Neon hatchet	*Chela cachius*	Asom
Burjors brilliance	*Chela dadiburjori*	Western Ghats, Kerala
Blue dotted hill trout	*Barilius bakeri*	Western Ghats, Kerala
Zebra danio	*Brachydanio rerio*	All-over India, excepting north-eastern region
Nilgiri danio	*Danio neilgheriensis*	Western Ghats
Giant danio	*Danio aequipinnatus*	North-eastern India
Moustached danio	*Danio dangila*	Bihar, Asom
Torquoise danio	*Danio devario*	Eastern India
Malabar danio	*Danio malabaricus*	Western Ghats, Kerala
South Indian flying barb	*Esomus barbatus*	Tamil Nadu, Karnataka
Slender rasbora	*Parluciosoma daniconius*	Throughout India
Black line rasbora	*Parluciosoma labiosa*	Nasik dist. of Maharashtra
Rhinocerous algaeater	*Garra bicornuta*	Thunga river, Karnataka
Sidewinder loach	*Aborichthys bijulensis*	Garo hills, Meghalaya
Puma loach	*Acanthocobitis rubidipinnis*	Upper Asom
Leopard loach	*Acanthocobitis botia*	North-eastern India
Black line loach	*Nemachelius anguilla*	Western Ghats
Banded loach	*Shistura beavani*	North Bengal
Polka dotted loach	*Shistura corica*	North Bengal
Ring loach	*Shistura denisoni dayi*	Bihar
Olivaceous loach	*Shistura devdevi*	Teesta River drainage
Many banded loach	*Schistura multifaciatus*	Eastern Himalayas
Victory loach	*Shistura scaturigina*	Eastern sub Himalayas
Fascinating loach	*Shistura semiarmatus*	Western Ghats
Long snouted loach	*Nemachilichthys ruppelli*	Karnataka, Kerala
Black panther loach	*Shistura yenjitee*	Bhutan
Grizzled loach	*Shistura sikmaiensis*	Manipur Valley
Zodiac loach	*Mesonoemacheilus triangularis*	Western Ghats, Kerala
Tail spot loach	*Lepidocephalus annandalei*	Upper Asom
Goalpara loach	*Lepidocephalus goalparensis*	Goalpara Asom, Odisha
Panther loach	*Lepidocephalus gunthea*	Northern and eastern India
Indian coolie loach	*Pangio pangia*	North-east Bengal, Eastern Madhya Pradesh
Jaguar loach	*Somileptes gongota*	North Bengal, Asom
Y-loach	*Botia lohachata*	Indus and Ganga drainage
Tiger loach	*Botia birdi*	Punjab, North India
Golden banded loach	*Botia dario*	Asom, Bengal, Bihar, Odisha
Twin banded loach	*Botia rostrata*	Asom
Striped loach	*Botia striata*	Tunga river, Kolhapur, Maharashtra
Velvet catfish	*Rita pavimentatus*	Andhra Pradesh
Butter catfish	*Ompok bimaculatus*	Throughout India
Gulper catfish	*Ompok pabda*	North-east India
Stripped glass catfish	*Pseudeutropius atherinoides*	Throughout India
Indian tiger shark	*Pangasius pangasius*	Large rivers of India
Giant river catfish	*Bagarius yarelli*	Throughout India

(Continued)

(Table 22.2. concluded)

Common name	Scientific name	Distribution
Thread tail catfish	*Conta conta*	Upper Asom
Clown catfish	*Gagata cenia*	North and North-east India
Black line catfish	*Glyptothorax anamalaiensis*	Base of Anamalai hills, Kerala
Copper catfish	*Glyptothorax telchitta*	Northern India, Odisha
Butterfly catfish	*Hara hara*	Northern India
Elongated mouth catfish	*Hara horai*	North Bengal
Dwarf anchor catfish	*Hara jerdoni*	North-eastern India
Giant mouth catfish	*Hara filamentosa*	Dibru river, Asom
Cheetah catfish	*Laguvia shawi*	Himalaya, Darjeeling, North Bengal
Devil catfish	*Chaca chaca*	Bengal, Asom, Odisha, Bihar
Red halfbeak	*Dermogenys pusillus*	Hooghly Estuary, Bengal, Odisha
Long nosed needle fish	*Xenentodon cancila*	Most places in India
Stripped panchax	*Aplocheilus lineatus*	Odisha, western and southern India
Red panchax	*Aplocheilus panchax*	Odisha, North and eastern India
Day's panchax	*Aplocheilus dayi*	Kerala
Jewel panchax	*Aplocheilus parvus*	Karnataka
Hi fin glass fish	*Pseudambassis ranga*	Throughout India
Giant glass fish	*Parambasis thomassi*	Western Ghats
Finger fish	*Monodactylus argenteus*	Indo-west Pacific
Spotted scat	*Scatophagus argus argus*	Estuaries
Red scat	*Scatophagus argus rubrifrons*	Hooghly estuary, Chilka
Leaf fish	*Nandus nandus*	Throughout India
Yellow sunfish	*Pristolepis marginata*	Kerala
Dwarf chameleon	*Badis badis badis*	North east, Odisha, Bengal
Red chameleon fish	*Badis burmanicus*	Upper Asom
Noble gourami	*Ctenops nobilis*	Eastern India
Striped gourami	*Colisa fasciata*	Eastern India
Dwarf gourami	*Colisa lalia*	Throughout India
Honey gourami	*Colisa sota*	North-east India
Peacock eel	*Macrognathus aral*	Eastern India
Red tailed eel	*Macrognathus jacobbi*	North Bengal, Odisha
Tyre track eel	*Mastacembelus armatus*	Bengal, Odisha, Bihar
Topaz puffer fish	*Chelondon steindachneri*	Hooghly, Odisha
Burmese puffer	*Chelonodon nigroviridis*	Gangetic delta, Odisha
Emerald puffer	*Tetraodon cutcutia*	North-eastern India
Small puffer	*Tetraodon travancoricus*	Kerala
Small puffer	*Carinotetraodon imitator*	Kerala
Sun/Yellow catfish	*Horabagrus brachysoma*	Kerala, South Canara
Yellow catfish	*Horabagrus nigricollaris*	Kerala
Canara pearlspot	*Etroplus canarensis*	South Canara - Karnataka
Orange chromide	*Etroplus maculatus*	Kerala
Barca snakehead	*Channa barca*	North-east India
Orange spotted snakehead	*Channa aurantimaculata*	North-east India
Rainbow snakehead	*Channa bleheri*	North-east India

Freshwater ornamental fish trade in India: With the strict enforcement of the wild life protection act of 1972, amended in 1980, lawful trade of all species of birds, mammals and reptiles has been banned for export as well as for the local trade. This has made ornamental fish hobby as a popular proposition, and over the last few years there is mushrooming of aquarium retail shops all around. It has also been noticed that Indian ornamental fishes are in greater demand in international market thereby offering greater scope and possibilities of commercial freshwater ornamental fish production and export to the tune of about US $ 30 million (about ₹110 crore every year). Export of ornamental fishes from the country is mainly confined to freshwater varieties; limited to fishes collected from nature predominantly from the north-eastern states and the Western Ghats (85%), and of a few bred varieties of exotic species (15%). Kolkata is the largest exit point, followed by Mumbai and Chennai. These metropolitan cities are also the major breeding centres for freshwater ornamental fishes. There are reports that in Kerala, Andhra Pradesh, Odisha, Asom, Bihar and many other places, people have started producing ornamental fishes.

The Central Institute of Freshwater Aquaculture (CIFA), Bhubaneshwar, plays a pivotal role in ensuring that such a hobby becomes fruitful by adding more to entrepreneurial development. Special efforts are being made to breed some of the indigenous varieties in captivity. Success in breeding and larval rearing has been achieved in the following--Indian rosy barbs (*Puntius conchonius*), Black line rasbora (*Parluciosoma daniconius*), Indian flying barb (*Esomus barbatus*), Dwarf gourami (*Colisa lalia*), Giant danio (*Danio aequipinnatus*). The College of Fisheries, Kochi, in a collaborative project with the National Bureau of Fish Genetic Resources (NBFGR) could develop technology for captive breeding and larval rearing of 12 ornamental fishes from Western Ghats–melon barb (*Puntius fasciatus*), filament barb (*Puntius filamentosus*), *Puntius exclamatio, Puntius melanostigma, Puntius sarana subnasutus, Danio malabaricus, Puntius pookodensis, Pristolepis marginata, P. fasciatus, Garra gotyla stenorhynchus* and loaches *Nemacheilus triangularis* and *N. monilis;* leading to their domestication. The NBFGR Centre at Kochi in collaboration with the Regional Agricultural Research Station, Kumarakom, successfully domesticated yellow catfish (*Horabagrus brachysoma*) and *Gonoproktopterus curmuca.* The College of Fisheries, Kochi, in 2010 standardized breeding and larval rearing technique of the much-sought-after species *Puntius denisonii*. Some success in broodstock development and breeding has been achieved on *Puntius chalakkudiensis, P. jerdoni* and *Osteobrama bakeri* also, but standardization of breeding is yet to be done. To conserve biodiversity as well as to adopt programme in entrepreneurial scale for export, technologies for commercial breeding are required for Indian species.

Commercial production of ornamental fishes: A wide range of ornamental fishes, ranging from cheap guppies to costly neon tetras, are bred by aquaculturists and are available almost at every city and town. Freshwater ornamental fish breeding does not require any sophisticated equipment, instruments or infrastructure and the space requirement can be adjusted to suit aquarium need. Breeding can be achieved even in any spare tank. One basic requirement is a clear understanding of the habit and biological requirement of the fish. Hobbyists could study behaviour and biology of fish during aquarium maintenance and could breed several fish varieties. Water quality parameters including temperature, plants and lighting are important factors influencing spawning and successful fry rearing. Most of the popular tropical ornamental fishes

are only about 3-4-cm long and can be kept in considerable numbers within a moderate-size aquarium.

Freshwater aquarium fishes are broadly grouped into two categories on the basis of breeding behaviour– egg-layers (oviparous) and live-bearers (ovo-viviparous) – and some categorize them as egg-layers with no care (non-guarders), egg-layers with care (guarders), egg-buriers, mouth-incubators, nest-builders and egg-carriers on the basis of the parental care. Important groups of egg-layers are: barbs, danios, rasboras, goldfish, tetras, bettas, gouramis and the major live-bearers are: guppies, platies, mollies and swordtails.

Barbs are one of the most important groups among egg-layers and most species of the group are known to have originated from India – rosy barb (*Puntius conchonius*), striped barb (*P. fasciatus*) and Aruli barb (*P. arulius*). The major species of the group of danios include giant danio (*Danio aequipinnatus*), pearl danio (*Brachydanio albalineatus*) and zebra danio (*B. rerio*). Zebra danio is the typical example of ornamental fish of Indian origin, which is bred and reared easily. Among rasboras, slender rasbora (*Rasbora daniconius*), glowlight rasbora (*R. panciperforata*) and scissors tail (*R. trilineata*) are important. Goldfish, *Carassius auratus*, is the most commonly available fish, preferred by most of the hobbyists because of its attractive colouration ranging from pure gold to red, orange, black and albino and also due to a range of shapes and sizes. Further, various types of morphological characteristics like divided caudal and anal fins of varying sizes, enlargement and protrusion of eyes, presence of pearl-like glittering scales, absence of dorsal fins, transparent and dazzling colours, obtained through cross-breeding or selective breeding make species more attractive. Some of the common varieties of goldfish available are comet, lion head, oranda (a modification of lion head), fringe tail, veil tail, fan tail, shubunkin (scale-less hybrid), telescopic eye, etc. The fish grows up to 20 cm in length, but starts breeding when only 6-cm long.

Tetras are small fishes of 3-8-cm long; majority of which have originated from South America. Most common species of the group are black widow tetra (*Gymnocorymbus temetizi*), serpae tetra (*Hyphessobrycon callistus*), rosy tetra (*H. rosaceus*), lemon tetra (*H. pulchripinnis*), flame tetra (*H. flammeus*), neon tetra (*H. innesi*), cardinal tetra (*Cheirodon axelrodi*), glow light tetra (*Hemigrammus erythrozonus*), head and tail light tetra (*H. ocellifer*), pretty tetra (*H. pulcher*) etc.

Betta splendens, popularly known as Siamese fighting fish, occurs in varied colours like green, red, blue, albino and sometimes with a combination of two or three shades. Attractive colours and hardiness of the species are reasons for its wide adoption by hobbyists. Males are brightly coloured with beautifully spread-over fins. They become aggressive in presence of other males. Angel fish (*Pterophyllum eimenkei* and *P. scalare*) is another important group of candidate species widely preferred with different varieties such as black, veil tail, marble and albino. Among gouramies, three spot gourami (*Trichogaster trichopterus*), pearl gourami (*T. leeri*), moonlight gourami (*T. microlepis*), snake skin gourami (*T. pectorails*), dwarf gourami (*Colisa lalia*), giant gourami (*C. fasciatus*), chocolate gourami (*Sphaerichthys osphronemoides*) and kissing gourami (*Helostoma temmincki*) are important ones. Bettas and gouramies are most popular among nest-builders, characterized by accessory respiratory organs, thus making species hardier.

Live-bearers are the second group of ornamental fishes, giving birth to young-ones and reproducing only a few offspring in comparison to egg-layers; though their breeding is relatively easy. Development of young-ones takes place inside the female, and they are released after about four weeks. Live-bearer species include guppy (*Poecilia reticulata*), black molly (*Poecilia sphenops*), swordtail (*Xiphophorus helleri*), platy (*X. maculatus*) and their variants.

Breeding of live-bearer species

Fishes in this group include multicolour guppies, mollies with enlarged sail-like dorsal fin; platys with usually rounded tail fin; and swordtails, so named because males have a long pointed sword-like extension to caudal fin. Babies produced by a live-bearer are normally 50-60 only, though some larger swordtails may reproduce as many as 100. If the live-bearers are fed properly with natural food, supplemented with better artificial feed, the mother produces more than 100 young-ones. Soon after larvae come out from the mother, they are to be separated to check predation /cannibalism. To keep their colour strain pure, one must isolate them from any possible contamination (crossbreeding). For which number of tanks are required – one for males and one for females, as well as a few breeding tanks for each selected pair and some tanks for young-ones. These are popular with fish-hobbyists due to their prolific breeding habit and acceptance of all kinds of food.

Guppy: Guppy (*Poecilia reticulata*) is a live-bearing fish, originated from South America, north of Amazon but it is presently seen worldwide. Probable reason for its spread in many countries perhaps is for controlling disease-carrying mosquitoes (by eating larvae). From aesthetic point of view, they look beautiful in a group. It has got a greater demand throughout the Europe.

Male guppy may reach up to 2.5-3.5 cm in length, and female is usually larger when fully grown. Guppies thrive in a large well-planted tank with a steady temperature within the range 20-25°C. During summer, a special cooling care has to be maintained to sustain guppies, as the water temperature in many places rises up to 37°C, even more during peak summer. Gravid females need to be removed from community tanks as soon as they start swelling with developing young-ones and are placed in the breeding tanks (30 cm × 20 cm × 20 cm), individually or in pairs. Tank should be provided with plants like *Cabomba* or *Hydrilla* and with aeration during laying of young-ones (20-200).

For mass breeding of guppies, a tank of 100 cm ×100 cm × 60 cm is ideal, where perforated cylindrical baskets can be provided at one side of the tank encircled with fibrous plastic flowing filaments where females can drop young-ones. Soon after the birth, young-ones escape from their mother and enter into perforated baskets, and latter they are collected from the baskets and placed in the separate tanks for further rearing.

Platies, swordtails and mollies: Platies, swordtails (*Xiphophorus*) and mollies

(*Poecilia*) are all close relatives of guppies and have originated from Central and North-Eastern South America. Adult live-bearers of platies and swordtails take 6-8 weeks, and of mollies 12-16 weeks to mature. Fertilization is internal and gestation period is of four weeks. Platies, swordtails and mollies are quite hardy fishes, but in no case they should be neglected with standard aquarium conditions. They breed well in most types of water, so long as it is not too soft or acidic. Many of the mollies appear to benefit from addition of a little aquarium marine-salt or common-salt to water (0.5-1 g/litre) ; ensure that salt level is maintained at every partial water change.

Sex-reversal in swordtails: Breeding habits of live-bearing fishes are very interesting and have attracted attention of scientists across the world. In swordtail (*Xiphohorus helleri*), phenomenon of sex-reversal is frequently noticed. Each immature fish could develop into a male or a female depending on which reproductive organs developed first, male or female. If ovaries (female reproductive organs) develop first, they secrete female hormone 'estrogen', and the fish will be a female. Later on female fish can turn into a functional male. Female to male change is common, but male to female change is rare. Sometimes, external factors such as *p*H can affect sexual development

Table 22.3. Instant breeding table for live-bearers

Species	Sexual dimorphism	Size	Optimum water condition for breeding	Gestation period (days)	Young-ones per female	Starter diet
Guppy, *Poecilia reticulata*	Male is smaller with more flowing fins and pointed anal fin or gonopodium	Male: 2.5-3.5 cm Female: 5-6 cm	Temp. : 20-28°C, water hardness 50-100 mg $CaCO_3$/litre (moderately soft water)	21-35	20-100	Finely powdered dried feed and rotifers
Platy *Xiphophorous maculatus*	Male is smaller and slimmer with gonopodium; Colouration Red, gold, blue, black, brown, etc.	Male: 3-4 cm Female: 4-5 cm	Temp. : 23-28°C, water hardness 50-100 mg $CaCO_3$/litre (moderately soft water)	28-42	10-100	Finely powdered dried feed and rotifers
Swordtail *Xiphophorous helleri*	Male is smaller and slimmer with gonopodium and pronounced sword-like projection on caudal fin	Male: 6-7 cm Female: 7-9 cm	Temp. : 23-28°C water hardness 50-100 mg $CaCO_3$/ litre (moderately soft water)	28-42	20-100	Finely powdered dried feed and rotifers
Black molly *Poecilia* sp.	Male with gonopodium; dorsal fin is flowing and bigger. Males are smaller than females and slimmer also	Male: 7-8 cm Female: 9 cm	Temp.:23-28°C, Aquarium-salt at 0.5-1.0 g/litre	40-70	30-70	Finely powdered dried feed and rotifers

of some fishes. It has been observed that low *p*H of 5-6 develops more males in the broods of swordtail and *p*H value more than 7.0 develops more females. The details regarding the breeding of live-bearers are presented in Table 22.3.

Breeding trap used for live-bearer species: When females of live-bearer species are ready to drop young-ones, they should be taken into breeding tank where individual or group of fishes can be kept in perforated nylon-bag cages from which young-ones escape through mesh from their mother to outside to avoid parental predation. Various types of net cages, perforated dustbins, or fabricated perforated containers of required size can be used for this. A box-type or cylindrical, but not a cage, can be fitted or hooked on to an aquarium wall for one or more mothers whose new-borns drop through mesh-opening into the lower space of aquarium. When it is observed that females have stopped dropping young-ones; young ones should be removed and reared separately with balanced nutritious diet.

Feeding for breeding: Individual requirement and habits such as predatory life-style of *Belonesox belizanus* (pike killifish), *Dermogenys pusillus* (halfbeaks) and some *Gambusia* spp. need to be taken into consideration, but generally speaking, live-bearers are omnivorous. This applies even to those species that are regarded as herbivores (plant eaters), like many of mollies. In fact, mollies sometimes eat their own young-ones, proving beyond doubt that they can digest animal-protein like any other carnivorous fishes.

Many live-bearers enjoy a diet with composition that takes them to the vegetarian-end of the nutritional spectrum. Feed composition should be balanced, providing proteins, carbohydrates, lipids (fats/oils), vitamins, mineral salts (trace elements) as needed and a bit of roughage (fibres).

During growth or recuperation, diets that are slightly higher in proteins than normal (say, around 35%), may be of advantage. At other times, lower levels of protein (around 25-30%) can be given in granular form. A compounded diet can be prepared using locally available ingredients. It has been proved from a couple of experiments conducted at the Central Institute of Freshwater Aquaculture (CIFA) that feed containing less or zero-fish meal content showed better growth and early maturation compared to feed containing more of fish-meal as a animal protein source. This shows that the animal has the tendency to consume and utilize plant material than animal-based feed.

Breeding of egg-layers

Most of the families of tropical aquarium fishes are egg-layers, wherein fertilization takes place externally.

Egg-scatterers laying non-adhesive eggs: Zebra fish is considered an egg-scatterer, laying non-adhesive eggs. Larger egg-scatterers are grouped under genus *Danio* and the other smaller under genus *Brachydanio*. The important danios include: the giant danio (*Danio aequipinnatus*), pearl danio (*Brachydanio albalineatus*) and zebra danio (*Brachydanio rerio*).

Like many aquarium fishes, zebra danios also eat away their own eggs and spawn after breeding. As the precautionary measure, aquarium bottoms are loaded with round pebbles layer of 6-8 cm diameter. Before setting-up breeding pair in any aquarium tank, parents are to be well fed with live-food like smaller zooplankton.

During breeding, male : female ratio should be maintained at 2:1 or 3:1. Female is introduced in the breeding tank one day earlier than males. Eggs are of smaller size and remain hidden behind pebbles. They require hatching time of two-three days under favourable temperature. As soon as tiny hatchlings are observed in the aquarium tanks, parents need to be removed. Hatchlings take two days to absorb yellow yolk-sac. After two days, they are fed with infusorians for 4 days. Subsequently rotifers and smaller zooplankton can be fed for a week, after which they can be provided powdered formulated feed.

Egg-scatterers laying adhesive eggs: Gold fish, *Carassius auratus,* is considered an egg-scatterer laying adhesive eggs. It is well adaptable for aquaria and open-outdoor cement cisterns. Gold fish varieties in the market are common gold fish, fringe tail, lion head, oranda, comet, shubunkin, telescopic eye, veil tail and red cap. At the time of maturity, when secondary sexual characters appear, male and female gold fishes are selected and kept in circular glass tanks (24"×12"×15") or ferro-cement tanks (3.5 ft ×2.5 ft) after disinfecting containers with 1 ppm solution of potassium permanganate ($KMnO_4$). Water should be mixed preferably with 50% groundwater and 50% filtered pond water. Containers could be kept in such a place, where it can receive some early morning sunshine and no sunlight afterwards. Some artificial nests need to be provided. Various types of sterilized natural submerged aquatic plants like *Hydrilla,* split plastic ropes with one end tied or burnt to make it blunt and even polythene strips are found suitable for this. Nests should float close to water surface, and the additional nests should be spread on the bottom of spawning tanks for the eggs that sink down. The water temperature should be maintained between 20 and 30°C; ideal temperature is 27-28°C.

Spawner and milter in 1:2 are released into breeding tank late in the evening. Egg-laying usually takes place within 6-12 hr of placing males and females together. The moment spawning is over, nests are transferred to a different container, or alternatively, the parent fish is transferred from breeding tank. If this is not done, the parents are most likely to eat away eggs to compensate post-spawning loss of energy.

Generally, female lays about 2,000-3,000 eggs. Healthy eggs are golden transparent at the beginning and gradually transparent area decreases. Unfertilized eggs remain opaque and continue to remain as such with arrested growth. These dead eggs become pale-white, and hair-like aquatic fungi would grow on all sides, giving it appearance of a small powder-puff.

Under ideal conditions, within three days, eggs hatch out with a hatching rate of 80-90%. Nest materials are taken out from tank when young larvae start floating. Generally, tiny larvae remain clinging to nest, so precautions have to be taken while transferring nest from breeding pool.

Egg depositors: Rasboras, group of small shoaling fishes, about 50 species from East Africa, South and East Asia, lay their eggs on the underside of the flat levels as such, are called egg-depositors. The very common ones are *Rasbora daniconius* (slender rasbora), *R. heteromorpha* (harlequin), *R. panciperforata* (glow light rasbora) and *R. trilineata* (scissor tail). They are ideal for a well-planted community aquarium where a shoal of 5-10 individuals look very attractive as they swim actively at the upper regions of the water. A temperature between 25 and 28°C is optimum for their breeding.

The smaller rasbora lays up to 100 nos eggs/female while larger female lays up to 250 eggs per female. But in general rasboras including harlequin are often fairly difficult to breed. Like barbs they require soft, slightly acidic (*p*H 5.5) water and temperature at 28°C. After conditioning male and female, they are placed in a tank planted with flat leaved plants. Rasboras in general and harlequin in particular prefer peaceful and quiet environment for breeding and low lighting levels. The male and female brooders are placed together in a breeding tank for a week. If they do not respond then they should be separated and reintroduced again later. Once spawning has occurred, as indicated by the sliminess of the female fish, remove both parents from the breeding tank. The hatching takes 24-36 hours, and resultant hatchlings become free swimming after 3-5 days. At this stage, the tiny hatchlings should be fed infusorians and newly hatched brine shrimp. As they grow bigger they should be fed zooplankton, like *Moina* and *Daphnia*. Adult rasboras feed on good quality dried foods.

Egg-buriers: Among the egg-buriers, killi fishes, *Aplochelius panchax, A. lineatus* and *A. blochii* are important. They lay their eggs in a soft peat at the bottom of the tank. In an aquarium, they lay their eggs in dense planted environment. They are good jumpers; therefore, they should be kept in covered aquarium. The eggs are capable of remaining viable even after dried condition and hatching may be possible even after some weeks or even months, when again placed in water. In drought conditions, parents may die but eggs remain alive until the next rains. They rarely grow over 3-4 cm in total length, and are short-lived.

Breeding of nest-builders

Among nest-builders, gouramis and their relatives are most popular. The so-called labyrinth or anabantid fishes consist of four families and almost 70 species of freshwater fishes from tropical Africa and South-east Asia. They possess an accessory respiratory organ, the labyrinth, which is an extension of gill-chamber, situated behind eyes/gills region of the head. Many of the anabantids are bubble nest-builders and incubate their eggs in floating nests; made especially by male fish.

The dwarf gourami (*Colisa lalia*) comes from eastern India, where it lives in still and heavily weed-infested waters. It may reach a length of 5 cm. Female is less brightly coloured and has more rounded dorsal and anal fins than male.

For breeding, males and females are kept separately in different tanks for a few weeks and fed with live-foods. When female's abdomen becomes grossly distended with eggs, it is transferred to a smaller breeding tank with water level of 5-6" (12.7–15.24 cm) , temperature range of 28-30°C, total hardiness of 100-200 ppm and *p*H of 7.0-7.5 and with plenty of fine-leaved plants such as *Cabomba, Myriophyllum* or other floating plants. After 1-2 days, a matured male is introduced in the breeding tank.

Transparent perforated plastic-sheet or a glass is used to cover over the tank to keep humidity and temperature at the high level, which help maintain the bubble nest in a good condition. Male soon begins to build a bubble nest,and after making the nest, courtship usually ends with both fishes embracing near the nest, resulting deposition of a large numbers of eggs in the nest. After the making of the bubble nest if female does not lay eggs then male becomes very aggressive and may even kill female.

After breeding, female is removed. The male guards eggs, which remain attached to floating bubble nest. Within 24 hours, hatching takes place. The moment the fry begin leaving nest, the male is also removed from the tank. After 36 hours, when young-ones remain in free-swimming stage, they are provided infusoria as starter feed. After a week, the fry start taking newly hatched artemia and small cladocerans. During this stage, fry require vigorous feeding. Subsequently when they grow little bigger they can be stocked in bigger cement-tanks for further growth.

Siamese fighting fish or betta, *Betta splendens*, is native of shallow and warm waters of Thailand, Malaysia and Vietnam. Like gouramis, this fish breathes atmospheric air, so it can be kept in very small container with water having *p*H of 7.0. Bettas accept all kinds of foods, preferably animal-protein supplemented diet. Adult fish attains 6-cm length. Cultured betta is white, orange, green, blue, crimson and black in colour. Fish exhibits sexual dimorphism, male's dorsal, caudal, anal and ventral fins are longer and may become extremely veil-shaped. After attaining sexual maturity, males become aggressive for their territories. If the female does not spawn after male forms bubble nest; male even kills female. It is this characteristic that has given the species its name Fighting fish.

The fish gets sexual maturity at approximately three months, but it is best to attempt breeding with fishes that are 9-12 months old. Allow one male to every two or three females; taking care to choose females that are at least of the same size as the male. Males are kept in small aquaria with a capacity to hold 2-5 litres of water. Since fighters have a labyrinth organ, aeration is not necessary. Regular maintenance required is only to change 50-75% of water in a week. Less aggressive females are also kept together in one aquarium containing 25-50 litres of water. Another breeding tank containing 50 litres of water (depth 15 cm) is required along with fine-leaf plants – *Myriophyllum* or *Cabomba*. No aeration or filtration is required at this stage. The tank has to be partitioned into two halves with fine meshed net in one portion, mature female is placed and in the other is placed mature male. Water temperature of 27°C is considered optimum.

Male starts building bubble nest quickly, and once this is underway, partition net is removed. At this crucial point, the female should be accepted by the male, otherwise male starts vigorous display of chasing, which ultimately ends in fin-tearing of female. If the fin-tearing occurs, the female is removed, and the same type of female is replaced after a few days. Fighter often spawn in early morning, and up to 15 eggs may result from one embrace and this is repeated many times during a period of a few hours to give a final brood of 200-300 eggs, although broods of 600 and more eggs have also been recorded. As the eggs are shed and fertilized, they sink to tank-floor. The male fish then collects them in his mouth and spits them into the bubble nest. At the end of spawning, the female is removed, but the male is left, as he guards nest for several days. However, about three days after spawning, the male is removed as well, since it may eventually eat young-ones. Eggs hatch after 36-48 hr. The smaller fry become free swimming after five or six days, when they accept infusoria or egg-yolk milk several times a day. After three or four days, the fry generally accept fine dry foods. Development of labyrinth organ in the small fry takes place when they are about three to four weeks old. At this time, it is vital that the air above the tank remains warm and humid, and hence a glass or plastic-sheet is recommended. If the air is too cool, it may lead to death of fish. The males and the females should be separated before they mature and start fighting.

Another nest-builder is angelfish (*Pterophyllum scalare*), which originated from Amazon region of South America. It grows up to 6" length in waters having *p*H of 6.5-6.9, alkalinity of 50-100 $CaCO_3$ mg/litre. Angelfish accepts flake food alone and requires live-plants like Amazon sword- plants (*Echinodorus*). Minimum water capacity of tank for breeding a pair of angelfish should be 60-70 litres. From matured angel group, those with straight top and bottom fins without any bowing or bends are selected; they should be healthy, strong, robust and active. In the beginning, 6-8 potential breeders are selected which can be set in a 100-litre tank and they are fed well with a good selection of live-foods. This fish does not exhibit sexual dimorphism. Experienced fish-keepers, however, learn to recognize visible differences in shape and size between male and female angelfishes after watching spawning behaviour exhibited during courtship. The breeding season of different species varies widely, a brief account of which is given in Table 22.4.

Feed for breeding and maintenance

Ornamental fish feeds, which are available in the market, are being imported from Singapore, Hong Kong, Korea, Thailand and many other countries. However, an entrepreneur if desires can prepare required feed by using locally available ingredients mostly from various agricultural byproducts. Mostly groundnut oil-cake, wheat-bran, soybean meal, tapioca floor, vitamin mineral mix and oil are used during ornamental fish feed preparation. These ingredients with different combinations containing 40-45% protein resulted higher growth and survival. Also incorporation of 1.25 ppm 3, 3',5-triiodo-L-thyronine (T_3) stimulated growth and disease resistance in gold fish. However, high doses did not give any beneficial effect in terms of survival.

Nutrient requirements of ornamental fish: Like all fishes, ornamental fishes too require proteins, lipids, carbohydrates, vitamins and minerals. Young-ones can be fed on 40-50% proteins, 4-6% lipids and 40-50% carbohydrates. The adult or brood fish can be fed with 30-35% proteins, 6-8% lipids and 40-50% carbohydrates. In addition to this, 1% vitamins-minerals could be added.

The feed ingredients of ornamental fish feed are generally selected on the basis of availability, nutrient composition and physical properties. Ingredient should be of very

Table 22.4. Database of the breeding season (months) of various ornamental fishes

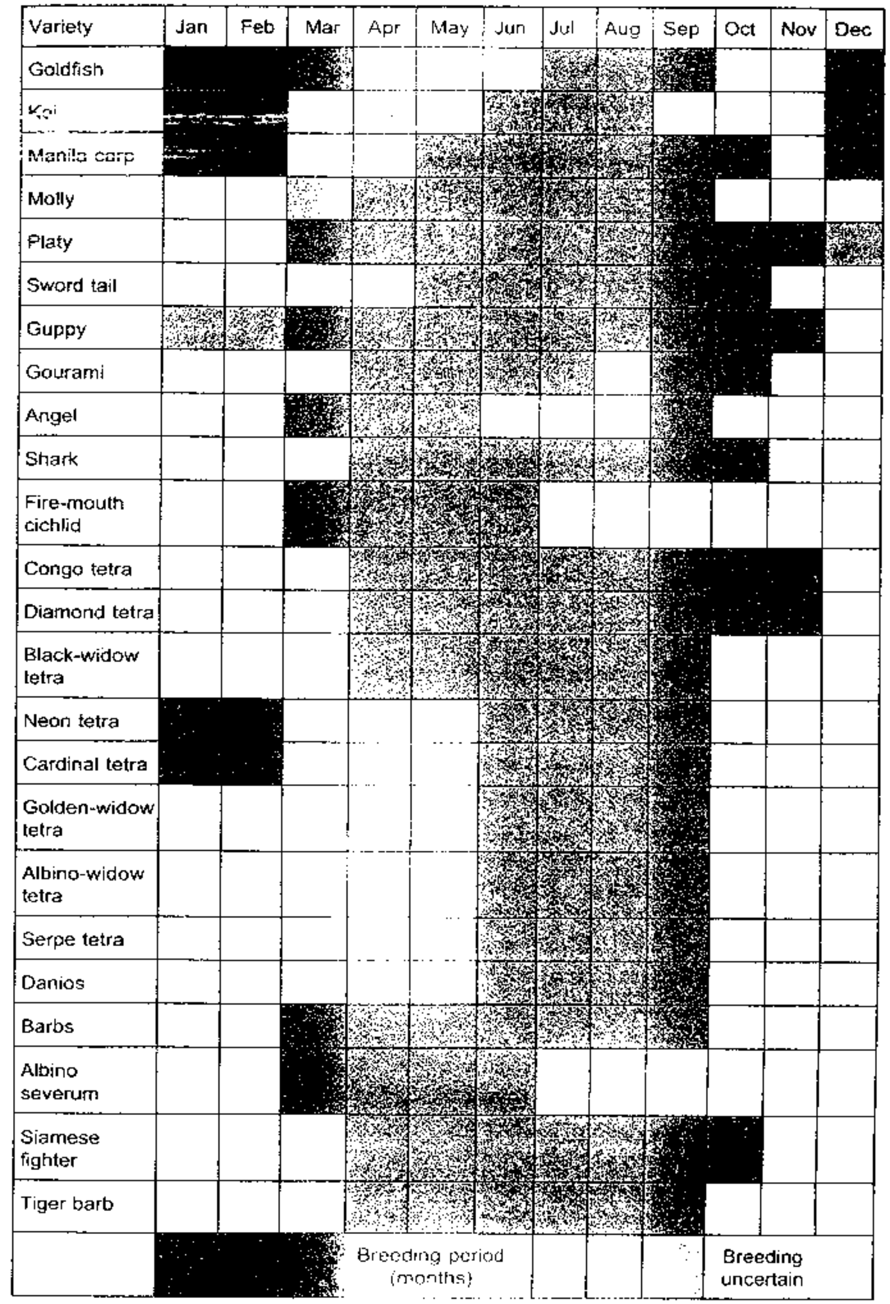


Table 22.5. Common ingredients and their proximate composition (%)

Sources	Crude protein	Crude lipid	Crude fibre	Nitrogen free extract (NFE) soluble carbohydrate	Ash
Plant source					
Groundnut cake (expeller)	40-45	4-8	6-7	30-35	7-8
Sesame cake	29-43	7-13	6-18	19-22	10-15
Gingelly oilcake	30-35	6-8	6-7	30-40	8-9
Soybean cake	36-40	8-10	4-6	30-35	6-9
Soybean meal (solvent extract)	45-55	1-2	4-6	30-35	5-8
Spirulina	50.5	1.0	2.1	26.7	11.0
Rice bran	8-11	12-16	10-15	40-45	5-8
Rice polish	11-14	10-15	7-9	40-45	5-7
Maize bran	9-11	4-6	2-3	70-80	2-3
Wheat bran	9-15	2-8	4-12	30-50	2-5
Wheat flour	13-14	3-4	2-3	60-50	2-3
Tapioca flour	2-3	1-2	2.0	78-86	0.2-2.3
Animal source					
Fish meal	40-50	6-10	2-3	5-8	25-35
Prawn head meal	28-30	8-10	1-5	3-4	45-50
Silkworm pupae meal	60-65	18-20	3-5	3-5	4-8
Liver meal	60-65	3-4	1-2	20-21	2-3
Earthworm meal	51.7	3.4	12-8	14-6	12-5

Table 22.6. Mineral and vitamin requirements of ornamental fish

Mineral	Amount/kg feed	Vitamin	Amount/kg feed
Calcium	5 g	A	5,000-10,000 IU
Phosphorus	7 g	D_3	100- 200 IU
Magnesium	500 mg	E	100-200 IU
Sodium	1-3 g	K	5-20 IU
Potassium	1-3 g	C	200-400 mg
Sulphur	3-5 g	B_1	50-100 mg
Chlorine	1-5 g	B_2	30-50 mg
Iron	50-100 g	B_6	30-50 mg
Copper	1-4 g	B_{12}	0.02-1.0 mg
Manganese	20-50 g	Biotin	5.0-1.0 mg
Cobalt	5-10 mg	Choline	400-200 mg
Zinc	30-100 mg	Folic acid	500-10 mg
Iodine	100-300 mg	Inositol (E)	200-300 mg
Molybdenum	Trace	Niacin	100-150 mg
Chromium	Trace	Pantothenic acid	50-100 mg
Fluorine	Trace		

good quality and free from pathogens. Common ingredients available in the country and their proximate composition are given Table 22.5, and the requirement of vitamins and minerals are presented in Table 22.6.

Feeding during pre-breeding and post-breeding period: Like all living animals, the nutritive requirement during pre- and post-breeding period is more. A better environment and a good nutritionally balanced diet for early gonadal maturation as well as to compensate losses of energy after spawning are required. In both cases, a highly nutritious diet (40-45% protein) is required. During pre-breeding stage, fish can be fed with various live-feed like brine shrimp, earthworms, tubifex, bloodworm, mosquito larvae, *Moina* etc. supplemented with protein-rich formulated diet. Further, it has been observed that 100 mg vit. E/kg diet of goldfish is better for early gonadal maturation.

Feeding for maintenance: A maintenance ration (crude proteins 20-25% and carbohydrates 50-55%) could be provided to fish meant for sale or for home aquaria,. But palatability factor needs to be considered, otherwise fish will not accept feed. High-carbohydrate, low-protein based ingredients are selected for making maintenance ration. High carbohydrate ingredients are rice-bran, rice-polish, wheat-bran, maize-bran, tapioca, etc. Besides the above ingredients, kitchen-waste with vegetable-peel, edible human waste-food, bone and meat waste, prawn shell, cooked chicken, raw and cooked fish, etc. can be processed for preparing an aquarium fish-feed. Too much animal protein can sometimes cause digestive upsets and fat degeneration in tissues. Care has to be taken in adding these ingredients to the feed.

Live-feed: Live-feed is live-organisms produced in nature and are considered as living nutritious capsule as they contain all essential nutrients which enhance breeding efficiency and excellent fish growth, besides providing vibrant colour. These are mainly infusoria (*Paramaecium*), whiteworm (*Enchytraeus*), brine-shrimp (*Artemia salina*), West-African night crawler (*Eudrilus eugeniae*), earthworm (*Eisenia foetida*), sludge-worm (*Tubifex*), water-flea (*Moina*), bloodworm (Chironomids), etc.

Ornamental fish breeding-cum-rearing unit for private entrepreneurs

Salient aspects of successful ornamental fish production are given here.

- Training on the subject is a prerequisite before starting an ornamental fish unit.
- Minimum land requirement is 500-1,000 square feet (46.45–92.80 m^2) for a small-scale farming practice, whereas 1 acre (0.4 ha) and more is for large-scale farming in which few earthen ponds are to be excavated for some species like koi carps, gourami, barbs, etc.
- Site selection is one of the main criteria; the farmer should select a cool environment for culture and breeding.
- Breeding and rearing unit should be made near a constant water and electricity supply. If the unit is located near stream, it will be excellent where the unit can receive plenty of non-polluted water and rearing unit can be made flow-through.
- Climatic condition like cold climates make this farming too expensive to make water warm to produce tropical fish. Whereas tropical climates favour production rate because of year-round breeding, rearing and better growth. So the entrepreneurs have to select fishes accordingly.
- Besides climatic condition, selection of candidate species depends on the water quality of area. Species prefers either soft water or hard water for breeding. And certain species can withstand a wide range of water. For example, all live-bearers prefer hard water-alkaline. Egg-layers like gold fish, gourami, danios, catfishes,

rosy barbs, fighters can tolerate wide range of waters. And angel, discus, tetras, oscar, loaches prefer soft -acidic water.

- Biofiltration unit is a prerequisite for smooth functioning of an ornamental fish culture and breeding unit.
- Broodstock selected should be of superior quality so that good quality fish-seed is produced. If broodstocks are not available in the area, one can think of rearing a desired quantity of smaller fish and further they can be developed into broodstock.
- Broodstocks can be allowed to breed for not more than two years. Fresh stocks from different sources may be added in every two years to selected parent stocks to improve breeding efficiency and for getting healthy offspring.
- Fish breeder should concentrate preferably on one species so that it helps him to develop expertise on the particular species, and a good variety of fishes can be produced as per the market demand.
- Constant availability of agro-based byproducts will facilitate preparation of pelleted diet for the fish. For preparing a pelleted diet,a mini pelletizer can be installed.
- Breeding and rearing unit may be established preferably nearer to air port/railway station so that live-fishes are easily transported for export and domestic market.
- The breeders should develop market relations with pet/ retail shops, potential farmers, vendors dealing with ornamental fish, marketing network, etc. to facilitate process of selling/procuring new broodstocks.
- A committed entrepreneur would always ensure to be in touch with the recent research developments in the field and attend training and exposure visits.
- All new incoming fishes should be quarantined from resident stock. Movement of fishes should be restricted from a suspected or unknown disease status area. Few quarantine, tanks are required little away from the unit so that a proper observation can be made on health aspects.
- If any abnormal behaviour is observed in any culture tanks, then isolate the fish immediately. If mass mortality occurs in the farm, do not medicate them of ones own, consult fish pathologist.

Fish diseases and control measures

Some of the common diseases encountered in freshwater ornamental fishes along with treatments are given in Table 22.7.

Providing conditions to ensure good health of cultured ornamental fish include the period from hatching to marketing and during house-keeping. Preventing disease is much more economical than giving expensive treatments, following disease outbreak. There is not a single, ideal, universal preventive programme that can be applied by every producer. Specific considerations must be taken into account for individual enterprise; however, some general preventive recommendations that can be made are as follows.

- Provide adequate space, clean water and balanced feed
- Prevent high fluctuations in temperature

Table 22.7. Common diseases of ornamental fishes and their treatments

Symptoms	Disease	Causative agent	Treatment	Observations
Pin-head size white spots on the body and fins	Ichthyophthyriasis	Protozoan parasites (*Ichthyophthirius*)	Increase temperature and treat with 5% methyiene blue (1 drop/ litre).Treat fish for 1 week	Contagious, observed during sudden drop of water temperature
White spots smaller than above	Oodinium	Unicellular parasite (mono flagellate)	Copper sulphate 0.1 mg/litre for 10-15 min. bath	Contagious
White clumps with cotton-like appearance	Saprolegnia	Fungi including *Saprolegnia*	1 tsp salt/ 2 litres water, 1-2 drops of 5% methylene blue or malachite green 2 mg/litre for 30 min. dip or 0.1 mg/litre for permanent bath	Favoured by wounds
Swollen eyes	Exophthalmus	Bacteria, viruses, fungi, sometimes together	1% silver nitrate on poped eyes, followed by 1% potassium permanganate	Treatment is difficult
Gradual disintegration of fins	Pseudomoniasis	Bacterial disease	Surgical removal of ragged portion by a fine sterilized scissor, paint the cut wounded portion by iodine solution. Repeat the same at 12 and 24 hours	Unusual swimming behaviour
Swollen abdomen, erected scale	Dropsy	Bacterial disease	No known cure. Antibiotics may be tried	Contagious, difficult to treat
Opercula sticking out, unusual swimming, tiny flukes on the gills	Gyrodactyliasis	Parasite fluke, *Gyrodactylus*	Formaldehyde 5-6 drops/litre; water dip treatment for 10 minutes. Repeat for 3 days	Not easy to detect

(Continued)

(Table 22.7. concluded)

Symptoms	Disease	Causative agent	Treatment	Observations
Red patch in the body	Argulosis/ learnaeasis	*Argulus/ Lernaea* Ectoparasite	Physical removal of parasite, 15 min. bath in 1-2% potassium permanganate, painting region with iodine solution. Repeat the same after 12 and 24 hours	Violent rubbing due to irritation
Unusual swimming behaviour	Longer exposure to poor water quality	Oxygen problems, poor water quality due to nitrogenous substances	Increase oxygen, one-third water exchange, check pH and nitrates level	Symptoms can also correspond to an infectious disease
Gasping for air at the surface	Lack of oxygen	Defective aeration	Increase aeration, check all water parameters	This can be a symptom for an infectious disease
Weight loss and poor growth	Nutritional problems	Underfeeding or lack of balanced diet	Fresh feed and live-food	Possibility of commercial vitamins in the feed
Skeletal deformity	Hereditary problem or lack of vitamin C in the feed	Genetic origin or nutritional disorder	If mass deformity occurs, separate parents, check vitamin C level	It is not unusual for a few of the fry in a batch to be affected

- Remove organic matter such as uneaten feed, dead fish and feacal matter as often as possible and prevent accumulation of algae
- Intermittently clean and disinfect system
- Always maintain compatible species
- Avoid unnecessary handling
- Provide diligent surveillance to recognize early signs of diseases
- All new incoming fishes should be quarantined from resident stock
- Movement of fishes should be restricted from a suspected or unknown disease status area
- Separate infected fishes
- After diagnosis, begin treatment of diseased fishes as soon as possible

Chemoprophylaxis in aquarium fish: Following chemicals will be useful for treatment of various diseases and parasites of fishes.

Iodine: Dilute by addition with equal amount of water to produce half-strength solution. Apply with a soft brush or cotton. Care must be taken during treatment that the solution should not come in contract with ěyes or gills.

***Malachite green*:** This must be only of zinc-free medical grade. Prepare a stock solution by adding 1 g to 500 ml of distilled water. The bath is made by mixing 2 ml of the stock solution in a litre of water. Zinc or galvanized iron containers should be avoided. Immerse fish for up to 1 hour.

***Methylene blue*:** A stock solution is made adding 1 g medical grade methylene blue to 100 ml warm distilled water. Add 1 ml of the stock solution to a litre of water. This can be stored for later use.

***Potassium permanganate*:** A stock solution is made by thoroughly dissolving 1 g crystals in 99 ml of warm distilled water. In ponds and planted tanks, stock solution should be mixed at 0.5 ml/litre. A bath of half hour duration is prepared by adding 1 ml to each litre of water. As colour fades after some time, water exchange is not necessary. This chemical is sensitive to light and should be stored in amber bottle. Never add crystals directly to water without dissolving them in a container.

Salt (Sodium chloride): Instead of common salt, marine or rock salt may be used. A 30-minute dip-bath is given in 2% solution. In serious protozoan (ecto-parasitic) diseased condition, 3-phase treatment is also given that consists of adding 2 g of salt per litre on the first day, followed by removal of 50% of the bath water with a fresh saline solution of 4 g/litre by the second day. Half of the treatment water is replaced with 4 g/litre solution again on the third day. Salt concentration may further be increased on the next day if the fish does not show any sign of recovery from distress (guppy and molly may stand a salt concentration till 8 g/litre). Upon completion of treatment, reverse process needs to be followed; adding freshwater slowly till salinity is negligible.

Aquarium plant propagation

Aquarium plant propagation is recognized as one of the powerful and growing industries in the aquarium trade. In India, aquarium plant propagation is new to entrepreneurs. Basically 3 types of plant propagation methods are being used all over the world – vegetative propagation, sexual propagation and tissue culture. The first two are well known and most widely used in the aquarium- plant trade; they are cheap and fairly successful with most plants (Table 22.8).

Table 22.8. Types of aquarium plants

Genus, family and origin	Name of the plant	Description
Acorus, Acaceae, Asia	*Acorus gramineus*	Known commonly as Japanese dwarf rush; native to temperate and cold waters. Grow in cool environment. Slow grower. Size- 10-30 cm
Bacopa, Scrofulariaceae, Southern United States and Central America	*Bacopa monnieri*	Similar to *Ludwigia* in appearance, easy to grow but needs strong light. Size- 30 cm
Cabomba, Cabombaceae, Southern United States, South America	*Cabomba aquatica*, *Cabomba caroliniana*	In weak light, this plant spreads out on the water surface. It grows fast, unless water lacks carbon dioxide. Water circulation is restricted. Size- 30-40 cm

(Continued)

(Table 22.8. concluded)

Genus, family and origin	Name of the plant	Description
Ceratophyllum Ceratophyllaceae, cosmopolitan	*Ceratophyllum demersum*	Ceratophylls though cosmopolitan but *C. demersum* species is common in aquarium; has very stiff leaves. Propagation is by cutting
Cryptocoryne, Araceae, South East Asia	*Cryptocoryne balansae, C. beckettii, C. ciliata, C. crispatula*	They are aquatic or amphibious, prefer soft to moderately hard, slightly acid to alkaline water. Vegetative multiplication is by runners. Size- 40-70 cm
Egeria, Hydrocharitaceae, cosmopolitan	*Egeria densa*	Fast and densely growing coldwater plant, requires regular pruning. It reproduces through flowering. Size- 30-40 cm
Hydrilla, Hydrocharitaceae, Native to parts of Asia, Africa, and Australia	*Hydrilla verticillata*	Hardy plant has many narrow leaves and long stem; a very fast grower
Hygrophila, Acanthaceae, South East Asia	*Hygrophila difformis*	Green ragged-edged leaves; undersides appear quite white; hardy species. Size -30 cm
Ludwigia, Ongraceae, Tropical regions	*Ludwigia repens, L. ascendens, L.alternifolia, L. brevipes*	Thick, fleshy green leaves often have reddish undersides; flourishes in good light and cool water.Size-30 cm
Myriophyllum, Haloragaceae, North and South America	*Myriophyllum aquaticum, M. spicatum*	Fine leaves need protection from suspended dirt in water, prefers soft, acid water.Size-40 cm
Sagittaria, Alismata-ceae, North and south America and Europe	*Sagittaria graminea*	Vegetative multiplication by seedlings, formed on a runner; prefers moderate lighting;soft or slightly hard water. Size- 40 cm
Vallisneria, Hydrocharitaceae Asia	*Vallisneria gigantea, V. spiralis, V. asiatica*	A grass-like species. Quite easy to grow but prefers bright lighting; reproduces by sending out runners; fast growing plants
Alternanthera, Amaranthaceae, South America	*Alternanthera sessilis, A. reineckii*	Plants prefer soft, acid water and multiply by cuttings; their reddish colour stands out in an aquarium. Size- 30-40 cm
Echinodorus, Alismataceae, South America	*Echinodorus amazonicus, E. major, E. tenellus*	Most hardy plants; prefer slightly acid to neutral water. Leaves turn yellow when they lack iron; reproduce by rhizome cuttings, on which seedlings have appeared. Size- 10-40 cm

Vegetative propagation: This is the most widely used method, and normally the easiest and the cheapest. Plant is propagated by using part of the plant itself either through a stem-cutting or other parts of the plant from where a new plant is grown. Example - *Rotalia, Nomaphilla, Limnophylla* species etc.

Sexual or seed propagation: This is the traditional way of propagation.This method is used when a new plant is grown from a seed or spore. Example - *Samolus* and *Cyperus* species.

Tissue culture or micropropagation: In this, plants are propagated in a sterile environment using just part of the plant like meristematic region. Plants are generally grown in the plastic or glass containers under controlled conditions through sterile-agar medium. Sometimes antibiotics and hormones are also used to control plant growth. Once the plants have reached a suitable size, they are taken out of the container and hardened in greenhouse. Most *Anubias* species are produced by this mehod.

Aquarium plant growing media

Media for production: There are obviously many growing media available for plant propagation. Aquarium plants are specialized crops that need media suiting aquarium conditions. Rockwool or cultiwool is most commonly used one. This is a type of fibre glass, often used for heat or acoustic insulation in houses and factories. Other media like synthetic nylon floss, peat moss and types of clays and composted materials like straw and pine bark are also used.

Media for planted aquarium: The medium in the aquarium needs to serve as an anchorage and as a source of nutrients to plants. Generally, a red clay soil mixed with 2mm to 8mm rounded gravel (about half clay and half gravel) is preferred. Soil should be steriled and free from any organic matter. A thicker layer (2 cm to 4 cm thick) of soil needs to be placed at the bottom of the aquarium depending on the size. On top of this, a layer of washed rounded gravel needs to be placed to stop clay being disturbed in the water. Rounded gravels (like river pebbles) are used through which debris can easily slide and bacteria can break it down to simpler forms. The clay should not be disturbed while filling the tank with water or during plantation. Plant roots need to be trimmed before planting or in faster growing plants even cut off to stop rotting in the tank. If possible, rock wool should be carefully removed from plants.

Initiatives on green certification of freshwater ornamental fishes

The potential for the development of ornamental fish trade in India is immense, though it is still in a nascent stage. The Government of India has identified this sector as one of the thrust areas for augmenting exports. The turn of the century has seen a spurt in the collection, culture and trade of freshwater ornamental fishes. Aqua-shows have now become an annual feature in some states as in Kerala, where Government support for such an activity is in vogue. For the trade to prosper, the three pre-requisites are quality, quantity and sustainability. Fish species diversity of the rivers and streams of the Western Ghats and North-east India are well recognized; with as many as 68% of the 338 species listed from the former, and over 50% of the 350 or so listed from North-east India are endemic. Of these, 40 to 50% are ornamental fishes, some fetching very high price in the international market; 90% of the freshwater ornamental fishes exported from India are wild caught indigenous species. The range of species caught and made available to the market often demands a continuous supply of "new fish species/varieties" and the hunt from the wild has increased tremendously in the global trade. As more and more 'beauties' from the rivers and coral reefs have started attracting world market, levels of exploitation have gone higher and higher and have led to adoption of destructive fishing practices. With other species of animals and plants currently in trade, new varieties have been produced by captive breeding, but with aquatic ornamentals, this is not yet the case. Unbridled exploitation of resources has crossed sustainable levels and has also led to drastic decline in number. Human interference has disturbed ecosystem of many water-bodies and only a few of them have remained in the pristine condition. In several parts of the world, there is growing awareness among the beneficiaries and user-agencies on the imperative need for sustainable exploitation of ornamental fish resources and for managing various ecosystems. Official data on the commercial exploitation of ornamental fishes from the wild are lacking, and resource monitoring has been poor. the true extent and impact of largely uncontrolled exploitation of natural ornamental fish resources has been only recently recognized.

In 2000, the Global Marine Aquarium Database (GMAD) was established by UNEP-WCMC (United Nations Environment Programme- World Conservation Monitoring Centre), in collaboration with the Marine Aquarium Council (MAC) and with members of various aquarium trade associations. Many industry members (wholesale exporters and importers) provided data to enable monitoring of the trade in marine ornamentals, including information on the species in trade, volumes traded and source. This has also led to the development of a set of guidelines/ code of practices for marine ornamental fishes by the Marine Stewardship Council (MSC). A similar one for the freshwater ornamental fishes was lacking, and the Marine Products Export Development Authority (MPEDA) Kochi in 2011 has brought out the *Guidelines for Green Certification of Freshwater Ornamental Fishes* for developing a value-chain approach from collection/culture to export of Indian ornamental freshwater fishes; to make the growing industry of freshwater ornamental fish trade sustainable, eco-friendly and monitor resilience of the resources. *Green certification is the certification given to a product to ensure its environmental and socio-economic sustainability.* It also ensures product quality, safety and traceability. The green certification guidelines attend to following aspects – collection from the wild, handling, transport, holding, breeding and culture facilities, conditioning for export, infrastructure and maintenance of records to conform to a value-chain system for delivering healthy ornamental fishes to the trade and the hobbyists. The guidelines also address the Chain of Custody verification methods to cover tracking/ traceability of the product all along the collection, production, transportation, holding, breeding and marketing chain. The certification requires that the capture, culture and marketing operations be improved to reduce mortality of fish, disturbances of ecosystem and sustain the resources in its natural habitat. The Certification protocols and procedures assure enhanced economic returns by reduction in mortality and cost of production. Green Certification guidelines are expected to be introduced on a voluntary basis in a phased manner once the implementing agencies are identified and training programmes organized for the stakeholders and the entrepreneurs for adopting the system. For wild caught native freshwater ornamental fishes, Green Certification will be made mandatory with a transition period of three years from the date of implementation of guidelines.

Marine ornamental fish culture

Over 25,000 fish species are reported inhabiting our oceans. Out of these, about 4,000 fish species are reef-associated and over 1,200 marine fish species (food and ornamental) are traded. About 800 reef fishes are in trade for aquarium purposes, and of these, 50% of the top traded species are clown and damselfishes and about 290 invertebrates (corals, crustaceans and molluscs) are in aquarium trade. However, more than 90% of the total marine organisms are still collected from wild for this lucrative trade. Only 100 are bred in captivity, and out of these, about 50 species of ornamental fishes and shrimps are produced commercially. The most commonly traded family of marine fishes for ornamental purposes is Pomacentridae, which accounts for 43% of all fishes traded. This is followed by species belonging to Pomacanthidae (8%), Acanthuridae (8%), Labridae (6%), Gobidae (5%), Cheatodontidae (4%), Callionymidae (3%), Microdesmidae (2%), Serranidae (2%) and Blennidae (2 %). Since marine ornamental fishes are low-volume high-value species and an easy way to get financial gains, hatchery production of marine ornamental fishes is gaining much importance as a commercial venture, and 15 and 30 million marine ornamental fishes and shrimps are traded each year world-wide.

India is a repository of more than 200 varieties of marine ornamentals; of which more than 50 are brilliantly coloured and have export potential. Among different ornamental fishes, members of the family Pomacentridae, commonly known as damselfishes and anemone fishes, are a diverse group of marine fishes found in tropical oceans, and have very high demand in marine ornamental fish trade and have always been the most popular due to their beautiful colour, small size, hardiness, longevity, clown fish's proclivity to live in association with sea-anemone, interesting display behaviour and adaptability to live in captivity accounts for their export potential. But most of these traded salt-water ornamental fishes are being collected from wild; there is a great concern regarding depletion of stocks due to over-exploitation as well as destruction of reef habitat and damaging collection methods all-over the world. As a result, marine aquarium industry has attracted much controversy over its sustainability. The possible alternative is to develop technology for captive propagation of target species resulting in decreased dependence on wild-caught specimens, which would help safeguard coral reef also and develop a new source of organisms for aquarium trade.

In spite of the availability of rich fauna in and around coral reef areas of Lakshadweep, Andaman and Nicobar Islands and Mandapam area, the country could not make much headway in export of marine ornamental fishes so far owing to non-availability of required infrastructure facilities. Considering these situations, the Central Marine Fisheries Research Institute (CMFRI) has taken initiatives on culture of marine ornamental fishes to generate scientific knowledge on ornamental fish maintenance, behaviour, influence of social status on sex change, pair formation, breeding, influence of lunar periodicity in spawning, parental care, egg incubation and hatching, development of eggs, larvae, and juveniles. These investigations have resulted in the development of hatchery technology for 16 species of marine ornamental fishes –

clown fishes *Amphiprion percula* (True pecula/clown anemone fish); *Amphiprion ocellaris* (Common clown/false clown anemonefish); *Premnas biaculeatus* (Maroon clown/ Spine cheek anemone fish); *Amphiprion sandaracinos* (Yellow skunk clown); *Amphiprion sebae* (Sebae clown); *Amphiprion frenats* (Tomato clown); and damsels *Dascyllus trimaculatus* (Three spot damsel); *Dascyllus aruanus* (Striped damsel); *Pomacentrus caeruleus* (Blue damsel); *Pomacentrus pavo* (Sapphire or Peacock damsel); *Neopomacentrus nemurus* (Yellow tail damsel); *Chormis viridis* (Green chromis); *Neopomacentrus filamentosus* (Filamentous tail damsel); *Chrysiptera unimaculata* (One spot damsel); *Chrysiptera cyanae* (Sapphire devil) and dotty back *Pseudochromis dilectus* (Redhead Dottyback) under captivity for the first time in India.

Rearing marine ornamentals in captivity principally is providing right nutrition and environment for broodstock to produce quality eggs, thereby larval rearing and grow-out of juveniles can be carried out. The major steps involved in captive production of marine ornamental fishes are setting-up of the tank, selection of broodstock, pair formation, broodstock management, feeding, breeding, egg incubation and hatching, provision of suitable environmental parameters, maintenance of high water quality, creating suitable condition for spawning and system for raising larvae and juveniles.

Selection of suitable candidate species

Ideal candidate species for captive breeding are the ones which are hardy, beautiful, compatible, are of high market demand, and spawn routinely and have large-sized larvae that can be raised in a short-time to juveniles with cultured live-foods and artificial feeds. Proper selection of healthy mature individuals that can be paired is the first important step in breeding marine ornamentals. Mated pairs (those that have previously mated) are ideal but often difficult to get. Species can be paired based on sexual differences, such as colour, size and external morphology and behaviour or their ability to change sex. Most often, when several juveniles or sub-adults are placed together, largest ones develop into the dominant sex or the breeding pairs.

Clown fish breeding

Social structure and behaviour: In the wild, clown fishes generally occupy in the social groups centred in a host sea-anemone with a sexually active pair of adults and one to three juvenile or sub-adults. Invariably the female is somewhat larger than the male. In nature, clown fishes show monogamous pair formation, and these pairs are needed to be collected for broodstock development and breeding programme. During transportation, fishes and sea-anemones should be kept in separate plastic transportation bags. The basic requirement for the production of clown fishes under the captivity is the availability of sufficient number of broodstocks or breeding pairs, which can be either collected from the coral reef habitat or can be purchased from the pet shop, depending upon the availability

Pair formation: In case mated pairs are not available, the fishes having different size groups can be collected and made to pair under captive conditions through pair formation. To make breeding pairs from juveniles groups, many social groups of clown fishes can be collected from wild and transported to laboratory in live condition. To conduct pair formation, five fishes of each sex of different size groups need to be stocked together along with a single host sea-anemone in a 500-litre FRP tanks fitted with a biological filter to reduce aggression. The pair formation tanks need to be maintained in the hatchery where an incident light intensity of 2,500 to 3,000 lux is available as the sea-anemones require sunlight for its better survival under the laboratory condition. The fishes and anemones should be fed two times per day with wet feeds such as meat of shrimp, mussel and clam at 15% of their body weight and with live-feeds like *Brachionus plicatilis*, *Artemia* nauplii and adult *Artemia*. Environmental parameters such as temperature 26 to 29°C, salinity 33 to 36 ppt, dissolved oxygen 4.6 to 6.2 ml/litre and *p*H 8.1 to 8.9 are needed to be maintained in all rearing tanks.

Sex change and pairing: As the clown fishes are protandrous (male first) sequential hermaphrodites, a peck order is established in which female is dominant, male is subordinate to female, and all the other juveniles are subordinate to adult male and female. Thus, generally all clown fish individuals start out as males and change into females when they reach larger sizes or when they lose mate. The male and the female form a monogamous pair bond that lasts until one member of the pair dies. If the female dies first, the largest male rapidly changes sex into female, and the second largest or dominant juvenile becomes an active male and that pairs up with the newly transformed female. By utilizing this adaptation, pairs of clown fishes can be developed under captive conditions through creating social systems. After 3 to 4 months rearing in the pair formation, in each tank one pair grow ahead of others and become spawning pair and the functional female and male (the two largest specimens of the colony) live together as pairs in which female dominates male and sub-adults are dominated by female and male. As the newly formed pairs are very aggressive and most of the time flee other subordinates rather than involving in the reproductive activity, it is very essential to stock each breeding pair in a separate broodstock tank.

Broodstock rearing systems: The success of broodstock development mainly depends upon the provision of suitable environmental conditions, feeding and day-to-day management. The purpose of keeping broodstock is to obtain consistent quality production of fertile eggs. Frequency of breeding and quality of eggs produced and larval survival are dependent upon broodstock feeding and suitable conditions provided. Broodstock holding can be done in a single or multiple tank systems designed to provide optimal environmental conditions (space, hiding, water quality) for good health and spawning conditions for adults. Generally, glass aquaria and Perspex tanks (500 to 1,000 litres) are provided with inbuilt filtration system or connected with central filtration units, and the tanks are kept indoors where lighting and temperature is controlled or also can be kept under semi-transparent roofed outdoor laboratories. Each tank has to be provided with aeration and water flow-through and coral sand bottom, necessary hide-outs, and also suitable substrata (coral stone, earthen pots, PVC pipes or asbestos sheets) for egg deposition in case of benthic broadcasters.

Tank set-up for broodstock: A clownfish broodstock or spawning tank should be of 250 to 500-litre capacity with a single healthy pair and a host sea-anemone. An ideal tank would be of 3ft × 2 ft ×2 ft size with a layer of coral sand on the bottom, a few live rocks, a healthy anemone, bright lighting along with good filtration, preferably an efficient protein skimmer to reduce ammonia and organic materials from fish. A trickle filter may be used with regular water changes to keep nitrates low enough for anemone to do well. Since gonad development and spawning of clown fishes are influenced by moon phases, broodstocks/spawning tanks need to be kept in an appropriate place where the fishes receive a regular day/night lighting cycle (moon phase). An anemone is not required to breed clown fish under captive conditions. But, generally clown fish selects a nest site adjacent to the sea-anemone for eggs deposition. Moreover, an added benefit of having an anemone is that it may release compounds that help protect eggs or even chemically induce immunity that clown fish has with the anemone. Hence provision of suitable host sea-anemone in the broodstock tank will provide conditions as in the wild, and this will certainly make the task much easier in the long-run.

Broodstock development and maintenance: The pairs formed should then be transferred to separate glass aquaria for broodstock development. Depending upon the production capacity and seed demand, several pairs can be maintained for commercial hatcheries. The broodstocks need to be fed with wet feeds such as meat of green mussel, shrimp, clam and fish egg mass, and can also be provided formulated feeds enriched with vitamins, minerals and algal powder at 10% of their body weight and supplied at an interval of every 3 hr during day time. Apart from these, the broodstocks are also fed with enriched rotifers 800 to 1,000 number/ml and artemia nauplii (200-400 numbers/ml) and adult artemia (3 to 5 numbers/ml) per day which apparently improves egg quality and hatchability than the brooders fed with non-enriched live-feeds.

Nutritional enrichment of live-feeds: Recent findings showed that bioencapsulation of live-food organisms with various nutrients have a vital role in larval survivability; as larvae require diets with high protein and sufficient amount of essential fatty acids [eicosapentaenoic acid 20:5n3 (EPA) decosahexaenoic acid 22:6n3 (DHA) and arachadonic acid (ARA)]; their incorporation is vital for augmentation of larval production. It is recommended that adequate nutrition has an important role in the reproductive success of all animals including fish, and it has been shown that essential fatty acids, vitamins (A, D, E and K), trace minerals and ß-and other carotenoids can affect fecundity, egg quality, hatchability and larval quality. Broodstocks fed with EPA (n-3PUFA) deficient diets produce eggs with significantly lower survival and high level of larval deformities. Though nutritional requirements of all animals vary throughout their life cycle, complex morphological and physiological changes invariably modify feeding and nutritional requirements. Larval rearing is perhaps the most difficult aspect that is holding back aquaculture of many of our tropical marine aquarium fishes. This is mainly because of the largely unknown dietary requirements of the different larval fishes. The success in larval rearing to a great extend depends upon the broodstock management and feeding, proper egg incubation and maintenance of high water quality.

Feeding with enriched live-feeds: PUFA and HUFA enriched rotifers and artemia are harvested, washed and released into 4 litres of bio-filtered sea-water containing mixed culture of micro algae : *Nannochloropsis oculata, Pavlova lutheri, Isochrysis galbana, Dicrateria inornata, Chlorella marina* and *Chaetoceros gracilis* (10^4 to 10^6 cells/ml) in 5 litres capacity transparent tub with mild aeration. The enriched rotifer and artemia are given in split doses (10.00 to 11.00 AM and 3.00 to 4.00 PM daily).

Water quality maintenance: High water quality is possibly the critical factor for breeding clown fishes or any marine fishes under controlled conditions. As a measure for this, sea-water needs to be filtered through a series of sand-filters before being taken to rearing tanks. In all the breeding tanks, temperature between 26 and 30°C, dissolved oxygen ranging 4.8 to 6.3 ml/litre, *p*H at 8.0 to 8.9, salinity between 32 and 36 ppt need to be maintained, and water of good quality with the aid of a specially devised filter system has to be circulated during rearing. Once a week, 25% of water need to be changed to avoid stress like a rapid increase in plasma cortisol concentration, depression of gonadal steroidogenesis, and subsequent development of gonadal atresia.

Substrate for egg deposition: Clown fishes have attached eggs and are known to spawn on rough surface substratum near to host sea-anemone. Hence, it is very essential to provide suitable substratum preferably tiles or earthen pots or shells of edible oyster or PVC pipes for egg deposition, which will help transferring deposited eggs to hatching tanks without mechanical injury.

Breeding: After broodstock rearing, each pair starts breeding within 4 to 6 months of rearing under captive conditions if broodstocks are provided nutritious food and suitable rearing conditions. A few days prior to spawning, male selects a suitable site near to sea-anemone and clears algae and debris with its mouth for laying eggs, and on the day of spawning, both parents together clean site for a longer duration, indicating that spawning may occur within a few hours. Under laboratory conditions, spawning can occur between 0500 hr and 1530 hr during day and it lasts for one hr to one-and-a-half hour. Each female lays 300 to 1,000 capsule-shaped eggs at 12 to 15 days interval, depending on the species of clown fish and fish size. Generally, egg size of clown fishes ranges between 1.5 mm and 3.0 mm in length with a width of 0.8 and 1.84 mm and adhere to the provided substratum with a stalk. Average of two spawnings per lunar month per pair results in an estimated annual fecundity of 7,200 to 24,000 eggs per breeding pair per year under laboratory conditions.

Parental care and egg morphology: As the parental care is inevitable for hatching out of larvae, parents should be allowed to remain in the parental tank itself till hatching. During incubation period, both parents look after eggs during the day time; it involves two basic activities – fanning by fluttering pectoral fins and mouthing to remove dead or weakened eggs and dust particles. The newly spawned eggs are white to bright orange in the initial two days, turn black on 3rd to 6th day and silvery after 6th day. Males are almost responsibile for caring of eggs, and spend a higher percentage of time at the nest; which increases gradually up to 70% of the time as the day of hatching approaches.

Incubation period: Eggs of clown fishes usually take 6 to 15 days to hatch depending on the water temperature. At 26 to 33°C, incubation period ranges from 6 to 8 days. One day prior to hatching, larvae within egg-capsule develop silvery colour, and glowing larval eyes can be viewed from a short distance. This is the time when decision must be made for mode of larval rearing. Larval rearing can be carried out in three ways: (*i*) Same tank or parental tank method, (*ii*) Transferring of eggs to hatching tank and subsequent larval rearing, (*iii*) Transferring of larvae to the larval rearing tank. Among these, the second method has been found suitable.

Egg hatching and larval rearing: On the expected day of hatching, two hours before sunset, eggs along with substratum need to be transferred from parental tank to hatching tank (100 litres), which should be dark for accelerating hatching. Hatching occurs soon after sunset and its peak is between 1900 and 2030 hr under darkness. Newly hatched larvae measure 3 to 4 mm in length and each has a transparent body, large eyes, visible mouth, and a small yolk sac and remains at the bottom of the tank for a few seconds and sooner becomes free swimming. The larval rearing can be carried out under greenwater system and feeding with super small (SS) rotifer *Brachionus rotundiformis* and newly hatched artemia nauplii. Clown fishes' larval period generally lasts for a maximum of 20 days and after which most of the fry resemble juvenile adult fish and begin to shift from partially pelagic to epibenthic and start eating minced shrimp, fish flesh, mussel meat, clam meat and formulated diets.

Larval feeding: At larval stage, provision of suitable size and nutritionally adequate enriched feed in high density is one of the important factors for survival. The larvae have little quantity of yolk material and they start feeding within a few hour after hatching; they accept small size organisms only due to small mouth gape, measuring between 80 and 123 μm. As such the larvae need to be fed with live-feeds measuring less than 100μ for their active feeding. All the rearing tanks need to be provided 24 hr light up for 15 days of post-hatch (dph). During this time, the larval tank must be kept very clean; with bottom siphoned of dead larvae, detritus and fecal matters twice a day. As any decaying matter on the bottom encourages potentially harmful bacterial growth, and will lower oxygen levels and will deteriorate water quality. Water changes will also need to be performed at a rate of at least 25% per day.

Feeding schedule of larvae can be performed in two stages: *Stage 1*: covered rotifer with algae feeding phase from day 1st to 8th day; *Stage 2*: the newly hatched artemia and rotifers with algae feeding phase from 9th to 20th days. For successful prey capture of larvae, 50-100 numbers /ml super small rotifers (*Brachionus plicatilis*) of 60 to 100 μ size and 10^5 -10^6 cells/ml of micro algae (*Chlorella* and *Nannochloropsis* sp. in 1:1 proportion) need to be provided after enrichment with vitamins and fatty acids. When larvae first start feeding, they do not possess any digestive enzymes. By eating a live-food, they basically get a fully packaged first meal – containing both nutritional requirements and enzymes for the breakdown of the food from live-foods. Hence measures should be taken to provide nutritionally adequate food at the first feeding.

As the larvae attain successful prey capture within two days, the density of rotifers in the larval rearing tank needs to be reduced to 30-50 nos/ ml from 3rd to 8th day. From 9th day onwards, larvae are weaned onto newly hatched artemia nauplii (5-10 nos./ ml) along with rotifers (SS and S type) (20-30 nos/ml) whereas algal concentration should be same as the prey capture step till 20th day of post hatch. Within this period of rearing, larvae develop adult striped colouration and metamorphose to juveniles.

Copepod as a live-feed: Survival can be significantly higher if larvae are fed with copepods. Higher omega-3 fatty acids found in copepods appear to be important for survival of larvae under stressful conditions. But they cannot be relied for hatchery operation, as the mass production of copepods often collapse due to several factors.

Rearing conditions: Maintenance of water quality is essential for rearing larvae of clown fishes or any marine fishes under controlled conditions. During larval rearing, from day 3rd to 8th post-hatching are found critical, may be due to change in feeding (exogenous). Since larvae are very delicate, aeration needs to be provided at four tank corners through PVC column to maintain dissolved oxygen; the other parameters, *p*H 8.0 to 8.9, water temperature 26-30°C, dissolved oxygen 5.5- 7.8 (mg/litre), salinity 32-36ppt, NH_4^+ /NH_3 and NO_2 values at 0 mg /litre and NO_3 levels below 0.2 mg / litre should be maintained. The tanks need to be cleaned daily with cotton and magnetic tank cleaner to remove dust and slimy coating formed inside the tank; and one-third water of the tank should be replaced with filtered sea-water along with enriched rotifers and artemia and micro algae.

Light intensity: Head-butting syndrome is another critical problem encountered during larval rearing, due to immature development of retina and subsequent hitting of larval head to sides of the tank. To reduce this, two major measures should be taken care of: (*i*) all 4 sides of the tanks should be covered with black-cloth or painted black to avoid light reflection; (*ii*) a low intensity light needs to be provided by hanging 2 nos. of 40 or 60 watt bulb or night lamp at a height of 15-20 cm from the surface of the water level in rearing tank for 24 hours from 0 day to 20th DPH (day post hatch), which enable larvae detecting and capturing their feed and also helps them swim towards surface at night rather than sinking to bottom which otherwise show high overnight mortality. Type of lighting is not critical and can be from any source of light–fluorescent or metal halide, etc. The reason for having a light is that larvae are visual predators and require light to hunt for their live-food prey. Besides, all the larval tanks need to be covered with net-cloth during night time to prevent entry of insects.

Precautions for larval feeding: The mortality during larvae rearing usually happens due to over-eating, intestinal blockage, ingestion of air-bubbles or bacterial problems. Though artemia is in regular use for larval rearing of marine fishes, there is one serious concern with the introduction of empty hatched cysts along with artemia nauplii to the larval rearing tank, and these cysts are often eaten by larvae and cause intestinal blockage. Hence care must be taken to separate all empty cysts from newly hatched artemia before being added to larval tanks. It is also equally important to add newly cultured or hatched live-food everyday because nutritional value of the live-food that remains in the tank decreases quickly. Nutritional quality of rotifers also depend upon the quality of feed offered. Hence every day, after water exchange from larval rearing tanks, new rotifers or artemia need to be added. The healthy larvae appear to have a well rounded body and they swim in a close horizontal position. Unhealthy larvae tend to buzz around on the surface at a 45° angle. Dead or weakened larvae need to be removed from tank to maintain water quality and to avoid mortality of healthy larvae.

Juvenile rearing: On the 19-20 days of post hatching, the larvae become juvenile and shift from pelagic to epibenthic stage, and look like miniature of adult fishes. The rate at which the young fish grows depends on the size of the rearing tank, stocking density, quality and quantity of food given and water temperature. As the clownfish exhibits social hierarchy, dominant clownfish will grow fastest and will suppress growth of fish below. This can be overcome with sufficient host anemones or culling juveniles to several groups in different juvenile rearing tanks of size 250 to 1,000-litre capacity fitted with biological filters. At this stage, stocking density needs to be reduced to 90-100 juveniles (size range between 8 and 10 mm) with a single host sea-anemone in glass or Perspex tank at 100-litre capacity for initial one to two months of rearing. During juvenile stage, fishes show different banding patterns and growth rate and on attaining 24 mm to 35 mm , stocking density needs to be reduced to 30 to 50 number with a single sea-anemone in 100 -litre tank with 80 litres bio-filtered sea-water until marketing. In 500 litres FRP tanks, 130 to150 juveniles can be reared with 1 to 3 sea-anemones.

Juvenile feeding: In the juvenile rearing, survivability of 100% can be obtained through feeding with different wet feeds – mussel meat, prawn muscle, fish eggs and minced flesh of trash fish at 15 to 20% of body weight. Apart from these, *Artemia nauplii* 10-15 numbers/ ml and rotifer (*Brachionus plicatilis*) 50-55 numbers/ml should be given twice a day that helps retain colour of fishes. Through this feeding schedule, the larvae will attain 10 to 12 mm within 30 days of post hatch. Juveniles reach 25 to 35 mm within 60 days and marketable size within 6 months after post hatch. In all juvenile rearing tanks, one-third water needs to be decanted and refilled with the same quantity of filtered sea-water once in a week, and adult *Artemia* (2-4 number/ml^2) should be provided as a supplementary diet.

Damsel breeding

Broodstock development: In one-tonne FRP tank, broodstock development of 6-8 damsels' fishes can be taken up. The tank should be fitted with biological filters having capacity to filter about 200 litres per hour to maintain optimum level of water quality. The tank should be kept under translucent roofing to reduce light intensity and water needs to be exchanged at 30% once in a week. Substrata should be provided for attachment of eggs during spawning. Feeding of the fishes is done once in a day @ 5-10% of the body weight. Various types of feeds like finely chopped fishes, shrimps and molluscan meat are given to brooders. It takes 4-8 months of maintenance for brooders to spawn in captivity. Fishes exhibit spawning behaviour; the parent fishes actively cleanse site for attaching eggs by rubbing it with their pelvic fins and picking off any loose particles or algae with their mouth a day prior to spawning. During spawning, females attach their eggs on the cleaned site, which are immediately fertilized by males. Spawning occurs in the morning hours. The eggs take 3 days to develop at 28° C. During this, parent fishes take care of eggs by fanning them with pectoral fins and tail. Mature fish of *Dascyllus trimaculatus* in the range of 9-10 cm lays approximately 12,000 to 15,000 eggs per spawning. The average periodicity of spawning is 2 weeks. Breeding takes place during early morning hours. Eggs remain attached either to the sides of the tanks or on to the substrata provided inside the broodstock tanks. The eggs are oval in shape. Parental care by the male was noted. Adults of *D. aruanus* of 7-8 cm lay approximately 8,000-10,000 eggs in each spawning at an interval of two weeks. Spawning takes place during early morning. Oval-shaped eggs remain attached either to sides of the tanks or on to the substrata. During incubation period, the parental care by male is exhibited by fanning of eggs. Adult fishes of *Pomacentrus caeruleus* of 7-9 cm lay approximately 5,000-6,000 eggs per spawning. Average periodicity of spawning ranges between 3 and 12 days. Spawning takes place during early morning and oval-shaped eggs remain attached on to substrata provided or to the side of the tanks. Parental care is exhibited by male. Mature *Chrysiptera cyanea* of 5 - 6.5 cm lays 2,000 - 2,500 eggs per spawning. The interval between successive spawnings ranges from 5 to 20 days. Eggs are oval-shaped and measure around 1.3 mm in length and 0.6 mm in width, and remain attached to sides of the tank or on to the substrata. Hatching occurs after third day of incubation. The larvae are altritial type but with mouth opening at the time of hatching. Newly hatched larvae averaged to 2.5 mm in length and the mouth gape around 150 μm. Parental care is exhibited by male.

Hatching and larval rearing: For hatching and larval rearing of damsels, the substratum with egg clutch needs to be transferred to the larval rearing tanks containing sea-water having the same physicochemical characteristics as the parent tank. A gentle air flow needs to be created over the eggs by placing an air stone near the egg clutch and the egg clutch left in darkness. Generally, hatching takes place after the third day of incubation. Larval rearing can be carried out in 5-tonne FRP tanks. The inner side of the tank should be light blue in colour in order to have a better contrast between the live-feed and the surroundings. Green water technique using microalgae *Nanochloropsis* needs to be adopted for the larval rearing of damsel fishes. The adults of two species of copepods, viz. *Euterpina acutifrons* and *Pseudodiaptomus serricaudatus*, were inoculated into the green water. When the copepods started their growth phase, as was noted by counting the number of egg-bearing copepods and nauplii, the newly hatched larvae were introduced into these tanks.

The most critical aspect of larviculture of pomacentrids other than clownfishes is the underdeveloped state of larvae at hatching and the consequent problems of starter feed. The four species of damsel fishes studied were with altritial type of larvae and the mouth gape of newly hatched larva ranged from 150 to 200 μ. Trials on feeding with the available strain of rotifer *Brachionus rotundiformis* as starter feed were not successful. Co-culturing of the selected two species of copepods, viz. *Pseudodiaptomus serricaudatus* and *Euterpina acutifrons*, in green-water along with larvae yielded positive results. The small size of the first naupliar stage of the copepods employed and the availability of different sizes of nauplii during the initial phase of larviculture has been successful in the first exogenous feeding of the larvae. The initial stages of nauplii noted in the larviculture system measured from 60 to 80 μm, which is suited for the first feeding of the larvae. High EPA, DHA and ARA content of copepods would also must have facilitated the larval survival and growth. It is also noted that the critical phase of larviculture will be over by 15-20 dph. After 15-20 dph, the mouth gape will reach around 450 μ and can be fed with freshly hatched *Artemia* nauplii. Absence of any mortality from this stage onwards indicates that once the starter feed problem is solved; the larviculture of these species could be accomplished easily with conventional live-feeds.

Quarantine

Newly acquired fish or shrimp may carry disease and may infect valuable, healthy, broodstock. They are, therefore, kept separately in a tank or system for three to four weeks where they are closely observed and treated with medications for possible disease outbreaks.

Packing and transportation

Fishes should be starved for about 2-3 days before being exported. A small amount of freshwater should be added to packing water and chemicals may be added to tranquilize for longer journeys. Packing starts just prior to transportation. Fishes are packed with oxygen and a little water, either singly in double polythene bags to ensure that fish are not stranded without water. Polythene bags are packed in cardboard boxes for short journeys and for long journeys they are packed in styrofoam boxes with some ice. Layers of paper may be inserted between plastic bags in the box to avoid sight of aggressive species. Packaging methods have improved considerably over years mainly owing to feedback from customers and many exporters; now guaranteed almost 100% survival for most destinations, provided good connecting flights are available. Regulation of standards of holding facilities and of packing is important to ensure minimum mortality of fishes at holding facilities and in transport.

Economic viability of ornamental fish production is more lucrative compared to other mariculture species due to their high unit value. The complete package of practices developed for their production have been taken up as an alternative livelihood option for small and large scale fish farmers. Transfer of technology to public and private sector entrepreneurs who approach is being planned by imparting hands-on-training through different modes under the Consultancy Processing Cell (CPC) of the CMFRI. In addition, the hatchery produced seeds are also being sold to the farmers and aquarium hobbyists and traders through Single Window System, and seed counters are in operation in marine hatcheries of the CMFRI at Kochi, Mandapam and Vizhinjam. This has resulted in the emergence of several ornamental fish trade shops all-over the country. In the near future, India can emerge as one of the leading international traders of marine ornamental fishes through hatchery production.

23. Shrimp Seed Production

In India, in brackishwater impoundments in West Bengal and Kerala, penaeid shrimp farming was an age-old practice. Scientific shrimp farming in well-designed farms had started in the late eighties, and peaked during 1994-95. At present, about 150,000 ha of brackishwater area is under shrimp farming with an annual production of 100,000 million tonnes. Two major inputs for successful shrimp farming are seed and feed. Traditional culture systems were dependent on the seeds present in the tidal water. During the initial stages of scientific farming also, seed were collected from wild, and were stocked in ponds. Non-availability of seed was the major constraint for development of the scientific farming in the early eighties. Though experimental hatcheries were in operation since late seventies, commercial hatcheries were set up only in the late eighties. Development history of shrimp hatchery technology, its present status, constraints, its role in sustainable shrimp production and its future research needs are discussed as follows.

Development history of shrimp hatchery technology

Japanese system of larval-rearing

Studies on the life history of *Penaeus japonicus* were initiated in 1933 in Japan with the beginning of shrimp farming. Larval stages non-availability from wild hampered research. But the observation that mature females lay eggs when held in aquaria, led to experimentation in artificial rearing of larval stages. There was not much success in the rearing till 1940, owing to lack of suitable live-feeds for larvae. Technique for pure culturing of *Skeletonema costatum* was developed that led to first successful rearing of *P. japonicus*.

Though various experimentations were done on water quality requirements and efficiency of different live-feeds, mass production of shrimp larvae was not successful till 1964. Mass production of *P. japonicus* postlarvae in large outdoor tanks was epoch-making event in shrimp-hatchery development in 1964. The method was popularly known as "community culture" method, and its basic principle was to keep shrimp larvae and their food organisms together in the same tank at an appropriate concentration by proper management of light intensity, aeration and nutrients' concentration. The technology was simple and involved filling up of the tank up to 80 cm, and mature females were introduced to lay eggs. The water was not changed until larvae attained mysis stage. Then fresh sea-water was added daily in small amounts. By the time shrimps attained post-larval stage, rearing water would be as deep as 2 m, almost full depth of the tank. Then 20-40% of water was changed daily, depending on the water quality deterioration. Essential points of water management were to avoid excess metabolites and food residues accumulation, and to keep relatively stable concentration of diatoms, as noted by brown colouration. The system required very little technical knowledge for keeping it in operation.

Though this system could produce shrimp-seed in a large scale, failures in rearing were common in it due to bacterial, fungal and protozoan infections. Total inability to control quality of rearing water seemed primarily responsible for onset of diseases. The system was modified in 1972 with chemical sterilization of water using sodium hypochlorite solution, production of *Chaetoceros* independently for feeding zoea and mysis stages, and introduction of formula feed in suspension for later stages instead of clam-meat suspension that was considered highly polluting.

High-density larval rearing (Galveston method)

The most significant modification of the early system was made in the Galveston Laboratory for larval rearing of *Peneaus azteus*, *Farfantepenaeus duorarum* and *Litopenaeus setiferus*. In this, instead of inducing a plankton bloom in larval rearing tank, pure algal cultures were produced separately and were fed at pre-determined amounts to larvae in the rearing tanks. The rearing tanks were of 2-tonne capacity fitted with air-lift pumps. Sea-water used for larval rearing was treated thoroughly to get rid of all suspended matter. For algal production, artificial sea-water was the medium. The algae were mass cultured independent of larval rearing, were concentrated by centrifuging and stored in frozen conditions. As and when required the algae were thawed, suspended, diluted and used in automatic continuous feeding device. Stocking densities for this system can be as high as 100 - 500 larvae per litre with survival rates ranging from 60 to 80 % from nauplii to postlarvae.

Small-scale hatchery technology (low-density rearing)

Simplified hatchery technologies were developed during early seventies in the south-east Asia, particularly in Thailand, Taiwan, Indonesia, the Philippines and southern China. They were known as 'Backyard hatcheries'. In this, hatcheries were located on a small plot of land and were run by a family group; and the rearing method was non-technical. The hatcheries utilized small tanks of 2-10 tonnes with capacity ranging between 2 and 10 million post-larvae 20 (PL 20) per year. In them, low densities and untreated water was used. Most of these hatcheries produced only one phase; like nauplii production or post-larva production.

In Thailand, these types of hatcheries are located away from the coast, and required saline water is prepared by diluting brine. The major advantages of these are low capital and operational cost and the production can be closed down or started as per the market demand. Disadvantage is lack of control over survival rates, which range between 0 and 90%

Induction of maturity in captivity

Till early seventies, penaeid hatcheries were dependent on the wild, fully mature spawners for larvae production. Though male penaeids were observed to mature and mate in their estuarine phase of life cycle, females of most of the species did not mature in estuaries or in captivity. Studies on hormonal control of maturation in decapod crustaceans by Adiyodi and Adiyodi in 1970 from India showed that removal of Gonad Inhibiting Hormone (GIH) through eyestalk ablation led to maturity in most of them. During 1971 to 1976, various authors succeeded in maturing different penaeid shrimps using eyestalk ablation, and it became an established technique for maturation of penaeid shrimps in captivity. Though completion of life cycle of various penaeid species has been achieved in captivity, quality of eggs produced is generally poor in pond-grown broodstock.

Status of shrimp hatchery technology in India

In India, rearing of shrimp larvae under controlled conditions was started on an experimental scale in the Central Marine Fisheries Research Institute (CMFRI) at Narakkal (Kerala) in 1976. A hatchery system was developed with mixed diatom and mantis shrimp powder as feed for different larval stages. A small-scale hatchery technology was developed for *Penaeus indicus*, and technology for *P. monodon* broodstock development in captivity was also achieved. By 1978, studies on the life history of almost all penaeid shrimps under captivity were completed and morphological features of all larval stages were documented. During early eighties, experimental and commercial hatcheries were also set up in India under public/private sector. But the production levels were low. By 1989-90, the Marine Products Exports Development Authority (MPEDA) established two large-scale shrimp hatcheries with technical collaboration with the external experts – TASPARC and OSPARC in Andhra Pradesh and Odisha respectively. The success of these hatcheries and the offer of subsidy/ assistance from the MPEDA induced establishment of a number of private hatcheries in the country.

Commercial penaeid shrimp seed production in India is restricted to two species – *Penaeus monodon* and *P. indicus*; maximum percentage of hatcheries producing *P. monodon*. Till-date, about 351 shrimp hatcheries are in the country with total production capacity of 14 billion PL20/year (Table 23.1). Nearly 80 % of the shrimp hatcheries are located in Tamil Nadu and Andhra Pradesh-with varying annual production capacities ranging from 2 to 200 million PL20.

Table 23.1. Shrimp hatcheries in India

State	Hatcheries	
	No.	Capacity in million (PL20/ year)
Gujarat	2	45
Maharashtra	8	345
Karnataka	14	321
Kerala	29	537
Tamil Nadu	81	3,078
Andhra Pradesh	191	9,335
Odisha	15	475
West Bengal	11	166
Total	351	14,302

Though induced maturation techniques have been standardized, most of the commercial hatcheries in India still depend on wild spawners for nauplii production, since fecundity and quality of eggs are comparatively better in wild-spawners than induced matured shrimps. In hatcheries, where induced maturation is practised, source of broodstock is from wild. Some of the smaller hatcheries now procure nauplii from larger hatcheries and rear them to post-larvae due to uncertainties associated with availability of wild-spawners and broodstock.

State-of-the-art of hatchery technology in India

The shrimp hatcheries in India follow 'unfertilized system' or 'Galveston system' with independent algal culture units. In any hatchery, major requirements are clean water, quality spawners, nutritionally adequate and acceptable feed and management of water quality during rearing.

Sea-water intake: There are numerous designs in use for various sea-water-based hatcheries. These designs are dependent on the characteristics of the site–topography, geology and climate. In mostly used system, water is drawn through intertidal bore-wells or through inshore open-wells. Low depth intertidal bore-wells (Fig. 23.1) are suitable where wave action is minimal. Inshore open wells (Fig. 23.2) can be used where wave action is more in intertidal zone and there is no freshwater aquifer in shoreline. Where water from inshore wells are low saline due to freshwater table, water is drawn directly from open-sea by constructing concrete jetties (Fig. 23.3) into the sea beyond breaker zone.

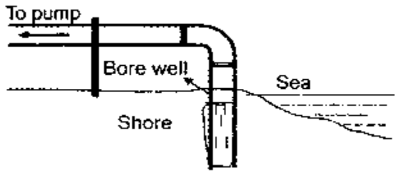


Fig. 23.1. Sea-water intake from inter-tidal bore-well.

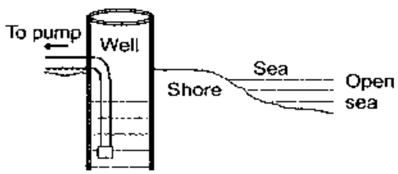


Fig. 23.2. Sea-water intake from inshore well.

Water quality: Sea-water used inside a hatchery should be free from suspended solids, living organisms and chemical contamination. It is, therefore, essential to provide facility for water treatment in the hatchery depending on the quality of the source water. Optimal levels of water quality parameters for shrimp hatcheries are given in Table 23.2.

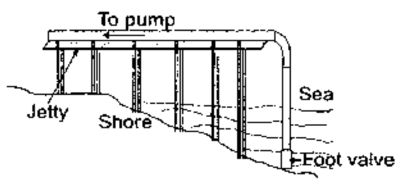


Fig. 23.3. Sea-water intake – direct pumping from open-sea.

Table 23.2. Water quality requirements for shrimp hatcheries

Parameters	Tolerable limit	Optimal levels
Temperature (°C)	18-36	28-32
Salinity (ppt)	26-34	30-34
pH	7.0-9.0	8.0-8.4
Dissolved oxygen (ppm)	Above 3	Above 4
Ammonia - N (ppm)	Up to 0.1	Less than 0.01
Nitrite - N (ppm)	Up to 0.1	Less than 0.01

Water treatment: Facilities for water treatment in a shrimp hatchery should be able to provide sea-water of required quality without suspended particles, biological and chemical contamination. If water is drawn from open shore, it contains suspended

particles, which are to be removed as a first step. Large suspended particles are easily removed by allowing water to stand overnight in settling tank by sedimentation process. When sea-water is drawn from intertidal bore-wells or inshore wells, water is free from suspended particles, and so no sedimentation is required.

The next step for sea-water is removal of unsettled suspended particles and other living organisms. This is done by filtration through sand-gravel filter, which is simple and most practical. Two types of sand-gravel filters are generally used in hatcheries: (*i*) filtration by gravity and (*ii*) filtration by pressure.

A simple gravity filter consists of a wooden or a concrete tank with layers of gravel and sand. Gravel layer is larger at the bottom with medium and smaller layers above it. Similarly, three grades of sand (coarse to fine) are used above gravel layers. A perforated PVC pipe embedded at the bottom of the gravel layer extrudes out of the tank, and acts as an outlet (Fig. 23.4). Water is pumped into the filter from the top, and it flows through sand and gravel-bed. The coarse suspended particles are trapped in the sand-bed and clean water is collected through the bottom outlet.

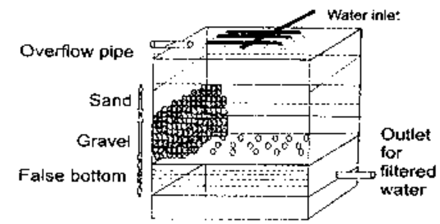


Fig. 23.4. Sand-gravel filter (by gravity).

Pressure/rapid sand filters use the same principle as that by gravity filters (Fig. 23.5). The difference is that water passes through sand and gravel bed through pressure. Filter housing is made of FRP and is sealed air-tight after arranging sand and gravel in position. The delivery from a pump of the required capacity is attached to inlet of the filter and filtered water flows out through outlet at the same velocity as pumped-in water. Filtering rate is very high, and hence it is called rapid sand filters.

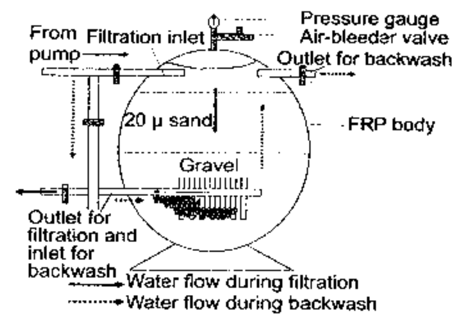


Fig. 23.5. Pressure sand filter.

Operation of the filter results in accumulation of waste materials on the sand-bed, and filtration capacity and rate reduces with such accumulation, and cleaning of sand-bed becomes essential. Allowing water to flow in the reverse direction, i.e. entering through gravel and flowing out through sand, is adapted and provision for such a backwash is given in all sand filters. Sand filtration removes coarse materials only up to 10 micron size. Further filtration can be done by using fibre-based cartridge filter (Fig. 23.6), which removes suspended particles of up to 1 micron. Fibre filter is enclosed in a non-corrosive housing. Water is pumped through cartridge to outlet; this could be easily fitted to water lines.

The filtered water still may contain microorganisms like bacteria, which cause diseases in larvae. Hence, it is desirable to disinfect water before use. Several chemicals, chlorine, hypochlorite, ozone, have been commonly used for disinfection. UV is used for sterilization of water (Fig. 23.7).

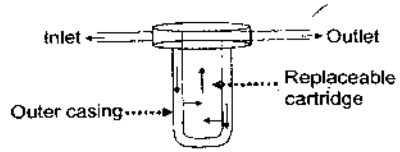


Fig. 23.6. On-line cartridge filter.

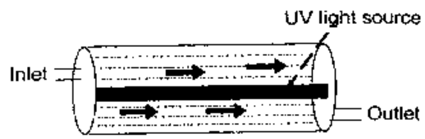


Fig. 23.7. UV filter.

Recommended concentration of disinfectants in water depends on the bacterial load. Usual range of active chlorine dosage is 5-20 ppm. Treatment should preferably last for 24 hours. Before using sea-water, excess chlorine should be neutralized by sodium thiosulphate. Further, EDTA (a metal-chelating agent) has to be applied in water to avoid contamination of heavy metals (Fig. 23.8).

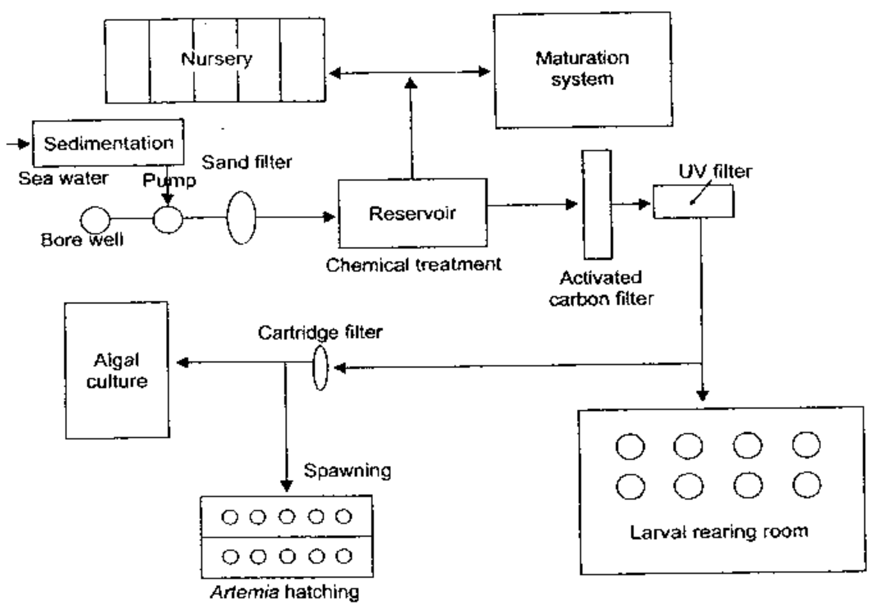


Fig. 23.8. Flow-diagram of water treatment.

Algal culture: In hatcheries, shrimp larvae are fed on unicellular diatoms– *Chaetoceros* and *Skeletonema* or nannoplankters – *Isochrysis and Tetraselmis*. Hence mass culture of these species is a pre-requisite for successful hatchery operation. Algal culture involves two major aspects: (*i*) collection, isolation, purification and axenic

Table 23.3. Composition of Guillard and Ryther's Modifed 'F' medium

Chemical	Quantity (mg)
Sodium nitrate	84.148
Sodium dihydrogen phosphate	10.0
Ferric chloride	2.9
EDTA	10.0
Sodium silicate	12.0
Vitamins	
Thiamin hydrochloride (B 1)	0.2
Cobalamine (B 12)	1.0
Biotin (H)	1.0
Trace metals	
Cupric sulphate	0.196
Zinc sulphate	0.44
Cobalt chloride	0.2
Manganese chloride	3.6
Sodium molybdinate	0.0126
Sea-water	1.0 litre

Table 23.4. Composition of Walne's Conway medium

Chemical	Quantity (mg)
Sodium nitrate	100.0
Sodium dihydrogen phosphate	20.0
Ferric chloride	1.3
EDTA	45.0
Boric acid	33.6
Manganese chloride	0.36
Vitamins	
Thiamin hydrochloride (B 1)	0.1
Cobalamine (B 12)	0.005
Trace metals	
Cupric sulphate	0.02
Zinc chloride	0.021
Cobalt chloride	0.02
Ammonium molybdinate	0.009
Sea-water	1.0 litre

culture of required species and (*ii*) mass culture technique. Algal culture requirements are clean uncontaminated sea-water, temperature and light controlled laboratory and nutrients. As seen earlier, water in the hatchery is treated, and for pure culture of algae, water is further purified by UV treatment. Pure cultures are maintained in 10 ml (test tube) to 20-litre flasks. Following nutrient media are generally used for pure culture (*i*) Guillard and Ryther's (1962) Modified F medium and (*ii*) Walne's (1974) Conway medium (Tables 23.3, 23.4).

Table 23.5. Composition of Liao and Huang's modified TMRL medium

Chemical	Quantity (mg)
Potassium nitrate	100
Sodium mono hydrogen phosphate	0
Ferric chloride	3
Sodium silicate	2
Sea-water	1.0 litre

Mass cultures of algal species are carried out in outdoor tanks of 1 to 40- tonne capacity according to the requirement of hatchery. Above media without vitamins and minerals can be used for mass culture. Liao and Huang's modified TMRL medium is also used (Table 23.5).

For mass culture, 10-20% of pure culture is used as the starter culture. In the pure culture, algae are maintained at 2-3 million cells/ml, and in the mass culture within 24 hours, they attain 3-4 lakh cells/ml. Required volume of algal water is calculated depending on the larval stage and larval tank volume, and directly pumped into larval tanks.

***Artemia* hatching:** *Artemia* nauplii are fed to mysis and post-larval stages of shrimps. Commercially available *Artemia* cysts are used. Cysts are washed thoroughly and disinfected with hypochlorite and then suspended in the clean sea-water at least 16-18 hours before actual requirement. Continuous aeration and subdued light is provided. After nauplii are fully hatched, they are separated from cyst-walls using their positive phototactic behaviour and fed to larvae as per the requirement. For this, small, black, conical FRP tanks of 40-100 litres with transparent bottom and draining outlet are used.

Induced maturation: Technology for induced maturation of *P. monodon* has been standardized, and is being adapted by many hatcheries. The basic requirements and technology involved are summarized in Table 23.6.

Table 23.6. Requirements for induced maturation system of *Penaeus monodon*

Housing	Ventilated roofed shed
Tank size	5-15 tonnes capacity circular or rectangular, made of fibre glass or concrete
Light intensity	Reduced, 100 lux (artificial) dim light
Light quality	Blue or green
Photoperiod	12 hours light : 12 hours dark
Water depth	80-100 cm
Water quality	
Dissolved oxygen (ppm)	Saturation by continuous aeration
Salinity (ppt)	30-36
*p*H	8.0-8.5
Stocking rate	4 numbers/m^2
Stocking size	Females - 90-180 g; Males - 60-90 g
Sex ratio	2 Females : 1 male
Water management	100% exchange/day using filters; 200% exchange by flow through system per day
Feeds fresh	Clam, mussel, squid and oyster meat @ 15% of the total biomass/day, polychaete worms @ 6% of the total weight or *Artemia* biomass @ 3% of the total biomass
Artificial (pellet)	2% of the total biomass during night
Feeding schedule	Four times in a day
Sampling	The females are to be examined for the development every alternate day using underwater torch-lights without handling

Spawning: Matured females from wild or from induced maturation tanks are treated with formalin (50 ppm, under strong aeration for 30 min) before being placed individually in 500-litre FRP tanks for spawning. In spawning tanks, no feeding is done. The room is kept in dark, without disturbance to spawners. Continuous aeration is maintained in tanks; spawning generally happens during night. Eggs are collected in the morning, washed thoroughly and dipped in formalin and placed in the same tank with fresh filtered sea-water for hatching.

Larval rearing: Major aspects of shrimp larval-rearing are water-quality monitoring and management, feed management, and health management. At N 6 stage, nauplii are collected from spawning tank and dipped in formalin (100-300 ppm for 30 sec) before stocking in the larval rearing tanks at 50–100 nos/litre. The larval rearing tanks are generally made of concrete/ FRP and their capacity ranges from 2 to 10 tonnes; their management methods are given in Table 23.7.

The schedule given in Table 23.7 is a generalized one. Various hatcheries adopt schedule according to the conditions of the source-water, water treatment methods followed and availability of live-feed. Further, some of the hatcheries use additional

Table 23.7. Feed and water management in shrimp larval-rearing

Days	0	1	2	3	4	5	6	7	8	9	10	12	15	20	30
Larval stages	Nauplius			Protozoea					Mysis				Post-larva		
Feeding schedule															
Algae/Diatoms				20 - 50,000 cells/ml											
Artemia nauplii									3 - 5 no./ml				2-5 no./ml		
Suspension feed/ Pelletized feed													5 - 10 g/tonne/ day in small doses		
Water exchange	No change. Only filling			30% change					50% change				50-100% change		

feed items such as *Spirulina* powder, *Artemia* flake diets, commercial micro-encapsulated diets, etc.

In India, health management is considered very important during larval rearing, especially after the outbreak of White Spot Virus disease. Seed is the major source of this virus, and it has been found to be vertically transmitted. Some hatcheries have adopted following practices.

- Screening of wild spawners and broodstock for virus.
- Treatment of wild and induced mature spawners with formalin to remove externally attached pathogens.
- Washing and treatment of eggs with formalin.
- Washing and treatment of nauplii with formalin before stocking in larval rearing tanks.
- Application of broad spectrum antibiotics in larval rearing tanks.
- Addition of broad-spectrum antibiotics in the feed for nursery rearing of postlarvae.
- Screening of all feeds used in the hatchery for virus/ bacteria.
- Screening of PL5 for white spot virus before transfer to nursery tanks.

Shrimp farmers have understood the importance of seed quality, and they have opted for buying certified seeds from hatchery. Hence, hatchery operators are concerned about the health of reared larvae.

Nursery rearing: Five-day-old post-larvae (PL5) are collected from larvae rearing tanks and stocked in 10-20-tonne concrete, outdoor tanks for further rearing up to PL20. They are stocked @ 15-25 nos/litre and fed with *Artemia* biomass/pelleted feed/suspension feed. Water is exchanged every day by 50-100%.

Good management practices (GMP)

Shrimp farming sector in the country is plagued with white spot viral disease since 1995, and seed is considered as one of the major sources for viral infection. Quality seed is an essential prerequisite for successful shrimp farming. Good management practices, followed in a shrimp hatchery to ensure quality seed production, are given here.

Spawner/broodstock quality

Vertical transmission of viral pathogens from mother shrimps to larvae through ovarian tissue is one of the sources of introduction of viral pathogens into the hatchery system. In addition, any stress caused to spawners will result in spawning of poor quality eggs. Following measures should be strictly followed to obtain good quality eggs.

- Spawners/ broodstock collected from commercial trawling operations will be very much stressed since trawling operation continues for more than 3-4 hours. Spawners caught in the net are severely stressed by the quantity of other fishes caught. It is essential that special trawling operations of shorter duration should be conducted for collecting shrimp spawners/ broodstock for avoiding undue stress.
- Spawners collected should be placed individually immediately in the disinfected water after capture and brought to land with minimal stress. When landward journey takes more than 6 hours, shrimps should be individually transported in oxygen packing.
- Undue delay at the landing site should be avoided and spawners/broodstock should be transported to hatchery in disinfected waters. In case of transportation for more than 3-4 hours, the spawners should be packed individually under oxygen. Maintaining spawners individually from the time of capture is important to avoid cross contamination with viral pathogens.
- Spawners/broodstock which have no lesions, damage to gills, loss of appendages and are of red colouration only should be selected.
- Prophylactic treatment of spawners/ broodstock with formalin at 50 ppm for 1 hour under strong aeration should be done before introducing stock into hatchery/ maturation system.
- Spawners/broodstock should be kept individually for acclimatization, and screened for WSSV using a terminal portion of pleopods and for MBV using faecal matter. Only spawners free from these pathogens should be taken into hatchery/ maturation system

Induced maturation under captive conditions

Healthy, pathogen-free, immature, broodstock, collected from wild, after prophylactic treatment and acclimatization should be taken into maturation tanks and allowed to recover from stress of capture and transportation for 4-5 days. Then they are induced to mature through eyestalk ablation; the guidelines are as follows.

- Hard-shelled, inter-moult healthy female shrimps free from disease or injury having spermatophore in the the lycum should be selected for eyestalk ablation.
- Females should be above 100 g in weight for ensuring good quality eggs.
- Eyestalk ablation is to be avoided for newly moulted and ready to moult female shrimps.

- Electrocauterization is the best way of ablating eyestalk as it causes minimum stress.
- Ablated female shrimps are stocked in maturation tanks along with unablated males @ 4 nos/m^2. Stocking of females and males in 2 : 1 ensures best mating success.
- Fresh feeds such as clam (*Meretrix casta, Meretrix meretrix*), mussel (*Perna viridis*) and squid (*Loligo duvauceli*) having similar amino acids profile as shrimps, and polychaete worms, *Artemia* biomass rich in long chain poly-unsaturated fatty acids are used as maturation feeds. Feed by visual observation should be provided in sufficient quantities.
- In addition to live-feed items, pelleted feed fortified with polyunsaturated fatty acids (PUFA) such as arachidonic acid, eicosopentaenoic acid and decasohexaenoic acid should be used to ensure good egg quality.
- Water quality should be maintained under optimal conditions with 100% to 200% water exchange per day.
- Light intensity should be maintained low, and ablated shrimps should not be disturbed by movement of personnel near maturation tanks.

Spawning and hatching

- Wild spawners/induced matured stock should be disinfected with formalin treatment before placing them individually in spawning tanks.
- Feed should not be provided in spawning tanks.
- Spawned eggs should be collected, washed thoroughly and disinfected by formalin- dip treatment and resuspended in fresh sea-water for hatching.

Washing and disinfection procedure for eggs

- Gently collect eggs in a 50-60 µm mesh net (a preliminary 300 µm net is used to collect and discard any faeces from spawning tank).
- Rinse gently in running sea-water for 5 minutes.
- Dip in 100 ppm formalin solution for 30 seconds.
- Dip in 50 ppm povidone iodine solution for one minute.
- Rinse again in running sea-water for 5 minutes.
- Stock eggs in hatching tanks.
- Egg quality should be assessed within 2 hours after spawning; it is easier to identify fertilized and unfertilized eggs.
- If egg quality is poor, it is advisable to discard eggs.
- Only active positively phototactic nauplii should be collected for transfer to larval rearing tank.

Washing and disinfection procedure for nauplii

- Collect nauplii gently in a 100µ-mesh net.
- Rinse them in running sea-water for 5 minutes.
- Dip them in 200 ppm formalin solution for 30 seconds.

- Dip in 50 ppm povidone iodine solution for one minute.
- Again rinse gently in running sea-water for 5 minutes.
- Stock nauplii in larval rearing tanks.
- Nauplii should be tested for white spot virus before transferring to larval rearing tank.

Larval rearing/nursery rearing

- Nauplii from a single spawner should be reared separately to avoid cross contamination.
- Stocking density of nauplii should be maintained at 50 nos/litre in larval rearing tanks.
- Algal feed should be initiated before nauplii moult to zoea I.
- Algal feed should be given in required quantity from cultures that are in exponential stage of growth.
- Algal feed should be concentrated to avoid introduction of large quantities of algal culture water with its nutrient load.
- Water quality in the larval rearing should be monitored for ammonia, nitrite and bacterial load.
- Uniform aeration in all parts of the tanks should be provided through air diffuser stones placed @ 1/ft^2. This will keep larvae and algal feed distributed uniformly in the tank.
- During water exchange, appropriate mesh size nets should be used for draining water so as to facilitate removal of faecal matter without stressing larvae.
- *Artemia* nauplii/flake diets should essentially be used from mysis II stage onwards along with algal diet.
- Prophylactic use of antibiotics or other drugs should be avoided. Instead probiotics could be used.
- At PL5, larvae should be collected from larval rearing tanks, disinfected with formalin dip treatment and distributed in outdoor nursery tanks @ 15-20 nos/litre.
- During later stages of nursery rearing, along with *Artemia* nauplii, other live-feed items like clam meat or balanced compounded feed can be used.
- Acclimatization to required salinity levels should be done gradually in nursery stage of rearing.
- Only PL20 should be sold to farmers after testing its quality with reference to presence of MBV and WSSV.
- At any stage of rearing, if WSSV is detected, the larvae from the whole tank should be discarded.
- For long distance transportation, the seed should be packed in thermocol boxes at reduced temperature.

Algal culture

- Algal culture should be maintained in pure form in indoors, temperature controlled rooms and used as started culture for outdoor mass culture.

- It is advisable to use UV-treated water for pure culture of algae to prevent contamination.
- The quality of mass culture should be tested before adding into larval rearing tanks.

Artemia *hatching*

- Artemia cysts should be disinfected before keeping them for hatching.
- Hatched *Artemia* nauplii should be segregated from cyst wall and unhatched cysts, before being used as feed in larval rearing tanks.
- Only nutritionally superior instar I nauplii should be used as feed.

Recent trends in shrimp seed production

Probiotics-based seed production: Food-safety issues like presence of antibiotic residues in shrimps that are exported have become contentious with stringent standards prescribed by importing countries. Usage of antibiotics in hatcheries needs to be stopped. Presently, techniques are being evolved to produce seed by using probiotics in larval-rearing phase. The probiotics are used in various stages of the larval cycle, mainly through water.

SPF and SPR broodstock: In the post disease scenario, emphasis has been given to produce pathogen-free seed to overcome huge losses due to WSSV. Specific Pathogen Free (SPF) broodstock are produced by rearing shrimps in a high bio-secure facility which excludes most of the OIE-listed pathogens over a period of 2-3 generations. SPF broodstock are commercially available of *Litopenaeus vannamei* and *L. stylirostris* from the United States of America. One company from Hawaii has also started marketing SPF *Penaeus monodon*. Specific Pathogen Resistant (SPR) shrimps are produced through selective breeding for disease resistance. A number of countries are attempting this for different shrimps species. *L. vannamei* and *L. stylirostris*, resistant to Yellow Head Virus, are commercially available.

Biosecurity in *Penaeus monodon* seed production

Biosecurity is measures and methods adopted to secure disease-free environment in all production phases for improved quality. Biosecurity is the ability to prevent losses due to diseases through effective elimination of pathogens and their carriers. Shrimp aquaculture industry has experienced severe setbacks due to devastating viral diseases which are transferred between regions through importation of broodstock, postlarvae and shrimp products. Biosecurity encompasses policy, regulatory, and programme frameworks (including instruments and activities) in response to managing risks associated with diseases. Basic elements of a biosecurity programme in a shrimp hatchery include physical, chemical and biological methods necessary to protect hatchery from the consequences of all diseases that represent a high risk. Biosecurity programme for shrimp hatchery includes following.

- Specific pathogen free (SPF) or high health (HH) shrimp stocks should be used.
- All incoming stocks should be quarantined in the designated area.

- All incoming stock should be analyzed for diseases.
- All incoming water sources should be treated to eliminate pathogens.
- Equipment and materials should be sterilized and maintained clean.
- Personal hygiene measures including washing of hands and feet and clothing need to be taken care of.
- Knowledge of the potential pathogenic diseases and the sources of risk and methods and techniques for their control and /or eradication is required.
- Specific pathogen resistant (SPR) stocks are to be used.
- Maintenance of optimum environmental conditions is required.
- Immune enhancers and probiotics should be used in place of antibiotics.

HACCP principles for biosecurity in *Penaeus monodon* seed production

The hazard analysis critical control points (HACCP) approach is a preventive risk management used to identify and control risk to human health in food-processing systems. Critical limits are set at critical control points (CCPs) in the system where controls must be applied to prevent, eliminate or reduce hazard. Monitoring and corrective actions are then implemented. HACCP principles have been applied as a risk management tool to control viral pathogens at shrimp research and production facilities. Biosecurity in *P. monodon* hatcheries can be achieved through isolation of breeding, hatchery and production phases. Critical control points (CCP) identified for maturation and hatchery stages are shrimp, feeds and water. Other potential risks to be covered by the implementation of Standard Operating Procedures (SOPs) and HACCP are disease vectors (human and animal), facilities and equipment.

For each operation, from broodstock receipt through maturation, larval rearing and nursery, all potential hazards, impacts on larval health and quality, and points of entry of pathogens should be identified. Following this systematic hazard analysis, CCPs should be identified. For each CCP, critical limits must be established and where these limits exceed, appropriate corrective actions are to be determined. A system to monitor the CCPs must be established along with a good system of documentation and recording. Some of the stages considered as CCPs are as follows.

Facility entrance: At the entrance, control is required on the access of operational workers, administrative employees, vehicles and other disease vectors to prevent transfer of infections from other hatcheries. Entry to the hatchery in general and each area in particular should be restricted only to authorized personnel. All staff and administrative personnel entering production areas must maintain personal hygiene.

Water treatment: Ensure that all water used in production units is appropriately treated to kill pathogens and their hosts.

Maturation: Quarantine all incoming broodstocks, check and disinfect fresh feed, clean tanks and water and air-lines and disinfect broodstock, eggs, nauplii and equipments.

Hatchery: Ensure regular dry-out periods, cleaning and disinfection of buildings, tanks, filters, water and air-lines and equipment, quality control and disinfection of fresh feeds, separation of working materials for each room and each tank.

Algae: Restrict entry of personnel to algal laboratory and tank facilities, disinfect equipments, water and air-lines, sanitation and quality control of algae and chemicals used.

Artemia: Disinfect cyst and nauplii and clean and sanitize tanks and equipments.

Economics of *Penaeus monodon* seed production

Capital investment required for a hatchery depends on the production capacity of the hatchery, sea-water quality and availability of shrimp spawners (Table 23.8).

Table 23.8. Economics of production of *Penaeus monodon* seed (20 million per annum post-larvae capacity)

Sl No.	Item	₹ in lakh
I.	**Expenditure**	
	A. *Fixed Capital*	
	1. Land and building	12.00
	2. Tanks (FRP/Cement)	8.00
	3. Machineries (Pumps, blowers, filters)	3.00
	4. Water supply/aeration connection	2.00
	5. Electrification	1.00
	6. Miscellaneous expenditure	1.00
	Sub-total	**27.00**
	B. *Variable Cost*	
	1. Cost of broodstock/spawners	5.00
	2. Larval feed	6.00
	3. Chemicals	3.00
	4. Electricity/Fuel	4.00
	5. Wages	4.00
	6. Miscellaneous expenditure	1.00
	Sub-total	**23.00**
	C. *Total Costs*	
	1. Variable cost	23.00
	2. Depreciation cost on fixed capital at 18% level	4.90
	3. Interest on fixed capital at18% per annum	4.90
	Grand total	**32.80**
II.	**Gross Income**	
	Sale of PL 20 million seed (at ₹ 250/1,000 nos)	50.00
III.	**Net income (Gross income-Total cost)**	**17.20**

Production of good quality, disease-free seed in the hatcheries is very important for sustaining the whole sector. Hence hatchery operators have an added responsibility. Good Management Practices and Standard Operating Procedures are to be implemented fully. Diseased broodstock/spawners should be avoided at any cost. Strict biosecurity measures are required to achieve these requirements.

24. Shrimp Farming

In India, since ages, shrimp culture has been followed as a traditional activity. In the early nineties, it witnessed a phenomenal growth, which was dependent on the culturing of a single species, tiger shrimp, *Penaeus monodon,* and during this period, shrimp culture was a low-risk, high-profit venture. In the late nineties, there were serious problems of viral diseases and environmental safety issues, which arose mainly owing to lack of planning and regulation. At present, risk of losing a crop to diseases has increased and profit margins, have decreased due to increased inputs' cost and lowered international market price. So, there is an urgent need to ensure sustainability of shrimp farming in the country through appropriate technical and policy interventions to ensure economic viability, food-safety, environmental soundness, social acceptability, equity, and conservation of resources. It has enormous potential for increasing employment generation and foreign exchange in the country. This chapter aims to bring out various issues that affect sustainability of shrimp farming and possible remedial measures that need to be taken at the farm level and at the national level.

Shrimp farming–global status

Shrimp culture continues to dominate crustacean aquaculture at the global level. It grew from 0.8 million tonnes in 1991 to 3.3 million tonnes in 2007 with corresponding value of 5.1 billion US$ to 13.4 billion US$ (Fig. 24.1; *Source:* FAO, Fishstat, 2009). Though more than 35 countries reported shrimp production; more than 90% of the contribution is by the top ten countries. In 2007, out of the total production of 3.3 million tonnes, 40% was by China, 15% was by Thailand, 12% was by Vietnam and

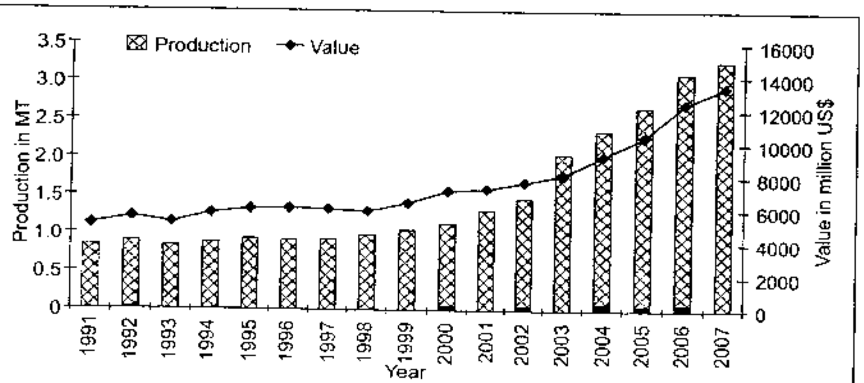


Fig. 24.1. Global shrimp aquaculture production and value (FAO, Fishstat, 2009) Total production – 3.3 million tonnes.

10% was by Indonesia. India stands at 7th position with a contribution of about 3% (Fig. 24.2; *Source:* FAO Fishstat, 2009).

More than 20 species of shrimps are being cultured commercially in different countries but the major contribution is from 6 species of shrimps–*Penaeus monodon, Litopenaeus vannamei, Fenneropenaeus merguiensis, F. indicus, F. chinensis* and *Marsupenaeus japonicus*. Higher rate of growth in shrimp aquaculture production observed since 2002 is mainly due to introduction of *L. vannamei* in China and other South-east Asian countries in place of *P. monodon*.

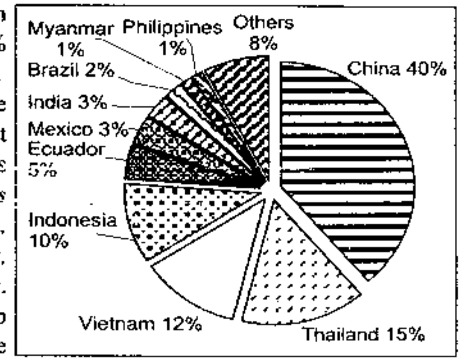


Fig. 24.2. Percentage contribution of different countries in shrimp production (2007) (FAO, Fishstat, 2009).

Till 2002, *P. monodon* was the major contributor (50-60%) and *L. vannamei* contribution was only 15-20%. In 2007, contribution from *L. vannamei* touched to 70% and of *P. monodon* reduced to 18% (Fig. 24.3; *Source:* FAO Fishstat, 2009).

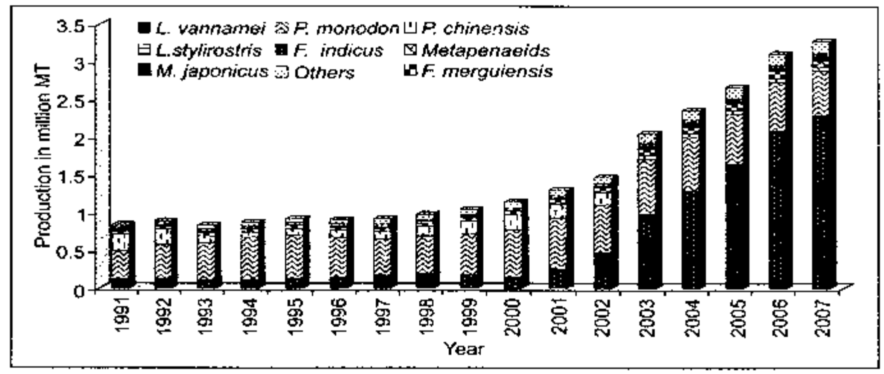


Fig. 24.3. Species-wise contribution to global aquaculture shrimp production (FAO, Fishstat, 2009).

Shrimp farming status in India

Development of shrimp farming

The country has vast potential for brackishwater aquaculture development in the coastal saline-affected lands. Role of shrimp farming in India's economy was realized in the early seventies, and the first Experimental Brackishwater Fish Farm was started in Kakdwip, West Bengal, by the Central Inland Fisheries Research Institute under the Indian Council of Agricultural Research in 1973, and an All -India Coordinated Research Project on Brackishwater Fish Farming was started in 1975 by the ICAR with centres in West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala and Goa.

Concurrently shrimp seed production studies were initiated in Narakkal, Kochi, by the Central Marine Fisheries Research Institute (ICAR). Large-scale development of shrimp farming took place only after 1988-89 with the establishment of the commercial shrimp hatcheries by the Marine Products Export Development Authority (MPEDA). Further, a semi-intensive culture technology was demonstrated in a pilot-scale project by the MPEDA and funded by the Department of Biotechnology. A number of development schemes were initiated by the Ministry of Agriculture and Ministry of Commerce, Govt. of India, for the development of shrimp farming, which paved way for the establishment of a number of shrimp hatcheries and farms in the coastal states in the early nineties.

The growth rate of the sector was phenomenal till 1995. Since 1995, this sector has been plagued with viral diseases, especially, White Spot Syndrome Virus (WSSV). Further, environmentalists had filed a Public Interest Litigation against shrimp farming, claiming it to be environmentally damaging. In 1996, the Apex Court had ordered for closure of all extensive and semi-intensive shrimp farms located within the Coastal Regulation Zone (CRZ), excepting traditional farms, and also for the establishment of an Aquaculture Authority to regulate shrimp farming activities in the country. In 1997, Ministry of Agriculture had established Aquaculture Authority under the Environment Protection Act, 1986. In 2005, Coastal Aquaculture Authority Act was enacted, and a Coastal Aquaculture Authority (CAA) was established with the mandate to regulate culture of all aquatic organisms in the coastal area.

Coastal resources and potential area for brackishwater aquaculture

India, by virtue of its extensive geographical stretch and varied terrain and climate, supports a wide diversity of inland and coastal wetland habitats. The coastal areas are productive and rich in natural resources. Its eastern coast is low-lying with lagoons, marshes, beaches and deltas while western coast is dominated by rocky shores. The islands of Lakshadweep are composed of atolls while those of the Andaman and Nicobar are volcanic in origin, arising from a submerged mountain chain. India has 14 major river systems, which have led to formation of a wide network of creeks and estuaries in the coastal areas, thus facilitating coastal aquaculture. The Ministry of Environment and Forests, Government of India, estimated that India has total estuarine area of 3.9 million ha and backwaters of 3.5 million ha; out of this, 1.2 million ha of coastal salt-affected lands have been identified to be potentially suitable for shrimp farming. West Bengal and Gujarat are the two states that have major potential area because of the high tidal amplitude. The state-wise details of the potential area for brackishwater aquaculture are presented in Fig. 24.4.

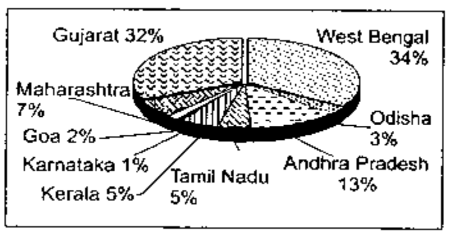


Fig. 24.4 State-wise potential area available for brackishwater aquaculture (Total area-1.2 million ha).

Farming systems

Traditional farming

In India, brackishwater aquaculture is traditionally practised in West Bengal, Kerala, Goa and Karnataka. In West Bengal, *bheri* fishery, locally known as "*bhasabhadha*" fishery, is in practice for centuries in 24-Parganas. In this system of culture, tidal water is impounded in the inter-tidal mudflats by raising bunds. Tidal water with all assorted fish and shrimp seed is allowed to enter through sluice-gates during spring tides. Harvesting of marketable sized fish and shrimp is done regularly during spring tides through traps placed near the sluice-gate. There is no need of manuring and feeding. Water is exchanged during every spring tide. In some *bheries*, paddy cultivation is carried out during monsoon months, and in perennial *bheries*, aquaculture is carried out throughout the year. The average production from this type of system is about 500-750 kg/ha; shrimps contribute 20-25% of the total production. At present, about 44,000 ha is under this system.

In Kerala, two types of shrimp culturing are traditionally practised in low-lying backwaters. In perennial fields, shrimp culture is carried out throughout the year using trap-and-culture method. In seasonal fields, rice cultivation is carried out during monsoon months using local variety '*Pokkali*', and after its harvest, shrimp culture is practised by trapping tidewater. In these types of culture, auto-stocking of seed from wild also takes place. A total of about 11,300 ha are under traditional system of culture with average productivity levels of about 500 kg/ha; mostly comprising Indian white shrimp, *Fenneropenaeus indicus* and other metapenaeid shrimps.

In Karnataka, shrimp culture is traditionally carried out in *kharlands* after a crop of '*Kagga*', a salt-resistant variety of paddy. About 2,500-3,000 ha is under this type of culture. The productivity level from this is low, at 50-150 kg/ha.

In Goa around 500 ha of '*khazan*' lands are under traditional farming. Shrimp farming in these lands is practised during December to April after harvesting of paddy.

Modern scientific farming

Modern scientific methods of shrimp farming include advanced animal husbandry methods – removal of pests and predators, development of natural food by using manures and fertilizers, stocking of healthy seed, feeding with nutritionally balanced feed, monitoring and maintenance of water quality and health management. In these methods, various degrees of control are maintained and accordingly various types have been classified.

Improved traditional: In the tide-fed traditional system of culture, selective stocking and feeding with local feed is done to increase production and productivity. Stocking density is kept between 4 and 6 nos/m^2.

Extensive/improved, extensive/modified extensive: No difference is between improved traditional and extensive system of culture excepting that farms are of recent origin and feeding is with high protein diets.

Semi-intensive: Stocking density is increased up to 10-30 nos/m^2; water quality management is increased with addition of pond aeration. Feeding is with high protein diets with strict feed management. Greater emphasis is on improved health management and use of probiotics. Presently, such high stocking densities are not permitted by the Coastal Aquaculture Authority (CAA).

Intensive/super-intensive: Cultured stock under fully controlled conditions with very high stocking densities 100-200 nos/m^2. Presently this is not being practised in India.

Area under culture and production

Out of the total potential area available, hardly 16% has been developed into shrimp farming, which includes 4% of traditional farming in West Bengal, Kerala, Goa and Karnataka. The area under shrimp culture was more or less stagnant from 1997 to 2007 at around 140,000 to 150,000 ha (Fig. 24.5). In 2008-09, the area reduced drastically to 100,000 ha–equivalent to the pre-1995 level. Similarly the shrimp aquaculture production showed a phenomenal increase between 1990 and 1995, and thereafter there was stagnation during 1996 to 2000. From 2000 onwards, there was a gradual increase in production that reached a maximum of 140,000 mt in 2006-07. But in 2007-08 and 2008-09, production levels drastically reduced and reached at pre-1995 level of 75,000 mt. The decline was owing to farmers not taking up farming in some of the developed areas since the farm-gate price realized by the farmers for 2007 crop was in the range of ₹ 200-220 kg for 25-30 g size shrimp, which was much below the price realized earlier. The reduction in global shrimp price was mainly due to increased supply of low-priced *L. vannamei* in China, Thailand, Indonesia and Vietnam.

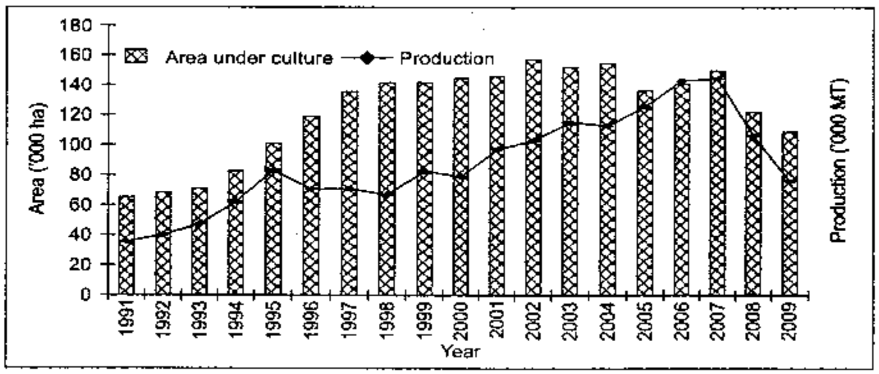


Fig. 24.5. Area under shrimp farming and production (*Source:* MPEDA, 2009).

Productivity

The average annual productivity of *Penaeus monodon* in India from 1990 to 2009 ranged between 472 and 1,018 kg/ha/year; was lower than productivity levels observed in Thailand and other South-east Asian countries. This was mainly because of the 40,000 ha of the traditional system of farming with low productivity levels depressed average values for India. Among the states, Kerala, West Bengal, Odisha, Karnataka

and Goa registered lowest productivity levels of about 500-600 kg/ha/year, since most of the traditional shrimp farming is carried out in these states; Gujarat registered maximum productivity level of 2 tonnes/ha/year.

Contribution to marine products' exports

Indian marine products' exports touched an all-time high of ₹ 8,299 crore in 2006. Shrimp is one of the major constituents of the marine products' exports, contributing nearly 55% by value (₹ 4,500 crore). Shrimp exports comprise both capture and culture production. During 2000-2007, cultured shrimp contributed above 80% of the total value of the shrimp export (₹ 3,300 to 3,870 crore). But in 2008-09, the total contribution from cultured shrimps had fallen to pre-1997 level of ₹ 1,900 crore. The contribution of cultured shrimps to total shrimp exports by volume and by value is presented in Fig. 24.6a,b.

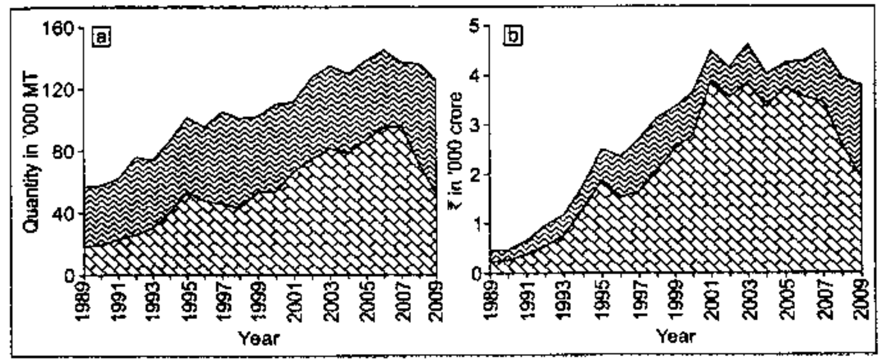


Fig. 24.6. (a) Contribution of aquaculture in shrimp exports by quantity. (b) Contribution of aquaculture in shrimp exports by value (*Source:* MPEDA, 2009).

Major issues and remedial measures

Viral diseases

One of the major issues facing shrimp farming industry is the loss owing to diseases, mainly due to viral diseases. Since 1995, shrimp farming has been seriously affected by viral diseases, especially White Spot Syndrome Virus (WSSV). The WSSV is a crustacean virus and is reported in all species of penaeid shrimps and most other aquatic crustaceans. Wild broodstock of *P. monodon* carries virus, which is easily transmitted vertically to larvae in the hatchery. The virus is horizontally transmitted in farms through water, vectors and through human and animal interventions. As there is no treatment protocol for the WSSV available worldwide, prevention is the only way to overcome this problem, following preventive measures are being adopted lately.

Prevention of vertical transmission of viral pathogens: To prevent vertical and horizontal transmission of pathogens, better management practices (BMPs) for hatcheries have been evolved. This involves additional infrastructure for biosecurity along with following certain Standard Operating Procedures. Salient points are discussed as follows.

To ensure that sea-water used in the hatchery is devoid of all pathogens, a process of settlement, disinfection with chlorination, biological filtration, micro cartridge filtration and UV filtration is adopted.

P. monodon hatcheries in India are mainly dependent on wild broodstock for production of nauplii. Screening of wild broodstock and spawners for WSSV is being undertaken before using them in the hatchery. To increase probability of detecting virus, some hatcheries test also after spawning; since spawning stress is considered to be one of the factors which can induce viral multiplication. Since the practice of mixing nauplii from different mother shrimps during rearing will lead to cross contamination, many hatcheries avoid it, and farmers insist on this BMP.

WSSV transmission from mother shrimp to nauplii is through extra-ovarian tissues which are shed as debris during spawning. Collecting eggs immediately after spawning and washing them thoroughly with filtered and treated sea-water will eliminate this risk. Eggs and nauplii are also disinfected with formalin dip to ensure that they are free from any external pathogens.

All the inputs into the hatchery such as fresh feed for broodstock, algal feed for larvae and *Artemia* nauplii for postlarvae are also disinfected before use.

Use of specific pathogen-free and specific pathogen-resistant broodstock: One of the important methods of ensuring disease-free status of broodstock is in domestication of species and development of specific pathogen-free (SPF) and specific pathogen-resistant (SPR) shrimps. The term Specific Pathogen Free (SPF) implies that facilities, operations and animals are free of the named pathogens to the limits of the diagnostic tests available. SPF designation refers to present pathogen status only, and is a function of where the shrimps are maintained (i.e. the level of biosecurity where the shrimps are cultured). SPF status is not a heritable trait. Although there are a number of commercially important traits exhibited by shrimps that are heritable, SPF status is not one of them. Offspring of SPF shrimps are not considered SPF unless they are produced and maintained at a SPF facility.

The availability of SPF and SPR stocks of *Litopenaeus vannamei* and the success of culturing them has led most of the South-east Asian countries to shift culturing of tiger shrimp to culturing of *L. vannamei*. Globally only one firm has developed SPF *P. monodon* and it is presently establishing SPF multiplication centres in Vietnam, Thailand and India. In India, Government of India, Ministry of Agriculture through the National Fisheries Development Board has entered into an agreement with M/S Moana Technologies, Hong Kong, for establishment of Multiplication Centre on Public-Private Partnership.

Development of SPR variety of shrimps is a long-term goal of SPF breeding programmes. It describes a genetic trait of a shrimp that confers some resistance against a specific pathogen. Specific Pathogen Resistant (SPR) shrimps usually result from a specific breeding programme designed to increase resistance to a particular virus. For

L. vannamei, SPR for specific strains of TSV and IHHNV are reported to have been developed, and they are available commercially.

Introduction of exotic white leg shrimp, *Litopenaeus vannamei*, has also been permitted by the Government of India through centralized quarantine with strict guidelines for seed production and culture–24 shrimp hatcheries have been permitted to import SPF broodstock and the process for issuing permits for farms is in progress. There is a need to establish multiplication centres for *L. vannamei*; following pattern carried out for *P. monodon*.

Prevention of horizontal transmission of pathogens: Stocking pathogen-free post-larvae of shrimps alone does not guarantee a disease-free culture since pathogens can still enter the culture environment and infect shrimps during culturing. Prevention of horizontal transmission of viral pathogens requires certain basic infrastructure, management of water intake, management of personnel and management of farm implements. These requirements are collectively called as 'Biosecurity' since they secure culture system from the entry of viral pathogens. For shrimp farms, 'Biosecurity' can be defined as 'the measures and methods adopted to secure a pathogen-free culture environment'. The following are the major requirements.

- Use of aged and disinfected water through chlorination in reservoir ponds for
- removal of pathogens as well as vectors.
- Physical barriers for vectors like crabs.
- Physical barriers for entry of birds, animals and unauthorized personnel.
- Strict hygiene and disinfection protocol for farm-workers and farm implements.

Studies carried out in Andhra Pradesh and Tamil Nadu indicated that most of the farms lacked biosecurity, and farmers were not aware of the necessity of such a system for preventing disease outbreaks.

Maintenance of optimal culture conditions

Adoption of the farm-level BMPs: Providing a stress-free environment to cultured shrimps will help in preventing diseases outbreak to a large extent. Stress mainly arises in cultured shrimps due to sub-optimal water quality characteristics. The factors like temperature and salinity, which have direct influence on shrimps, are due to extreme climatic conditions beyond the control of the farmers. But organic and nutrient loading, pollutants and contaminants due to various aspects of cultural practices may result severe stress to organisms and lead to disease outbreak. To prevent such an occurrence, BMPs for farms have been evolved, based on the following principles.

- Location of the farm to be decided based on the water and soil quality with special reference to their tolerable range and the presence of contaminants and pollutants.
- Farm to be designed so that water quality is maintained within optimal conditions.
- Preparation of ponds for culturing with removal of organic load and mineralization of nutrients in the soil while increasing water fertility to sustain growth of natural food through fertilization and manuring.
- Maintenance of water quality through aeration and water exchange within optimal

range with safeguard for extreme climatic conditions.

- Feed management to avoid over-feeding or under-feeding.
- Health management through continuous surveillance for pathogens and monitoring growth rate and feed uptake of shrimps.

Improving immune status of shrimps

Invertebrates, including farmed shrimps, are not equipped with cells that are analogous to antibody-producing lymphocytes in fish and warm-blooded animals. Shrimps are, therefore, apparently dependent on non-specific immune mechanisms to resist infections, and they lack some kind of specific immunological "memory" as is found in fish and warm-blooded animals. Hence it will be futile to vaccinate a shrimp against a specific disease by administration of vaccine preparations of the disease causing micro-organisms. Shrimps are dependent on non-specific immune processes for their resistance to infections. Immunostimulants which stimulate such processes and render shrimps more resistant to diseases are becoming important tools in health management of commercial shrimp farms. The Central Institute of Brackishwater Aquaculture (CIBA) has developed an immunostimulant, CIBASTIM, from heat-killed bacterial consortia and tested its efficiency in extensive field trials. Application of immunostimulant has resulted in overall improvement in survival and growth of cultured species.

Stagnation in development of brackishwater aquaculture

India has vast potential for development of brackishwater aquaculture, but the development has stagnanted at about 200,000 ha, which is hardly 16% of the total area assessed to be suitable for brackishwater aquaculture. As indicated earlier, there is stagnation in the total area developed for shrimp farming. There is need to bring more area under culture, and following policy initiatives are required.

- Reassessment of potential sites for coastal aquaculture as per the provisions of CAA Act, 2005, through remote sensing and GIS.
- Integration of Aquaculture in Coastal Zone Management Plans of the maritime states with clear zonation and provision of buffer zones as specified under the CAA Act, 2005. Master Plans for new areas should be based on the 'carrying capacity' of the source water-body.
- Land lease policies for Government owned lands should be standardized for all maritime states.
- Revenue classification is outdated and needs to be revised as per the present land use.
- Provision of infrastructure facilities is needed like road and electricity for areas identified suitable for aquaculture.
- Policy framework for considering aquaculture at a par with agriculture in the matters of credit, insurance and inputs like electricity.

Reducing risks and production cost

To ensure that all developed areas are used for brackishwater aquaculture and to

develop more areas, it is imperative that risks for losing crops are reduced and cost of production is brought down. Other than improving health management, one remedial measure that would reduce risk is species diversification. Since feed costs are 40-50% of the cost of production, any intervention to reduce feed costs would make an impact on the profitability of the brackishwater aquaculture.

Species diversification

Scientific brackishwater aquaculture in India is synonymous with monoculture of tiger shrimp, *P. monodon*. In comparison, China has more than 40 species under aquaculture in coastal farms. Dependence on a single species is very risky especially when it is totally dependent on export market. Unfortunately, shrimp farming sector in the country is facing with such a situation at present, and there is a serious drop in area under culture as well as total production. The only way this can be remedied is by diversifying with other species of shell-fishes and finfishes.

In India, culture of mud-crabs and seabass are two alternatives available for brackishwater aquaculture. The CIBA has developed technologies for breeding, nursery rearing and culture of mud-crabs as well as seabass. Owing to seed production technologies perfected by the CIBA, it is possible to produce seabass seed throughout the year. Frontline demonstrations on seabass nursery and grow-out are underway in three states. Culture technologies are also available for Indian white shrimp, *Fenneropenaeus indicus*, Banana shrimp, *F. merguiensis* and Kuruma shrimp, *Marsupenaeus japonicus*. In the CIBA, serious efforts are underway for development of breeding and culture technologies for mullets, and a National Agriculture Innovation Project with Fisheries college, Tuticorin, CIBA, and Central Marine Fisheries Research Institute (CMFRI) is for seed production of cobia. Since seed and feed are major inputs for any culture, research efforts are required in breeding, hatchery technologies and development of feed for other species of fishes.

Reducing feed input cost

Cost of feed is linked to use of fish-meal and other ingredients; cost of which is increasing year after year. Substituting with less costly and locally more abundantly available ingredients is guaranteed approach to cut-down feed costs. Increasing natural productivity of ponds and directing into shrimp growth and more controlled feed management is also an approach worth exploring. Using a combination of both the approaches, the CIBA has been able to develop a low-input low-cost shrimp culture technology with a production target of 1.3 tonnes/ha/crop at a stocking density of 6 nos/m^2.

Overcrowding of small farms

In India, brackishwater aquaculture sector consists of more than 90% of farmers under the category small; owning less than 2 ha of water area. Unregulated development during the initial stages has led to overcrowding of shrimp farms in areas where infrastructure facilities like roads and electricity were available. This has resulted in many small farms depending on a single creek or canal for both intake as well as outlet. And the small farmers are at an economic disadvantage for implementing Better Management Practices and other mandatory requirements for food-safety and environment safety.

To deal with this situation, farmers in certain areas of Tamil Nadu have formed strong associations of either political or social groupings, and practices followed by constituent farmers are strictly controlled, especially in seed procurement and water management. The success of these associations in raising disease-free cultures led to formation of 'Aqua clubs' by Andhra Pradesh government, and later the 'Societies' concept was developed by the NACA-MPEDA programme. The National Centre for Sustainable Aquaculture (NaCSA), under the aegis of the MPEDA, provides assistance for these societies in the formation and adoption of BMPs under the cluster-based management. Many south-east Asian countries are adopting Indian model for assisting small-scale farmers in getting collective bargaining power for various inputs and accessing markets. This group approach will also help in implementing biosecurity requirements for disease prevention and mandatory requirements like common waste-water treatment systems.

Dependence on export market

Shrimp farming in India is dependent on the export market. Hence the sector is seriously influenced by global demand and supply. During the last few years, cost of *P. monodon* has come down in the world market due to large-scale production and supply of *L. vannamei* by the South-east Asian countries. Further, in the WTO regime, non-tariff barriers like anti-dumping duty, countervailing duties and sanitary and phyto-sanitary (SPS) measures have been introduced by importing countries, which also have led to reduced profit margin to producers. The problem is confounded by rejection of shrimp exports due to antibiotic-residues detected in the consignments.

Since the sector is dependent on the global market, it is essential that product competitiveness is improved as per requirements of consumers. Specific measures to increase competitiveness of Indian farmed shrimps and brackishwater aquaculture in general is outlined as follows.

Certification

There is a general concern among consumers that shrimp culture is environmentally unsustainable, socially inequitable, and that products are not safe. As of now, food-safety issues are addressed at the shrimp processing level, with the mandatory application of the HACCP. The concern has now shifted to producers, and to secure better market access, there is an increasing interest in certification of aquaculture production systems, practices, processes and products.

The American and European markets increasingly recognize that some form of certification is a way of assuring buyers, retailers and consumers that aquaculture products are safe to consume and that products have originated from aquaculture farms that have adopted responsible management practices. A number of private certifying schemes with specific standards are already available and in some countries, state sponsored schemes are in place to improve product competitiveness. In most of these cases, the certification schemes are still voluntary and involve an investment for producer. Hence in India, where more than 90% of farmers are with small farms of less than 2 ha, there are no takers for these schemes. The only issue at this point is these certifications and traceability issues might become mandatory in a few years time. It is essential that Government of India and other regulatory agencies involved in shrimp farming should plan ahead and introduce a subsidized certification scheme that is globally acceptable.

Antibiotic-free shrimp

To address issue of rejection of shrimp exports due to antibiotic-residues detected in consignments, there is a need to create greater awareness among farmers, and BMPs presently being adopted for health management need to be expanded to address food safety concerns. This would also benefit domestic consumers. Regulatory measures also need to be in place to ensure that all inputs used in brackishwater aquaculture like the various chemicals and feeds are free of antibiotics.

Organic farming

Organic farming is another way of adding value to produce. This is also another form of certification scheme where standards specify use of organically produced inputs and maintenance of welfare of animals with minimal disturbance to ecological conditions of the farming area. Though organic agricultural products are already being produced and marketed, organic farming is in a very formative stage in aquaculture. The major issues in the organic standards for shrimp especially tiger shrimp are as follows.

- Induction of maturity is through eyestalk ablation, which involved mutilation
- Non-availability of domesticated SPF broodstock
- The upper limit of production level specified is too low
- The fish meal component in feed should be from a sustainable source

In India, under the initiative of the MPEDA, organic certification for scampi, *Macrobrachium rosenbergii,* culturing as per the standards of Naturland has already been done as a group activity, which fetches a premium of 20% on the sale price for producers. Traditional shrimp farming in West Bengal and Kerala, which does not use any inputs could be easily taken up for organic certification. The CIBA has identified that use of wild seed in the traditional farms of West Bengal and use of non-organic feed are the major impediments to certify these traditional farms as organic. Efforts are underway in the Kakdwip Centre of the CIBA to develop organic farming practices. Presently Agriculture Products Export Development Authority (APEDA) is developing guidelines for certifying organic shrimp, and once these are accepted by other countries, then cost of organic certification would be reduced.

Development of domestic market

The drastic reduction of area under shrimp farming during the last two years has been mainly due to fall in global shrimp prices and the resultant low profit margin. There is an urgent need to develop domestic market for shrimps and to popularize products for domestic consumption for sustainable development of the sector. The National Fisheries Development Board has taken some initiatives in this regard. Some of the private entrepreneurs are also working for establishment of sale outlets and also contract farming of Indian white shrimp, *Fenneropenaeus indicus*. With the introduction of *L. vannamei* culture in the country, the need for domestic marketing channels for smaller sized shrimps is all the more important.

Shrimp farming was a low-risk, high-profit commercial venture in the early nineties, and after 1995 due to viral disease outbreaks, it became high-risk, high-profit enterprise. During the recent years, after 2006, the global prices of shrimps have come down and the cost of inputs used in culture like feed, chemicals and electricity have gone up, resulting it a high-risk, low-profit farming,and that eventually discourages farmers to continue shrimp farming. The following remedial measures should be implemented at the earliest to safeguard livelihood options of brackishwater aquaculture farmers.

- The technology developed by the CIBA on low-input, low-cost shrimp farming with organic inputs should be popularized, which will eventually lead to economic sustainability of the sector.
- Diversification of systems and species of culture like seabass and mud-crab should be popularized under Centrally Sponsored Schemes.
- Culture of exotic shrimp, *L. vannamei,* should be strictly monitored and illegal culture of non-SPF seed from pond reared broodstock should be prevented.
- A cost-effective National Certification Scheme as per global standards should be put in place and traceability should be established for all aquaculture products meant for export market. Provision should be made for cluster certification.
- Though strict regulations are available under CAA Act, 2005, it is essential that farmers should be made aware of the food-safety and environment-safety requirements and the necessary precautions should be undertaken by the farmers voluntarily.
- Domestic market should be established for shrimps and the linkage between the farmer and the market should decide the practices to be adopted by the farmer. There is a need for continuous supply of the materials to the market, and accordingly research should be addressed for the development of culture practices with multiple staggered stocking with continuous harvest in a cluster-based approach.

25. Mariculture

Mariculture is rearing of aquatic organism under controlled or semi-controlled conditions in the coastal and offshore waters; in which salinity is maximal and not subjected to significant daily or seasonal variations. Apart from the contribution in production of protein-rich food, mariculture has been livelihood source for several coastal villagers. Global production from marine environment steadily increased over years, and during 1999 to 2007, it increased from 21.6 million tonnes to 31.3 million tonnes. In 2007, mariculture contributed to 87.3% of global total production from marine water and brackishwater environment (Table 25.1). Concurrently, production from Asia also followed similar trend, increased from 19.0 to 27.9 million tonnes; contributed to more than 89.2 % of the global marine production.

Table 25.1. Global production (in tonnes) of aquatic resources from marine and brackishwater environments and percentage contribution of Asia in mariculture

	2003	2004	2005	2006	2007
Global production					
Global MAR total	25,379,270.9	27,361,550.5	28,661,586.7	29,944,849.7	31,327,385.8
Global BW total	2,885,742	3,177,707	3,571,891	4,092,098	4,574,334
Global BW and MAR	28,265,012.9	30,539,257.5	32,233,477.7	34,036,947.7	35,901,719.8
% contribution of MAR to total	89.8	89.6	88.9	88.0	87.3
Asia production					
Asia MAR	22,552,991	24,369,546	25,718,603	26,683,490	27,946,536.1
Asia BW alone	2,237,380	2,486,998	2,755,736	3,267,721	3,646,056
Asia (BW + MAR) total	24,790,371	26,856,544	28,474,339	29,951,211	31,592,592.1
% contribution of MAR to total	91.0	90.7	90.3	89.1	88.5
% contribution (BW + MAR) to total	87.7	87.9	88.3	88.0	88.0
% contribution Asia MAR	88.9	89.1	89.7	89.1	89.2
% contribution Asia BW alone	77.5	78.3	77.2	79.9	79.7

*BW, Brackishwater; MAR, Mariculture.
Source: FAO, 2008.

Nearly 15 countries in Asia have mariculture programmes, and among these, China is the major producer, contributing to 71.35 % of the continents' total production, followed by Philippines (6.19%), Republic of Korea (5.85%) and Japan (4.34) (Table 25.2). China's mariculture production has been valued at 15,679,917 thousand US dollars; 66.98% of the total value estimated for the continent, followed by Japan (16.39%) and Republic of Korea (7.3%).

Since the last decade considerable changes have taken place in diversification and production of mariculture in India; most significant is the emergence of oyster and mussel farming as a commercial aquaculture programme, and the production estimate in 2007 was 10,044 tonnes, which was more than the production from several other Asian countries. However this has not been included in the FAO list. Apart from increased production, India has several new technological developments like tissue culture of marine pearls, hatchery techniques for lobsters and ornamental fishes that have potential to make an impact on the country's economic development.

Table 25.2(a). Value (in '000 US dollars) and mariculture production (in tonnes) from Asian countries in 2007

Countries	Production in tonnes	%	Countries	Value in '000 US dollars	%
China	19,442,606	71.35	China	15,679,917	66.98
Philippines	1,687,578	6.19	Japan	3,836,350	16.39
Korea, Republic of	1,592,885	5.85	Korea, Republic of	1,707,947	7.30
Japan	1,183,950	4.34	Turkey	400,743.8	1.71
Cambodia	995,510	3.65	Indonesia	371,031.5	1.58
Korea, DPR	535,513	1.97	Korea, DPR	283,365	1.21
United Arab Emirates	404,700	1.49	Philippines	262,528.1	1.12
Bahrain	374,154	1.37	Myanmar	193,212	0.83
Turkey	319,600	1.17	Vietnam	189,500	0.81
Kuwait	309,124	1.13	Saudi Arabia	174,472	0.75
Thailand	104,102	0.38	Taiwan Province of China	140,249.1	0.60
Malaysia	83,187	0.31	Thailand	61,800.8	0.26
Oman	78,303	0.29	Malaysia	27,864.4	0.12
Myanmar	48,303	0.18	Israel	24,886.7	0.11
Taiwan Province of China	34,942	0.13	Cyprus	20,202.9	0.09
Israel	16,256	0.06	China, Hong Kong SAR	16,835.2	0.07
Saudi Arabia	14,545	0.05	Singapore	8,017.1	0.03
China, Hong Kong SAR	8,112	0.03	Cambodia	4,650	0.02
Indonesia	6,987	0.03	United Arab Emirates	4,332	0.02
Vietnam	4,078	0.01	Oman	608	0.00
Singapore	2,847	0.01	Kuwait	330	0.00
Cyprus	2,418	0.01	Pakistan	128.8	0.00
Pakistan	92	0.00	Bahrain	4.5	0.00
Qatar	0	0.00	India	0	0.00
India	0	0.00	Qatar	0	0.00

Table 25.2 (b) Production of farmed oysters and mussels in India

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Mussel	800	1,000	1,250	2,000	3,250	4,500	10,060	7,894	16,789
Oyster	150	250	350	800	800	900	1,500	2,150	2,400
Total	950	1,250	1,600	2,800	4,050	5,400	11,560	10,044	19,189

Mariculture technologies are specific to marine resource, which is farmed, and the design and structure of the grow-out system is largely based on the topographic features of the growing environment. Farm structures like rafts, long-lines, racks and cages are grow-out structures used in mariculture while different types of re-circulatory and raceway systems have been developed for land-based mariculture. General designs

are modified considering behavioural pattern and biological requirement of the species farmed. Molluscs, seaweeds, crustaceans and finfishes are major groups that are farmed in the marine environment. A brief description of the resources farmed globally and in Asia in each of the category are presented, followed by status of mariculture in India.

Farming of molluscs

Molluscs characterized by their sedentary mode of life and high nutritive profile have been farmed since many centuries. Oysters, clams, mussels and scallops are major groups of farmed bivalves. Apart from these, marine pearl oysters are also farmed for gems they produce, the lustrous pearls and mother-of-pearl (pearl oyster shell). Global production of edible molluscs has been estimated at 11.88 million tonnes (Table 25.3) with oysters contributing most, followed by clams, mussels and scallops. Molluscs production in the Asian continent witnessed phenomenal increase during the second half of the last century – from 22.75% in 1950 to 90.67 in 2007 (Table 25.4).

Table 25. 3. Global production(in tonnes) of different groups of molluscs during the year 2007

Oyster	4,397,468
Clam	4,114,690
Mussel	1,622,678
Scallop	1,463,235
Cephalopod	27
Gastropod	290,145
Total	11,888,243

Source: FAO,2009

Nearly ten countries in Asia (Table 25.5) are farming molluscs, and there has been substantial increase in the production from these nations during the last two decades. Production from China was estimated at 9.3 million tonnes in 2007. In 1984, though

Table 25.4. Percentage contribution of mollusc production in Asia to that of global production

	1950	1960	1970	1980	1990	2000	2007
Oyster	22.75	60.84	64.22	76.15	81.09	93.50	93.30
Scallop	0.00	0.00	100.00	99.51	99.48	97.97	97.40
Mussel	23.98	19.60	22.83	27.75	53.82	48.64	52.30
Clam	100.00	100.00	100.00	100.00	94.67	96.36	99.00
Cephalopod	0.00	0.00	100.00	0.00	0.00	0.00	0.00
Gastropod	0.00	0.00	100.00	100.00	57.97	76.06	99.40

Table 25.5. Total mollusc production (in tonnes) in different Asian countries

Country	Total in 1984	% contibuted by countries	Total in 2007	%
China	565,530	41.2	9,323,988	86.81
India	0	0.0	0	0.00
Japan	331,612	24.2	451,700	4.21
Korea, Republic of	280,786	20.5	474,554	4.42
Malaysia	63,583	4.6	54,518	0.51
Philippines	34,923	2.5	40,622	0.38
Singapore	526	0.0	1,861	0.02
Taiwan Province of China	50,231	3.7	29,841	0.28
Thailand	45,188	3.3	362,800	3.38
Turkey	0	0.0	1,100	0.01
Total	1,372,379		10,740,984	

China topped Asian countries, its contribution was only 41.2 %, followed by Japan (24.2%) and Korea (20.5%); by 2007, though production from all nations increased (except Malaysia and Taiwan), their contribution share to total production in Asia decreased drastically primarily due to augmented production from China. Based on the production figures of India during 2007 and comparing it with other Asian countries, it can be said that India ranks 7th among Asian countries in molluscs production.

Oyster farming

Oysters are one of the most valued seafood and are farmed extensively. Nearly eleven species of oysters are commercially popular (Table 25.6), and of these *Crassostrea gigas* is the most important one. In Asia, during 2007, 4.1 million tonnes of oysters were produced of which 3.5 million tonnes were from China contributing to 86% of the continent's oyster production (Table 25.7). Korea and Malaysia also produce significant quantities of oysters.

Table 25.6. Common and scientific names of commercially important oysters farmed in different parts of the world

Common name of oysters	Scientific name of oysters
American cupped oyster	*Crassostrea virginica*
Chilean flat oyster	*Ostrea chilensis*
Cortez oyster	*Crassostrea corteziensis*
European flat oyster	*Ostrea edulis*
Gasar cupped oyster	*Crassostrea gasar*
Hooded oyster	*Saccostrea cucullata*
Indian backwater oyster*	*Crassostrea madrasensis*
Mangrove cupped oyster	*Crassostrea rhizophorae*
Olympia flat oyster	*Ostrea conchaphila*
Pacific cupped oyster*	*Crassostrea gigas*
Slipper cupped oyster*	*Crassostrea iredalei*
Sydney cupped oyster	*Saccostrea commercialis*

*Resources farmed in Asia

Table 25.7. Total oyster production (in tonnes) in different Asian countries

Country	1984 Production	1984 % contribution	2007 Production	2007 % contribution
China	249,180	33	3,509,989	86
India	0	0	0	0
Japan	257,126	34	201,200	5
Korea, Republic of	203,312	27	321,276	8
Malaysia	0	0	863	0
Philippines	14,617	2	20,508	0
Singapore			9	0
Taiwan Province of China	29,012	4	28,199	1
Thailand	4,851	1	21,800	1
Turkey	0	0	0	0
Total	758,098		4,103,844	

In India, commercial production of the oysters started during late nineties, and increased to 2,400 tonnes in 2008. This figure is not recorded in the FAO data, and it can be seen that our country's production was higher than most of the Asian countries.

Oyster farming in India

Oyster resources: In India, available main oyster species are *Crassostrea madrasensis, C.gryphoides, C.rivularis* and *Saccostrea cucullata*, and of these, *C.madrasensis*, commonly known as the Indian backwater oyster, is the most preferred one for farming.

Site selection: Open-sea and estuarine areas, where salinity does not drop below 15 ppt, are suitable for oyster farming. To ensure maximum production, selected site should be biologically suitable for the species. Farm structures should not cause hindrance to navigation and fishing. The main aspects which should be looked into before fixing the site are as follows: open seas free from strong wave action; salinity range of 15-32 ppt; high plankton production; moderate water current; *p*H above 7 and less than 8.5; low silt load; dissolved oxygen > 3.5 ml/litre; market for selling produce should be nearby; avoid sites prone to toxic algal blooms; and site be away from industrial pollution and domestic sewage discharge points.

Farm structures: Three types of farm structures – racks, longlines and rafts can be used as farm structures; and depending on the depth at the site and the nature of the site like calm or rough sea, farm-structure type is decided. Racks are suitable for estuaries and shallow seas and these are constructed using bamboo or casuarina poles. These poles are driven into bottom, 1-2 m apart and are connected horizontally with poles. The horizontal poles should be above the level of water at high tide. Longlines made of synthetic rope of 16-20 mm diameter as the main line or rafts made of wood are good for deeper areas. These are supported by floats, and anchored in position at the either ends using concrete blocks or anchors (grapnel, granite, concrete).

In India, rack and ren is popular and farmers construct racks using bamboo or casuarina poles in shallow intertidal areas at depth < 4 m. Oyster seed for farming is collected from natural beds by placing empty oyster shells strung on 3-mm diameter nylon-rope with a spacing of 15 to 20 cm between each shell (5 shells per metre of rope) in the water column during spawning period. For large scale or commercial seed collection purposes, shells are strung continuously without spacers (10 to 15 shells per metre) and after attachment of seed, shells are removed and restrung at 5 shells per metre; ideal density for grow-out. If oysters are grown in trays then empty shells or lime-coated tiles can be placed in trays for seed collection.

The new concept of 'Remote setting' whereby pediveliger larvae of the edible oyster are transported in dry, moist and cool condition and made to set on shell clutches at a distant place has been tried by the Central Marine Fisheries Research Institute (CMFRI). During 2004-05, such spat on shells was strung and given to farmers to help them to overcome drawback of low spat fall. Oysters can be cultured in clusters or as a single oyster. The seed collection method differs for these methods. If planned for a single oyster culture, then trays are used as containers. These trays can be suspended from grow-out structures.

Nursery culture: In oyster farming, nursery rearing of spat is relevant only when seed is procured from hatchery. For nursery rearing, relatively calm waters with adequate flow to bring phytoplankton are preferred. Oyster spat is enclosed in velon-screen bags of suitable mesh and suspended from racks. Strings 3 or 4, each with six shell-valves containing 80-100 spat, are enclosed in a bag.

In the rack and ren method of farming, spat collected using oyster shell string (ren) is allowed to grow at the same site while in the tray method, spat collected on shells is kept in the trays of 40 cm ×40 cm × 10 cm at a density of 150 to 200 oysterlings/ tray, which are later transferred to a rectangular tray of 90 cm × 60 cm × 15 cm at a stocking density of 150 to 200 oysters. Average growth rate of the oyster is 7 mm/month, and at the end of 12 months, oysters attain an average length of 85 mm. Production estimates by ren method are at 4.25 tonnes/300 m^2/year and by tray method are at 120 tonnes/ ha/year; compared to ren method, production cost is high for tray method.

Technology adoption: Oyster farming development as a small-scale industry has led to employment generation in coastal villages. Self-employment of villagers as owners of aqua-farms and as part-time workers in activities related to seed collection, seeding, meat shucking and marketing have led to economic empowerment of villagers, especially women. On an average it benefitted more than 500 families.

Production: Average production from a commercial farm has been estimated at 2.5 tonnes from 500 rens. The Brackishwater Fish Farmers Development Agency (BFFDA) provides grants or subsidies of ₹1,500 per farmer for stocking 500 rens. Usually three members of a Self Help Group (SHG) join together and a farm is constructed. The production details of commercial farm in Kayamkulam estuary in Kerala are in Table 25.8.

Table 25.8. Production details of commercial farm in Kayamkulam estuary in Kerala

Number of rens per farm	Average 1,500
Farm particulars	One unit 6 m × 4 m (3 nos) constructed by utilizing the amount given for 3 members, i.e.₹1,500×3 =₹4,500; No.of rens 500×3 = 1,500
Production per ren	Average 5 kg/ren; Total production per farm = 5 kg×1,500 rens= 7,500 kg; Heat shucked meat weight = 8 % of 7,500 = 600 kg; Amount (₹) from sale of 600 kg of meat @ ₹ 60/ kg of shucked meat = 900 x 40 = ₹ 36,000 per farm
Income from farm per family /unit	₹ 6,000 to ₹ 12,000, depending on the stocking in the farm

Oysters, which were previously marketed in fresh condition in the nearby local markets, are now converted into value-added products and canned oysters are sold in domestic urban markets. Socio-economic evaluation showed that farmers utilized profit for meeting various family commitments. Income has been found to range from ₹ 700

to ₹25,000 per annum per farmer depending on the farm stocking; 78% farmers utilized money for repayment of financial liabilities while 12% invested on improving their living conditions, and 10% used money for daily household expenditure during lean fishing season.

Economics: The most popular method of oyster farming is the rack and ren method, where seed is collected from natural beds. Economics of oyster farming is given in Table 25.9.

Table 25.9 Economics of edible oyster culture by rack and ren method in 300 m^2 (30 m × 10 m) of unit

	₹
I. Material cost	
(a) **Poles**	
1. Horizontal poles (6 m) 33 Nos. @ ₹ 80/pole	2,640
2. Vertical poles (3 m) 126 Nos. @₹ 40/pole	5,040
Total	7,680
(b) **Nylon ropes and oyster rens**	
1. Nylon rope for rens and racks:15 kg @ ₹ 120/kg	1,800
2. Cost of 6,360 shells @ ₹ 0.10 for making 1,060 strings including cleaning charges	636
	2,436
Total (a+b)	10,116
II. Fixed cost	
1. 50% depreciation on ₹ 7,680(item No.I (a)	3,840
2. Interest @ 18% on initial investment of ₹ 10,116(Item No.I)	1,820
Total	5,660
III. Labour cost and other charges	
1. Fabrication of oyster rens (1060) @ ₹ 0.65	690
2. Fabrication of racks	300
3. Harvest	750
4. Depuration @ ₹ 250/tonne	1,075
5. Heat shucking including fuel cost @ ₹ 15/ kg (240 kg)	5,100
Total	7,915
IV. Total cost(II + III) (5,660 +7,915)	13,575
V. Expected production:shell-on oysters	4.25 tonnes
1. Wet meat weight (10% of total weight)	425 kg
2. Heat shucked meat (8.5 of total weight)	340 kg
3. Shell alone	3.4 tonnes
VI. Revenue	
1. Heat shucked meat @ ₹ 60/kg (340 kg)	20,400
2. Value of shell @ ₹ 400/tonne	1,360
VII. Total revenue	21,760
VIII. Net profit (VII-IV) 21,760 – 13,575	8,185

Prospects: Oyster farming can be very easily taken up in the coastal regions of Indian maritime states and in the Island systems, provided hydrological conditions meet requirement of mussels. Among maritime states, Kerala has well established commercial farms and there are more than 3,000 villagers directly earning additional income every year through oyster farming. There is a good potential for developing mariculture activity in other states like Karnataka, Goa, Maharashtra, Tamil Nadu, Puducherry and Andhra Pradesh.

In Kerala, training programmes on oyster farming are conducted from time to time by the CMFRI, State fisheries departments and Krishi Vigyan Kendras (KVKs).

Financial support for oyster farming is given to villagers. Schemes like SJRY (Swarna Jayanthi Rozgar Yojana) support such programmes. Rural Development Banks, BFFDA (Brackishwater Fish Farmers Development Agency), ADAK (Aquaculture Development Agency for Kerala) also provide financial support for oyster farming. Project proposals as per the proforma given by the agency should be submitted at least 3 to 4 months before the commencement of farming operations.

Mussel farming

This is one of the most popular mariculture operations in temperate countries. Global farmed mussel production was estimated at 16.22 lakh tonnes in 2007, registering increase of 22.8 times over 1950 with contribution from 40 nations farming nearly 9 different species belonging to genera *Perna* and *Mytilus* (Table 25.10) and a few others showing byssus formation. High market price and consumer demand together with efficient post-harvest development have catalyzed growth of this industry.

Table 25.10. Common and scientific names of commercially important mussels farmed in different parts of the world

Common name of mussels	Scientific name of mussels
Australian mussel	*Mytilus planulatus*
Blue mussel	*Mytilus edulis*
Chilean mussel	*Mytilus chilensis*
Cholga mussel	*Aulacomya ater*
Choro mussel	*Choromytilus chorus*
Green mussel*	*Perna viridis*
Horse mussel*	*Modiolus* spp.
Korean mussel*	*Mytilus coruscus*
Mediterranean mussel*	*Mytilus galloprovincialis*
New Zealand mussel	*Perna canaliculus*
River Plata mussel	*Mytilus platensis*
South American rock mussel	*Perna perna*

*Resources farmed in Asia

Mussel production increased considerably from Asia during the last two decades– from 2.1 million tonnes in 1984 to 8.48 million tonnes in 2007 (Table 25.11) and the number of countries involved in mussel farming increased from 5 to 8. China being the major producer of mussels contributed 52.9% in 2007 of the total mussel production. Thailand (275,000 tonnes) and Republic of Korea (98,121 tonnes) were other major producers. Mussel production from India was 16,789 tonnes in 2008, and this has not been reflected in the FAO data.

Apart from being rich in proteins and vitamins, mussels have several medicinal properties. Green-lipped mussel is taken as a food supplement in over 20 countries, mainly to help maintain mobility of different body joints. Mussels have anti-inflammatory, anti-histamine, prophylactic and therapeutic properties and currently research is being carried out for developing an effective low-cost anti-AIDS drug from mussel-meat.

Table 25.11. Total mussel production (in tonnes) in different Asian countries

Country	1984 Production	1984 % contribution	2007 Production	2007 % contribution
China	136,582	64.6	448,667	52.9
India	-	0.0	0	0.0
Japan	0	0.0	0	0.0
Korea, Republic of	26,041	12.3	98,121	11.6
Malaysia	0	0.0	4,035	0.5
Philippines	20,306	9.6	20,114	2.4
Singapore	526	0.2	1,852	0.2
Taiwan Province of China	0		0	0.0
Thailand	27,825	13.2	275,000	32.4
Turkey	-	0.0	1,100	0.1
Total	211,280		848,889	

Mussel farming in India

Marine mussel farming technology developed by the CMFRI is very simple, eco-friendly and easy to adopt. Raw materials are available in the villages; no supplementary feeds are required. Only site selection, materials used for farm structure and quality of seed will contribute towards its success. During the last decade, mussel farming has emerged as a popular mariculture culture activity, next to shrimp culture in the coastal villages of Kerala. The success of mussel farming is evident from the fact that farm production which was about 20 tonnes in 1996 has increased to 16,789 tonnes in 2008. During 2007, India with a mussel production of 7,894 tonnes ranked 5 th among the Asian countries.

Mussel resources: In India, two species of marine mussels, green mussel *Perna viridis* and brown mussel, *P. indica* are distributed in rocky coastal areas and of these,green mussel is extensively farmed along the south-west coast, especially Kerala.

Site selection: In addition to meeting optimal ranges of hydrographic parameters suitable for physiological and biological processes of the candidate species, water quality of the site with respect to biotoxin, microbial load and trace metal is important. Considering consumer safety, most nations have identified water quality criterion required for bivalve farming. Guidelines set by European Union, one of the major markets of farmed bivalves, regarding water quality of farm site has to be strictly adhered for export market (Table 25.12). Exports to European and US markets require certification on the level of bacterial contamination, biotoxins and trace metals in the mussel-meat as well as in the growing areas.

Farming technology: The technique for farming uses property of mussels to adhere to the solid substratum using its byssus.

Mussel seeding: The core material used for seeding is coir-rope, nylon-rope and flexible-plastic strip. Bristled ropes increase holding capacity of seeds, as they attach better. Old fish-net twisted like a rope or plastic tapes or flexible-plastic strips of 5.5 cm width are equally good for seeding and growing mussels. Mussel seed is collected from intertidal/subtidal beds during low tide. Ideal size of seed is 15-25 mm. About 500-1,000 g of seed is required for seeding 1m length of rope. Rope length is decided considering

Table 25.12. European Union standards to be met for export of mussel products

Parameters in farm site	Mandatory level
Colour	>1 mg Pt/litre
Temperature	± 2°C from normal sea temp.
*p*H	7-9
Salinity	12-48 ppt
Dissolved oxygen (saturation)	>80%
Suspended solids mg/litre	30%
Petroleum hydrocarbon	Should not be deposited in the flesh
Organo-halogenated substances	Should not exceed harmful levels in shellfish and larvae
Bacteriological parameters: Maximum permissible limit (Nos/100 ml)	
Faecal coliforms	< 300 in the shellfish flesh and intervalvular liquid
Heavy metals in tissue: Maximum permissible residual level (ppm)	
Mercury	1.0
Cadmium	3.0
Arsenic	75
Lead	1.5
Tin	250
Nickel	80
Chromium	12
Pesticides in tissue : Maximum permissible residual level (ppm)	
BHC	0.3
Aldrin	0.3
Dieldrin	0.3
Endrin	0.3
DDT	5.0
Antibiotics and other pharmacologically active substances in tissue: Maximum permissible residual level (ppm)	
Tetracycline	0.1
Oxytetracycline	0.1
Trimethoprim	0.05
Oxolinic acid	0.3

depth where raft/rack is positioned. The process of wrapping mussel seed around a core (usually a rope) with the help of a biodegradable netting material is termed as mussel seeding. The netting material around the seed disintegrates within a week. The mussel seed will secrete byssus threads and will attach itself to rope within this period.

Pre-stitched tubes: To reduce labour charges and physical stress, biodegradable wrapping material can be pre-stitched into tubes of 20 to 25 cm width and 1.25 m length. By this method, manpower can be almost halved (from 8 to 4 man-days for seeding 100 ropes). It also helps in uniform distribution of mussel seed around the core material.

Mussel-seeding device: A semi-automated mussel-seeding device that can be easily operated by two people has been designed and fabricated by the CMFRI.

Management: Management of mussel farms is essential to avoid loss of farm stock and to make maximum profit. Periodic inspection of farm structure and crop should be done and maintenance work should be attended on time. The main points which have to be checked during the culture period are as follows.

- Farm structure - replacement of broken wooden poles
- Floatation systems - replacement of leaking floats or placing additional floats to increase bouncy to support crop weight

- Mooring systems - checking anchors and placing them in right position if displaced from original position due to swells and currents in the sea
- Mussel ropes- If mussels come out as clusters, provide an external support to mussel-rope either by winding a nylon-rope (3 mm dia) or by covering rope with a wide-meshed old fish-net.

Mussels production: Mussels are farmed for 4 to 8 months, depending on the growth of the mussels. Under open-sea conditions, mussels reach harvestable size in 3 to 4 months while in estuarine conditions, growth may be marginally slower. Farmed mussels are harvested manually by lifting ropes from water; these are washed and then de-clumped or stripped from ropes. The CMFRI has developed a declumping unit lately which can be operated very easily. This will reduce physical labour for separating mussels attached to rope. The de-clumped mussels are kept for depuration. Purification processes by which mussels are rendered free of harmful materials is called depuration. Depuration can be done simply by starving bivalves in clean and filtered sea-water/ brackishwater for a certain period of time. More effective depuration can be made by using disinfected sea-water. Mussels are transported in the shell-on condition, and will remain fresh for nearly 24 to 30 hours if kept in a cool place.

Marketing: Mussels are normally marketed shell-on. The process of removing meat from the shell is called shucking. Live-mussels can be shucked using stainless steel knives and by inserting it at a point where byssal threads come out. Byssus threads remnants, if any, should be removed (de-bearding) before marketing of the meat. Shucking can be easily done by gently heating to open shell valves.

Technology adoption in India: Mussels attain 80-90 mm size within 5 months with an average weight of 36-40 g. An average mussel production of 12 kg can be expected from one-metre length of seeded rope. Among maritime states, Kerala was the first to recognize advantages of mussel farming technology in rural development. In 1996, the state extended financial support for mussel farming through the DWCRA (Development of Women and Children in Rural Areas) as a component of the IRDP (Integrated Rural Development Programme). Selection of women-beneficiaries was carried out and they were grouped into self help groups (SHGs each of 10-15 members) and were given financial aid @ ₹ 8,800 per member with 50% subsidy. The loan period was 5 years with an interest of 12.5% per annum. Apart from this, they were provided with a revolving fund of ₹ 5,000 with no interest.

Nearly 1,800 families have started mussel farming in Kerala, Karnataka and Maharashtra, and approximately 5,500 families have benefited through ancillary job opportunities like seed collection and marketing with an earning of ₹ 150 to ₹ 200 per day during seeding and harvesting season. Presently, financial support to farmers in Kerala is through Aquaculture Development Agencies, Gramin banks and Panchayat schemes like DWCRA; in Maharashtra it is through developmental funds of local bodies and in Karnataka, it is through BFFDA.

Economics: Minimum investment for mussel farming in an estuary is ₹ 10,000 and in the open-sea is ₹ 26,000. In shallow areas, in a wooden rack of 5 m×5 m (0.0025ha), 100 seeded ropes (of length 1m) can be stocked. The capital cost for bamboo and core material is ₹ 3,700, and recurring expenditure including cost of seed and labour charges for seeding, constructing farm and harvesting will be ₹ 5,600 (Total= ₹ 9,300). The yield will be 850 kg and the income from sale of shell-on mussel will be ₹ 8,800; giving a net income of ₹ 3200 in 6 months. In most instances, labour charges are for the farmers themselves. In North Kerala, the profit is higher than this because of very high production rates. In an open-sea raft, farm capital cost will be ₹ 11,000 and recurring cost will be ₹ 15,000 (total ₹ 26,000). The yield will be 2 tonnes; giving a total income of ₹ 24,000, providing a net income of ₹ 9,000 in 5 months (Table 25.13).

Table 25.13. Economics of mussel farming by rack and rope method

	Amount (in ₹)
I. Expenditure	
A Fixed capital	
1. Horizontal poles of 6 m long,100 nos @ ₹120	12,000
2. Vertical poles of 3 m long, 100 nos@ ₹ 60	6,000
3. Rope for seeding 150 kg @ 120	18,000
Sub-total	36,000
B Variable cost	
1. Rope for rack construction,6 kg @ ₹120	720
2. Cotton netting material 300 m @ ₹20	6,000
3. Cost of mussel seed 24,00 kg@ ₹6	14,400
4. Canoe hiring charge 30 trip @ ₹100	3,000
5. Labour for seeding, rack fabrication 120 mandays @ ₹150	18,000
6. Minor items like buckets,bins,needles etc	2,000
7. Marketing expenses	6,000
8. Transportation charge	6,880
Sub-total	57,000
C Total cost	
1. Variable cost	57,000
2. Depreciation on fixed capital @ 50% /year	18,000
3. Interest on fixed capital @ 15%	5,400
Grand total	80,400
II. Gross income (Expected production 10 tonnes)	
1. Sale of shell on mussel @ ₹ 10/kg	100,000
III. Net income (gross income – total cost)	29,600

Prospects: Mussel farming can be very easily taken up in coastal regions of Indian maritime states and in the Island systems provided hydrological conditions meet requirement of mussels. Among maritime states, Kerala has well established commercial farms and there are more than 5,000 villagers directly involved with mussel farming. There is a good potential for developing this activity in Karnataka, Goa, Maharashtra, Tamil Nadu, Puducherry and Andhra Pradesh.

Training and financing for mussel farming is taken care of as in oyster farming.

Social impact: To assess impact of mussel farming in North Kerala, a study conducted during 2005-06 indicated several ancillary industries related to mussel farming. During 2005-06, approximately 1,799 tonnes of mussel seed valued at ₹ 98 lakh were collected and supplied to mussel farmers in Kasaragod. The mussel farmers at Kozhikode and Malapuram utilized approximately 29 and 49.8 tonnes of seed valued at ₹ 1.02 and 1.7 lakh respectively. Altogether 1,878 tonnes of seed valued at ₹ 101.7 lakh were collected from different centres for mussel farming.

For collecting required seed for Kasaragod, Kozhikode and Malapuram, the employment opportunities in terms of man days was estimated as 17,991, 292 and 499 respectively (Total =18,783 man days). The business turn over at collection site was estimated ₹ 5,397,386, ₹ 87,750 and ₹ 149,696 (Total = ₹ 5,634,832 or ₹ 56.3 lakh) respectively when the price per 100 kg of seed mussel was ₹ 300.

Production of material for farming: Coir rope, nylon rope, bamboo poles and other materials are used for mussel farming. During 2005-06, approximately 600 tonnes of coir rope worth ₹ 30 lakh, cotton cloth worth ₹ 30 lakh and nylon thread worth ₹ 4.5 lakh were used as inputs in the industry; 19 main centres were identified as the major centres which supply material for mussel farming (Anayarangadi, Athani, Atholi, Beypur, Chaliyam, Cheruvathoor, Elathoor, Faroke, Kadalundi, Kattilapeedika, Koilandi, Kotta, Kozhikode, Oori, Padanna, Parappanangadi, Thekkae kattil, Thuruthi and Vadakkaekad)

Development of mussel markets: From north Kerala, farmed mussels are marketed to southern regions even up to Kollam about 500 km from the production sites. There are 14 major purchase points at seven locations – Kannur (4), Koduvally (2), Thalasherry (1), Muttangal (1), Payyoli (1), Kozhikode (4), and Chaliyam (1). This has helped mussel- venders to get a consistent supply of mussels in addition to normal supply of mussels by mussel-fishers. Related to this, a market chain itself has developed, linking farmers, agents, wholesalers, retailers, restaurants and even meat-shucking units lead by women. There are about 100 women earning livelihood through shucking for major mussel-venders.

Transport of raw and farmed material: Supplying seed to farmers and distribution of harvested mussels from farm site to distant markets is done by several coastal villagers, mostly youngsters. Trucks with a capacity of 3, 4, 6 or 10 tonnes, ply between production and distribution sites. Based on the quantity of seed utilized, it has been estimated that for transportation of seed for supplying at Kasaragod, Kozhikode and Malapuram, approximately 360, 3 and 5 labour days (Total= 368 labour days) @ 2 persons for 10-tonne capacity truck and for transporting harvested mussel from farm site 2,249, 63 and 120 labour days of employment for truck drivers was created @ 2 persons per truck of 6-tonne capacity (Total =2,432 labour days). Thus during the crop season of 2005-06, 2,807 labour days related to main transport alone could be created.

Clam and cockle farming

A total of 4.14 million tonnes of clams were produced through mariculture during 2007 from 22 different species (Table 25.14). During 1950 to 1980, Asia was the major producer of clams globally. Subsequently other nations also started farming clams, and in 2007, 80.0% of the clams produced were from Asia. During 2007, China produced 3.9 million tonnes, contributing to nearly 95% of the continent's production. Thailand (66,000 tonnes), Korea and Malaysia (49,620 tonnes) (Table 25.15) were other major producers.

Table 25.14. Common and scientific names of commercially important clams farmed in different parts of the world

Common name of clams	Scientific name of clams
Banded carpet shell	*Venerupis rhomboides*
Bear paw clam	*Hippopus hippopus*
Blood cockle*	*Anadara granosa*
Butter clam	*Saxidomus giganteus*
Common edible cockle	*Cerastoderma edule*
Constricted tagelus*	*Sinonovacula constricta*
Globose clam*	*Mactra veneriformis*
Grooved carpet shell	*Ruditapes decussatus*
Inflated ark*	*Scapharca broughtonii*
Japanese carpet shell*	*Ruditapes philippinarum*
Japanese hard clam*	*Meretrix lusoria*
Northern quahog(=Hard clam)*	*Mercenaria mercenaria*
Oriental cyclina*	*Cyclina sinensis*
Pacific geoduck	*Panopea abrupta*
Pacific horse clam	*Tresus nuttallii*
Pacific littleneck clam	*Protothaca staminea*
Pullet carpet shell	*Venerupis pullastra*
Rooster venus*	*Paphia gallus*
Sand gaper	*Mya arenaria*
Smooth mactra	*Mactra glabrata*
Striped venus	*Chamelea gallina*
Warty venus	*Venus verrucosa*
Anadara clams	*Anadara* spp.
Carpet shells	*Ruditapes* spp.
Donax clams	*Donax* spp.
Razor clams	*Solen* spp.
Venus clams	*Veneridae*

*Resources farmed in Asia

Table 25.15. Total clam production (in tonnes) in different Asian countries

Country	1984 production	1984 % contribution	2007 production	2007 % contribution
China	175,955	54	3,903,914	95.8
India	-	0	0	0.0
Japan	521	0	3,300	0.1
Korea	51,433	16	50,521	1.2
Malaysia	63,583	20	49,620	1.2
Philippines	0		0	0.0
Singapore	0	0	0	0.0
Taiwan Province of China	21,075	0	1,627	0.0
Thailand	12,512	4	66,000	1.6
Turkey			0	0.0
Total	325,079		4,074,982	

Clam farming in India

Resources: A number of clam species belonging to Archidae, Veneridae, Corbiculidae, Solenidae, Mesodesmidae, Tellinidae and Donacidae occur in coastal regions of India and among these most important are *Villorita cyprinoids, Paphia malabarica, Meritrix casta* and *Anadara granosa*. Considering the importance of clams, experiments have been conducted to farm these species and results have indicated feasibility of farming them in pen and on bottom methods. However, there is no commercial culture of clams following strict farming protocol, but a method of semiculture, whereby fishers stock seed clams which occur in the fishery in certain areas to be harvested later, is followed in some regions. Salient features of the experiments conducted and the relaying method is as follows.

Experimental clam farming: Experiments on culture of blood clam (cockle) were done in the Kakinada Bay.

***Anadara granosa*:** It is the dominant cockle resource of the region. Seed clams of *A.granosa*, with mean length 24.3 mm, mean weight 6.7 g were collected during low tide and stocked at densities 140 and 175 number per m^2. After 5.5 months of culture, clams attained 25.5 to 32.9 g weight and 39.2 to 42.7 mm length. The retrieval was 83.4 to 88.6% when pen enclosures were used and 41.5% without pen. Production rates of 39 to 41.6 tonnes/ha/5.5 months were obtained when pen culture was practised and 21 tonnes/ha/6 months when pen was not used. Thus both retrieval and production rates were reduced by about 50% in blood clam culture when pen was not used.

***Meritrix meritrix*:** In Mulky estuary, Karnataka, culture of *Meritrix meritrix* grew from 23.6 mm to 37.5 mm average length in 4 months with a survival rate of 75.5 months.

***Villorita cyprinoides*:** Its experimental culture was done in Vembanad lake, Kerala. Production rates in different stocking densities were tried and it was suggested that with a stocking density of 500 nos/m^2 about 1.2 tonnes of clam were harvested in 6 to 7 months.

Relaying of clams: In the two main estuarine systems of Kerala, relaying of clams is practised. Clam fishers of Vembanad Lake collect *Villorita cyprinoides* seed during spat fall season, mainly in June and November, and stock them in water-bodies adjacent to their residing place to be harvested at a later stage. Apart from this, they sort seed clams from fishery landings as and when they occur and stock them for further growth. In the same manner as described for *V.cyprinoides*, the clam pickers of Ashtamudi Lake collect seed of *Paphia malabarica* and stock them during January to February to be harvested later. This method of clam culture termed relaying or semiculture in a way protects resource from depletion. It allows clams to grow to their full potential and gives them a chance to utilize their reproductive potential before being fished. Annually about 800 tonnes of relayed clams are harvested by fishers.

Marine pearl farming

Pearl, a jewel from the sea is one of the oldest of the known gems, produced by pearl oyster. Historical evidences indicate that India exported this valuable merchandise to Greece and Rome more than 2,000 years ago. Altogether, 32 nations are in some stage of pearl culture from pilot-scale research to major production, and in recent years some of these have expanded their industries rapidly to garner a share of the multi-billion dollar industry.

Pearl sac principle: In nature, pearl is formed in an oyster when some extraneous matter such as sand grain, piece of shell, etc., enters oyster tissue, which causes irritation to it. As a defense mechanism, oyster's pearl secreting cells of the mantle migrate into the tissue, multiply by cell division and surround foreign particle and form 'pearl sac'. This secretes nacre, which gets deposited over the particle and produces a natural pearl. The technology for pearl production, involves artificial introduction of a bead along with a secretory mantle tissue into a recipient oyster.

Farming and pearl surgery: The brief details of the technology for production of high quality marine pearls and protocol including site selection, farm structures and implantation procedures are in Table 25.16.

Harvest and processing: Harvesting of cultured pearls is usually done manually. Pearls are extracted by cutting and separating two valves, making an incision on the gonad and squeezing pearl out. In some cases pearls are removed from pearl-sac without damage in such a way that the oyster can be reused for implantation. The harvested pearls are washed in distilled water, polished with refined salt and again washed in distilled water. They are sorted according to size, colour, shape, lustre, iridescence and other external characteristics into A, B and C grades.

Marketing: Pearls are sold by weight, either as loose or as stringed. Grade A pearls cost ₹ 1,500 per gram if they are of 3-5 mm in diameter. Grade B costs ₹ 1,000 and Grade C costs ₹ 500 per gram. The global cultured pearl industry has an estimated wholesale value of US $ 1.1 billion and a retail value between US$ 3 and 5 billion.

Technology adoption in India: In the beginning of this century, with the active collaboration of the M S Swaminathan Research Foundation, the CMFRI started village linked pearl culture programmes in the villages near the Gulf of Mannar and Palk Bay. These activities are making a positive impact on the rural communities through empowerment of women and employment generation. While India has been a net importer of raw pearls during the early nineties, from 1996 onwards, it has also been able to export cultured pearls, albeit in small quantities (US$ 0.017 million in 1996). Within the institute through continued seed production programme, the pearl oyster resource was developed, and pearls worth ₹ 10 lakh were produced and marketed within the country during 1996 to 2002.

Transfer of technology programmes have shown that pearl culture can be commercialized by promoting it as a community development programme at the village or societal level with segmented entrepreneurship having different activities such as seed production; surgery/implantation; grow-out units and value-addition and marketing. Active collaboration of the research institutes with the concerned departments of the state governments can promote income-generating capacity of pearl culture in a participatory mode. Armed with three main advantages – faster growth rates, quality nacre production and a technology for seed production – there is ample scope for development of pearl culture industry within the country. However, several policy issues such as rules for leasing of farming area, legal protection of farmers and development of market demand especially related to international pearl trade have to be sorted out.

Table 25.16. Protocol for marine pearl farming in India

	Pearl culture site selection and implantation	
Selection of suitable sites	Areas with • Salinity above 30 parts per thousand • Good phytoplankton production • Mild/moderate current • Low siltation • Depth 2 to 3 m and above	
Selection of oysters for operation	Oyster age Weight Stage of maturity Overall health	Above 1.5 to 2.0 years > 25 g (40 mm) Spent resting stage Good, free from polychaetes/ sponge/trematode infections
Conditioning	Arranging oysters in a container with their hinge pointing downwards Narcotization of selected oysters by sprinkling menthol in the sea-water Insertion of a small wooden peg between two valves to facilitate nucleus implantation	
Preparation of graft tissue	Select healthy non-narcotized oyster Cut mantle into thin strips of 5-cm length and 0.5-cm width Remove mucous and muscle from mantle Cut mantle strip into 20 to 25 pieces of 2-3 mm² Keep cells live by adding Azumin/Eosin solution in sterilized sea-water and use within 15 minutes	
Implantation	Mounting oyster in the stand with the valves facing upwards	
	Making incision at the right place and placing the graft mantle piece	Single implantation-in the gonad near the intestinal loop Double implantation - additionally, close to hepatopancreas Multiple implantation- more than double implantation
	Placing sterilized nucleus on the graft mantle piece	
Convalescence	Placing implanted oysters in fresh sea-water with mild circulation for two to three days Maintain water quality by water exchange Remove dead oysters and shift healthy implanted oysters into the natural environment	

Value-added pearls

Mabe pearl production in India: The Central Marine Fisheries Research Institute, Kochi, developed cultured marine pearl production technology during the early eighties. Scientists have succeeded in perfecting a simple technique for value-added marine pearls, called mabe (mah-BAY) pearls. A mabe pearl is a dome-shaped or image pearl produced by placing a hemisphere or miniature image against the side of the oyster-shell interior. The result is an exquistic pearly nacre-coated miniature image of anything like Ganesha, Saraswathy, Lakshmi, Asoka, Crescent and Holy Cross. These miniatures can be made into pendants, eardrops and images. A fine quality mabe pearl of 10-mm can fetch easily more than US$ 100 in the international markets and an average of ₹ 1,000 in local markets. The main advantage of Indian marine mabes is the very short gestation period (2 months as compared to 18 months) apart from superior nacre quality of Indian marine pearl oysters (*Pinctada fucata*) over the ones produced in freshwater mussels. The technology developed is very simple, and can be easily adopted by farmers, unlike technology for free round pearl production, where skilled hands and large capital are involved.

Preparation of base images: A base image of 10 mm^2 is required to make a mabe pearl. Specially fabricated metallic dyes are used to get required designs. The raw ingredient used in the process is mollu[illegible] powder which is sieved and mixed with resin glue to form uniform semi-hard dough. This dough is hand-mixed into pellets and kept on the die, over which a formulated mineral oil mixture is already applied. With the help of a specially designed hand press, the dough is pressed into the die to make a fine impression of the image on the dough. The dough is slipped out of the die with a sharp knife and trimmed to appropriate dimension and shape and kept for hardening. This process takes about 2-4 hr after which mould is trimmed and shaped with a carborundum grinder. Base images are stored in a cool and dry place until use.

Implantation of images: Oysters above 45 mm length are suitable for insertion of base images and they are placed in shallow pan with their hinges down. Oysters which open their valves are pegged with wooden splits, and using an oyster speculum, the shell gap is gently widened. The oyster is held with cupped left valve in the palm of the hand. The base image is picked with a fine-angled forceps and inserted face-up through the anterior end, near the byssal notch, where gap is the widest. The pallial muscles offer slight resistance; the image is slid through under the mantle so as to be placed in the deep sinus close to dorsal hinge. The image is therefore bound by hinge, pallial muscles and adductor muscles and cannot be easily dislodged. The oyster is immediately placed in fresh sea-water with hinge down and ventral margin facing up. Individual oysters are then placed in specially made wood- framed velon screen (large mesh) pouches made into strips, again taking care to see that the ventral margin is at the top. Up to 10 oysters can be placed individually in pouches in one cage. The cage is then suspended from the raft with suitable weight to keep it upright.

Harvest and processing: Along the south-west coast of India observations indicate that within 15-20 days, the nacre coating is initiated on the base image. Fusing of the image to the shell is complete by day 20. By the end of 60 days, it is possible to get complete and adequate nacre-coating on the image to produce a fine mabe. Rejection and mortality is high (100%) when image size exceeds 10 mm^2. Longer period of incubation results in masking of finer image details. Mabe images are cut-out from the shell using a sharp knife and then carefully trimmed of all blemishes and made into jewellery. The reverse side is usually finished with appropriate shape mother- of-pearl to present a uniform and fine appearance at the back also.

Economics: The profit analysis shown here is indicative for setting up a

Table 25.17. The profit analysis for setting up a 5 m × 5 m raft in the open-sea, stocked with 2,000 adult oysters

Capital cost (including rafts and cages)	₹ 40,000 ₹ 20,000 (depreciated value)
Recurring cost (including cost of pearl oysters, base images, implements and labour charges)	₹ 176,000
Total expenditure	₹ 196,000
Income from raw mabes (1,000 nos)	₹ 302,000
Profit before value-addition	₹ 106,000
Cost of value-addition into rings, pendants, drops, mementos etc in silver @ ₹ 500 per piece	₹ 500,000
Income from sale of value-added mabe (1,000 nos)	₹ 5,56,000
Profit after value addition	₹ 2,60,000

5 m × 5 m raft in the open-sea, stocked with 2,000 adult oysters and getting 50% yield of mabes through 4 crops in a year (Table 25.17).

Akoya: The finest Akoyas originally produced in Japan are more perfectly round (7-10 mm diameter) than most other pearls and have the highest lustre, which make them desirable. Akoya pearls are, by far, most fashionable, are used in necklaces, especially 14 to 16-inch choker and 17 to 19-inch princess–the two most popular jewellery pieces. Japan with nearly 2,000 Akoya pearl farms had monopoly for Akoya pearls until China also started producing Akoyas in about 1,000 pearl farms during the past half a decade.

Indian Akoya: In India, attempts have been made to produce fucata pearls similar to Japanese Akoya by implanting larger oysters grown in Kollam Bay along the south-west coast of India (Table 25.18). The largest cultured pearl obtained in this experiment was of 7.88- mm diameter, weighing 0.68 g with average nacre thickness of 1.37 ± 0.27 mm.

Table 25.18. Indian Akoya produced in the CMFRI in 2002
[*Keshi* pearls (not implanted) are also included]

Period	Pearl Grading						
	A	B	C	Baroque	Deformed/ trash	Total	*Keshi*
Total	36	41	26	10	18	131	39

Baroque pearls: The baroque pearl technically is any pearl that is not round and has an interesting irregular shape. Baroque pearls have a distinctive enough shape to be attractive. Baroque pearls can be natural or cultured. They have a spent appeal, because of their very beautiful tints of colour and iridescent flashes, which are the result of pools of nacre (where the baroque shape creates an area in which nacre can collect and is deeper than along other part of the pearl). Baroque pearls with their distinctive irregular shapes are more common than round pearls, which make them more affordable to make beautiful jewellery.

Keshi pearls (Japanese word for tiny): Seed pearls are tiny, round, natural pearls, usually under 2 mm. They are rare today, but are often seen in antique jewellery. They are sometimes cut in half to create a larger supply for particular jewellery creation, or to remove blemishes or a misshapen side; these are much less expensive than full seed pearls. Keshi pearls also called chance pearls are baroque pearls accidentally produced in sea-water oysters used for cultured pearl production. Sometimes an oyster rejects its bead implant, but particles of the accompanying mantle tissue used alongside the bead remains; these particles of the mantle tissue stimulate production of nacre, resulting in wonderful interesting pearl known as keshi. They are unusual because like natural pearls, they are essentially all nacre and all natural.

Tissue culture of pearls: A tissue-culture technology for marine pearl production of *Pinctada fucata* and abalone, *Haliotis varia* has been achieved for the first time in the world. This technology can be extended to other pearl producing molluscs; and unlike *in-vivo* pearl culture, *in-vitro* technology will give ample scope for manipulation of pearl quality and also in increasing pearl production. Shell beads used in organ cultures of mantle tissue of both pearl oyster and abalone were analysed through scanning electron microscope (SEM) for coating, if any, on the beads. The chemical crystals deposited on the beads were also analyzed by energy dispersive X- ray micro-analyzer (EDS). The analysis revealed organic matrix formation of nacreous layer and deposition of crystals. These results were obtained simultaneously in both pearl oyster and abalone and were exactly similar to earlier studies in Japan on shell regeneration and structure.

Black-lipped pearl oyster farming in India: This pearl oyster, *Pinctada margaritifera* is found in Andaman and Nicobar Islands. During 2006-09, the techniques for mabe pearl production of this oyster and winged pearl oyster, *Pteria penguin* were developed by the CMFRI through a project funded by the Ministry of Earth Sciences. Several island nations like Tonga and Fiji are making efforts to develop mabe pearl production as an income-generation programme for the islander. In India also efforts are on to develop technology as a source of livelihood for the islanders, especially as a Tsunami Rehabilitation programme

Gastropod farming

Commercial farming of gastropods started only after 1960 and in 2007, production attained was 2.9 lakh tonnes. Asia currently contributes 99% of total global production. Now nearly 10 species of abalones are farmed (Table 25.20) Among the Asian countries, only China and Republic of Korea, farm gastropods,and in 2007 China produced 284,012 tonnes of gastropods (Table 25.19). India has not yet started farming abalones and other commercially important gastropods.

Table 25.19. Total gastropod production (in tonnes) in different Asian countries

Country	1984 Production	1984 % contribution	2007 Production	2007 % contribution
China	0	0	284,012	98.48
Korea, Republic of	17	11	1,065	1.5
Taiwan Province of China	144	89		
Total	161		288,377	

Table 25.20. Common and scientific names of commercially important mussels farmed in different parts of the world

Common name	Scientific name
Blacklip abalone	*Haliotis rubra*
False abalone	*Concholepas concholepas*
Horned turban	*Turbo cornutus*
Periwinkles	*Littorina* spp.
Perlemoen abalone	*Haliotis midae*
Stromboid conchs	*Strombus* spp.
Tuberculate abalone	*Haliotis tuberculata*
Variable ablone	*Haliotis varia*

Abalone farming

Abalones have soft meat and are capable of producing good quality rainbow coloured pearls.

Abalone meat, rainbow pearls and shell (mother of pearl) have high market demand. Abalones are herbivorous and their grow-out systems are specific to this gastropod. Abalone is one of the most prized sea delicacies worldwide. Farming of abalones began in the late fifties and early sixties in Japan and China. A very rapid development of abalone cultivation took place in the nineties, and it has now widespread to many countries including USA, Mexico, South Africa, Australia, Japan, China, Taiwan, Ireland, Iceland and others. Currently, requirement of the industry is met mainly from land-based farming supported by well-developed hatchery-seed production technique. In the international market, abalone of size 7 to 9 cm costs approximately US $ 3 to 4. Recent prices (in US dollars) for some abalones are quoted as $ 40 per kilogram for live abalone in the shell, $ 66 per kilogram for fresh, processed abalone, $ 45 per kilogram for frozen abalone, $ 80 per kilogram for canned abalone. Since the sixties, there has been a downward trend in the supply of abalones from wild fisheries all over the world. This has left a tremendous gap in the supply of abalone products to the marketplace. Because of this, abalone farming has a very positive outlook for the future.

Abalone culture in India: In India, the technique for induced breeding and larval rearing of *Haliotis varia* has been developed. Preliminary success has been achieved in pearl implantation and tissue culture. However, the resources are sparse.

Farming of *Babylonia spirata*: Viable methods for collection, transportation and maintenance of broodstock of *B. spirata*, commonly known as whelk, were developed. Average number of eggs in the capsules is 500-900. Veliger stages are released from the capsule on 6th and 7th day with an average size shell length of 450μm. Metamorphosis is completed in 17-19 days. Settlement starts from 19th day when they reach a size of 800-1,000 μm. Optimum stocking density of larvae was 150 larvae/litre in which the settlement was 69.8%. Growth rate of juveniles was found 0.06 mm/day. Juveniles attain shell length of 31mm, width 21.3 mm and weight 1,010 g by 18 months.

Cephalopod culture

Mariculture of cephalopods has not been considered a high priority area, mainly because of the high production cost, operational difficulties and also due to the fact that the market demand is met by fishing industry. Experiments conducted on the rearing of squids, cuttlefishes and octopods were successful, and in India broodstock development and rearing of *Sepiella inermis, Sepia aculeata, Sepioteuthis lessoniana,* and *Sepia pharaonis* was possible; 11 generations of spineless cuttlefish were reared in the hatchery and more than 8,600 juveniles (2 to 40 mm) were ranched near Hare Island.

Considerable progress has been made in the rearing of the pharaoh cuttlefish *Sepia pharaonis* to maturity from egg in 5 months.

Table 25.21. Major finfishes farmed and their production during 2007

Common name	Scientific name/group	Production in 2007	% contribution
Atlantic salmon	*Salmo salar*	1,407,432	43.950
Marine fishes	Different teleost species	272,419	8.507
Rainbow trout	*Oncorhynchus mykiss*	271,656	8.484
Japanese amberjack	*Seriola quinqueradiata*	157,905	4.931
Gilthead seabream	*Sparus aurata*	119,320	3.726
Coho(=Silver)salmon	*Oncorhynchus kisutch*	115,376	3.603
Japanese seabass	*Lateolabrax japonicus*	102,935	3.215
Milk fish	*Chanos chanos*	80,655	2.519
Silver seabream	*Pagrus auratus*	74,378	2.323
Lefteye flounders	*Paralichthys olivaceus* and others	66,549	2.078
Large yellow croaker	*Larimichthys croceus*	61,844	1.931
European seabass	*Dicentrarchus labrax*	58,344	1.822
Porgies	*Colamus brachypomus* and other sparids	56,489	1.764
Red drum	*Sciaenops ocellatus*	51,827	1.618
Groupers	*Epinephelus* spp.	49,506	1.546

Marine finfish culture

Marine finfish culture originated only in the last century. The first marine finfish to be successfully cultured was Japanese yellowtail *Seriola quinqueradiata*, and a low intensity yellowtail culture enterprise existed in Japan in 1928. Currently about 20 marine species are commercially cultured and the list of 15 most important fishes farmed and their production during 2007 is given in Table 25.21. The global production of finfishes through farming has been estimated at 3,201,553 tonnes. Atlantic salman, *Salmo salar* is the most important farmed species, and in 2007, 1.4 million tonnes were produced, which formed 44% of global production.

Finfish production in Asia during 2007 was estimated at 122,766 tonnes from nearly 18 countries (Table 25.22) that are farming several marine food fishes (Table 25.23). Major production was from China (6.8 lakh tonnes), followed by Japan (2.6 lakh tonnes) and Korea (0.96 lakh tonnes). Main species

Table 25.22. Total marine finfish production (in tonnes) in different Asian countries during 2007

Country	Production in 2003	% contribution in 2007
Bahrain	1	neg
China	6,88,563	56.1
China, Hong Kong SAR	1,532	0.1
Cyprus	2,388	0.2
Indonesia	7,785	0.6
Israel	2796	0.2
Japan	259,700	21.2
Korea, Republic of	96,438	7.9
Kuwait	55	0.0
Malaysia	0	0.0
Oman	90	0.0
Philippines	80,405	6.5
Qatar	0	0.0
Saudi Arabia	32	0.0
Singapore	2,239	0.2
Taiwan Province of China	5,179	0.4
Turkey	79,888	6.5
U.A.E.	570	0.0
Total	122,7661	

Table 25.23. Fishes cultured in Asian countries in marine environment

Country	Fishes
Bahrain	Sobaity seabream
China	Amberjacksi, Cobia, Flatfishes, Groupers, Large yellow croaker, Percoids, Porgies, Seabreams,Puffers, Red drum
China, Hong Kong SAR	Areolate grouper, Goldlined seabream,Greasy grouper, Hong Kong grouper, Mangrove red snapper, Russell's snapper, Silver seabream, Snubnose pompano
Cyprus	European seabass, Gilthead seabream, Marbled spinefoot, Red porgy, Sharpsnout seabream, Shi drum
Indonesia	Barramundi (=Giant seaperch),Groupers
Israel	European seabass, Gilthead seabream, Red drum, Striped bass, hybrid Tilapia
Japan	Bastard halibut, Blackhead seabream, Coho (=Silver) salmon, Crimson seabream, Filefishes, Flathead grey mullet, Jack and horse mackerels, Japanese amberjack, Japanese jack mackerel, Puffers, Silver seabream
Korea, Republic of	Bastard halibut, Flathead grey mullet, Groupers, Japanese amberjack, Japanese seabass, Marine fishes, Okhotsk atka mackerel Porgies, seabreams,.Scorpionfishes, Silver seabream, Thread-sail filefish
Kuwait	Gilthead seabream, Goldsilk seabream,Orange-spotted grouper,Sobaity seabream
Malaysia	Mangrove red snapper
Oman	European seabass,Gilthead seabream, Porgies, seabreams
Philippines	Groupers, seabasses,Jacks, crevalles nei, Milkfish, Snappers, Spinefeet (=Rabbitfishes), Tilapias
Qatar	White-spotted spinefoot, Yellowfin seabream
Saudi Arabia	Barramundi(=Giant sea perch), Flathead grey mullet, Goldlined seabream, Groupers, Spinefeet (=Rabbitfishes)
Singapore	Barramundi (=Giant seaperch), Flathead grey mullet, Groupers, Milkfish, Snappers, Snubnose pompano, Spinefeet (=Rabbitfishes), Spotted coral grouper
Taiwan Province of China	Amberjacks, Barramundi(=Giant seaperch),Blackhead seabream,Cobia,Croakers, drums, Daggertooth pike conger, Flathead grey mullet, Groupers, Milkfish, Porgies, seabreams, Silver seabream,Snappers, jobfishes, Yellowback seabream
Turkey	Atlantic salmon, Common two-banded seabream, Gilthead seabream, Seabasses, Trouts
United Arab Emirates	European seabass, Gilthead seabream, Goldlined seabream, Greasy grouper, Mullets, Sobaity seabream, White-spotted spinefoot

which contribute significantly are Japanese amberjack (*Seriola quinqueradiata*), silver seabream (*Pagrus auratus)*, large yellow croaker (*Larimichthys croceus*) and red drum (*Sciaenops ocellatus*). Finfish culture in coastal areas, such as shallow lagoons, protected coasts, estuaries and straits, in various types of cages is popular in south-east Asia. Floating and stationary cages made of polyethylene netting with mesh size ranging from 2 to 8 cm depending on fish size have proven to be technically feasible and financially viable. Square and rectangular cages with sizes from 20 to 100 m^2 are preferred by farmers for easy management and maintenance.

Marine finfish farming in India: In India, culture of *Lethrinus*, *Epinephelus*, *Mugil cephalus*, *Chanos chanos* and *Etroplus suratensis* has been tried either in monoculture or in the integrated systems. Pen and cage culture of finfishes has been tried but commercial semi-intensive and intensive farming is not yet practised. Success has been achieved in the broodstock development and spawning of greasy grouper *Epinephelus tauvina*, *Lates calcarifer* and *M. cephalus*. Out of three, larval rearing technology of *Lates calcarifer* has been commercialized. A technology package has been developed for pond breeding of *Etroplus suratensis* also has been which can easily be followed by fish farmers.

During 2006 09, the Central Marine Fisheries Research Institute, Kochi, has made commendable progress in marine cage culture. In 2007, a cage of 3-m diameter and 4-m depth was floated in Vizhinjam Bay and stocked with juveniles of *Caranx sexfasciatus* of average size 81.7 mm and 7.8 g weight. The seed were collected using shore-seine. Within 4 months, they grew to an average size of 210 mm (186 g). Sturdy open-sea cage protected by outer predator nets and special shock absorber to withstand and absorb pressure was moored at a depth of 11m about 300 m from the RK beach of Vishakhapatnam. About 1,350 seed of Asian seabass *Lates calcarifer* of 14.5 g were stocked in the cage and reared by feeding low-value tarsh fish. After 125 days with a survival of 73%, 550 kg of seabass weighing between 300 g and 1,200 g were harvested. The Asian Seabass cage culture is getting impetus due to availability of its seed and funding provided by National Fisheries Development Board (NFDB), Hyderabad.

Marine ornamentals culture

Marine ornamentals are fish, corals, and invertebrates. Indonesia and the Philippines supply more than half of the global marine ornamentals, and US is the major importer of marine ornamentals. More than 98% of the marine ornamental fishes are collected from wild that is harmful to natural stock, leading to stock depletion and reduction in species diversity.

Ornamental fishes are sold live and healthy. The marine aquarium industry is growing at a faster pace. With the advances in the technology to maintain live ornamental marine fishes in home aquariums, the trade of colourful species has increased to the point where supply is hardly keeping up with the demand. The current retail value for angel fishes averaged at $ 25.00 each, and butterflyfish and trigger fish at $ 15.00. Price of clownfish ranged from $ 5.00 to $ 15.00, and damselfish was lowest priced at $ 3.00. Demand already exceeds supply and market potential appears to be excellent.

In India, techniques for breeding and larval rearing of four species of damselfishes–*Neopomacentrus filamentosus*, *N. nemurus*, *Pomacentrus caeruleus* and *P. pavo*– have been developed on an experimental scale. A technology for commercial-level hatchery production of clownfish *Amphiprion chrysogaster* was developed for the first time in India. During 2007-08, broodstock development, breeding and standardization of larval and juvenile rearing of the Maroon clownfish *Premnas biaculeatus* was done at the CMFRI. Similarly, redhead dottyback, *Pseudochromis dilectus*, a species which is hardy and suitable for aquarium, was also bred under captivity.

However commercialization of these technologies are yet to be attempted. Future work will be directed towards commercialization of technology.

Marine crustaceans farming

Three major groups of crustaceans farmed are, shrimps, crabs and lobsters. In addition to these, some minor groups are also farmed. Since most of these species are moderately euryhaline, they are farmed more in brackishwater environment and hence their production in brackishwater is more. However lobsters are farmed mostly in the marine zone. Global production of crustaceans from marine zone has been estimated at 7.0 lakh tonnes and that in Asia at 4.77 lakh tonnes (Table 25.24). The list of common and scientific names of commercially important farmed crustaceans is given in Table 25.25.

Table 25.24. Global production (in tonnes) of crustaceans in Asia during 2007

	Global	Asia	Asia contribution (%)
Total crustaceans	706,763	477,976	67.6
Shrimp	452,513	223,757	49.4
Crabs	209,233	209,232	100.0
Lobsters	70	70	100.0
Miscellaneous marine crustaceans	44,947	44,917	99.9

Table 25.25. Common and scientific names of commercially important marine shrimps, crabs and lobsters

Common name	Scientific name
Shrimp	
Indian white prawn	*Fenneropenaeus indicus*
Kuruma prawn	*Penaeus japonicus*
Fleshy prawn	*Fenneropenaeus chinensis*
Giant tiger prawn	*Penaeus monodon*
Banana prawn	*Fenneropenaeus merguiensis*
Green tiger prawn	*Penaeus semisulcatus*
Crabs	
Portunus spp	*Portunus pelagicus*
Indo-Pacific swamp crab	*Scylla serrata*
Gazami crab	*Portunus trituberculatus*
Blue crab	*Callinectes sapidus*
Lobsters	
Palinurid spiny lobsters	*Palinurus homarus*
Flathead lobster	*Thenus unimaculatus*
Mud spiny lobster	*Panulirus polyphagus*
Japanese spiny lobster	*Panulirus japonicus*

Marine shrimp resource: The major production of shrimp is from brackishwater, and in Asia, there are nearly 8 countries farming shrimp in the marine zone. China is the major producer, and in 2007 this country produced 157,735 tonnes, followed by Myanmar, 48,303 tonnes (Table 25.26). In India, the exclusive marine production of shrimp is not in vogue. However there are regions in Andhra Pradesh and Gujarat where there are sea-based farms for *Penaeus monodon*.

Table 25.26. Total crustacean production (in tonnes) in different Asian countries

Country	Marine shrimp	%	Crab	%	Lobster	%
China	157,735	70.5	209,144	99.96	0	0
Japan	1,700	0.8	0	0.00	0	0
Korea	1,321	0.6	0	0.00	0	0
Myanmar	48,303	21.6	0	0.00	0	0
Philippines	–	0.0	41	0.02	68	97.1
Saudi Arabia	14,528	6.5	0	0.00	0	0
Singapore	10	0.0	47	0.02	2	2.9
Total	223,597	100	209,232	100	70	100

Lobster resource: Due to a high market demand, low wild catches and a continuing increase in prices, lobster has become a promising candidate for closed-cycle and controlled aquaculture. In the past, the development of land-based farming was severely hampered by lack of suitable technology and production methods, where the major constraints have been: need for single rearing cages to avoid cannibalism, need of heated water, lack of high quality dry food, high labour costs, inadequate technological solutions and high investment costs. Philippines and Singapore are the two Asian countries producing farmed lobsters, and the production from these two has been estimated at 68 and 2 tonnes respectively. *Panulirus homarus, P. ornatus* and *P. polyphagus* are the main species having high value in the export market. These are fast growing and highly adaptable to culture conditions. The CMFRI was successful in breeding, larval rearing and seed production of the sand lobster *Thenus orientalis*. Over-exploitation of this resource has resulted in stock depletion, and the average annual production has fallen from 900 tonnes to less than 400 tonnes in the last fifteen years. Export of sand lobsters declined from 400 tonnes to about 131 tonnes, valued at 4.51 crore (about 10–12 US $ per kg).

Cage farming of lobsters: At Vizhinjam, in a 5-m diameter cage, 1,200 juveniles of spiny lobster (*Panulirus homarus*), weighing between 70 and 95 g, were stocked in January 2009. Lobsters at harvest weighed 260 g on an average after four-and-half months of rearing. The retrieval was 85%.

Lobster fattening is a simple technique wherein healthy lobsters (< 100 g) are stocked at 2 kg/m^2 in a flow-through system or at the rate of 1 kg/m^2 in a recirculation system. Lobsters weighing on an average of 80 g can be fattened to above 100 g within a month, and a threefold increase in price can be expected while lobsters weighing below 100 g take 5-6 months to attain 300 g in a grow-out system. A major constraint for commercial culture of lobsters is non-availability of hatchery technology for seed production.

Seed production and farming of slipper lobster: A major breakthrough was achieved in breeding and hatchery production of two species of scyllarid slipper lobster *Thenus unimaculatus* and *Petrarchus rigosus*, a smaller species of high ornamental value. Phyllosoma larvae of *Thenus unimaculatus* were reared for the first time in India. The technology comprises broodstock constitution and management, induced maturation, larval culture, feed development and harvest of post larvae. Larval cycles of *T. unimaculatus* and *P. rugosus* completed in 26 and 32 days respectively. In *T. unimaculatus* survival from phyllosoma I to post larva ('nisto') was 22% and from nisto to juvenile was 100%. Larval rearing of *Thenus unimaculatus* could be achieved in 30-35 days using combination diet of fresh clam meat and zooplankton. Arrow-worm *Sagitta enflata* was preferred by phyllosomal stage I and stage II while the advanced phyllosomal stages (stages III and IV) showed excellent response to ctenophore *Pleurobrachia bachiae*.

By rearing *T. unimaculatus* seeds in closed recirculatory systems with *in-situ* fluidized substrate bed filters and reduced light intensity and using fresh clam meat as feed, the sub-adult size weighing approximately 35g can be obtained in about three to four months, and in 180 days, animals attain an average weight of about 150g (160-164 mm TL), which is minimum legal size for export of *T. unimaculatus*.

Crab farming: The global production of crabs has been estimated as 2.0 lakh tonnes, and Asia is the major producer. However, crab farming strictly from the marine environment is limited. *Scylla serrata, Portunus trituberculatus* and *Callinectes sapidus* are the three main species farmed. China is the major producer, and in 2007, 2.0 lakh tonnes were produced, contributing to 99%, followed by Singapore and Philippines.

In India, *Scylla serrata* and *S. tranquebarica* are highly valued crabs and viable technologies have been developed for fattening them. Crab fattening is practised by few farmers in Kerala, Karnataka and Tamil Nadu.

Water crabs (freshly moulted crabs) of 550 g and above are stocked and maintained for 3 to 4 weeks for hardening shell thereby increasing their commercial value.

Crabs are fed with trashfish at 5 to 10% of the biomass/day thrice daily at regular intervals and harvested after 3 to 4 weeks. Though crab fattening is widely practised, authentic records of the production are not available.

Seaweed farming

Seaweeds are the natural source of phycocolloids such as agar-agar, algin and carrageenan, and they are rich in minerals, vitamins, proteins, essential amino acids and are low in fat content. Globally, seaweed production in 2003 was estimated at 12.48 million tonnes with Asia contributing 99.9% (12.38 million tonnes) (Table 25.27). There are three major groups of seaweeds, viz. brown, red and green, and production of these three is 4.9 million tonnes, 2.5 million tonnes and negligible (5,518 tonnes) respectively. In additional to this, 4.9 million tonnes of other aquatic plants were also farmed.

Among the Asian countries involved in farming, China contributed to 78.67% (9.7

Table 25.27. Global and Asia farmed seaweed production

Seaweed	Production	1984	2003	% to global / Asia production 2003
Total seaweeds production	Global	3,246,096	12,481,610	
	Asia	3,235,766	12,397,824	
Brown seaweeds	Global	2,326,587	4,906,167	39.3
	Asia	2,323,087	4,906,075	39.5
Red seaweeds	Global	865,972	2,598,275	20.8
	Asia	849,141	2,505,124	20.2
Green seaweed		13,515	5,518	0.04
Other plants	Global	40,017	4,971,650	39.83
	Asia	40,012	4,968,918	40.03

Table 25.28. Total seaweed production (in tonnes) in different Asian countries

Country	Red seaweeds	Brown seaweeds	Green seaweeds	Others	Total	%
Cambodia				7,800	7,800	0.06
China	727,530	4,093,840		4,922,690	9,744,060	78.67
Indonesia	231,900				231,900	1.87
Japan	337,354	110,848		19,503	467,705	3.78
Korea, Dem. People's Rep.	0	444,295			444,295	3.59
Korea, Republic of	193,553	257,092	1,355	54	452,054	3.65
Malaysia				18,871	18,871	0.15
Philippines	984,726		4,163		988,889	7.98
Taiwan Province of China	61				61	0.00
Vietnam	30,000				300,00	0.24
	2,505,124	4,906,075	5,518	4,968,918	12,385,635	

Table 25.29. Major seaweeds farmed and their production (in tonnes) in different Asian countries in 2003

Common name	Species	Production	%
Harpoon seaweeds	*Asparagopsis* spp.	12	0.00
Caulerpa seaweeds	*Caulerpa* spp.	4,163	0.03
Zanzibar weed	*Eucheuma cottonii*	879,580	7.05
Spiny eucheuma	*Eucheuma denticulatum*	81,329	0.65
Eucheuma seaweeds	*Eucheuma* spp.	10,931	0.09
Gracilaria seaweeds	*Gracilaria* spp.	100,824	0.81
Warty gracilaria	*Gracilaria verrucosa*	12,226	0.10
Elkhorn sea moss	*Kappaphycus alvarezii*	23,012	0.18
Japanese kelp	*Laminaria japonica*	4,614,372	36.97
Green laver	*Monostroma nitidum*	1,355	0.01
Brown seaweeds	*Phaeophyceae*	33,728	0.27
Aquatic plants	*Plantae aquaticae*	4,971,650	39.83
Laver (Nori)	*Porphyra tenera*	1,258,461	10.08
Red seaweeds	*Rhodophyceae*	231,900	1.86
Wakame	*Undaria pinnatifida*	258,042	2.07
Wakame	*Undaria* spp.	25	0.00
	Total	12,481,610	

million tonnes), followed by Philippines 7.98% (0.98 million tonnes), Japan (3.78%), Republic of Korea (3.65%) and North Korea (3.59%) (Table 25.28). Main species of seaweeds farmed are Japanese kelp *(Laminaria japonica)*, laver (*Porphyra tenera*) and cotoni (*Euchema cottoni*); contributing to 36.97%, 10.08% and 7.05% respectively (Table 25.29). Requirement of seaweed based industries are met through farming in Japan, China, Philippines and Korea

In most South-east Asian countries, seaweeds farming is encouraged by the government, and this has lead to creation of employment opportunities. One typical example is the seaweed industry in Philippines which has led to coastal area development. Till eighties, seaweed was an alternate source of livelihood and now it is a major source of livelihood. About 1 to 1.2 lakh people are involved in seaweed farming. High profit and fast returns are the main reasons for increased rate of adoption of seaweed farming. Strategies for seaweed development planned by government such as the establishment of seaweed nurseries, promotion of seaweed health, post-harvest facilities and pilot semi-processing plants have supported growth of this industry.

Seaweed farming in India: In India, *Gracilaria edulis* has been identified as the species suitable for farming. Seaweeds farming is either by vegetative propagation using fragments from mother-plants or by reproductive method using different kinds of spores such as zoospores, tetraspores, carpospores etc. Vegetative propagation is done by two methods; one, wherein, seaweed thallsus (fronds the seed material) collected from the natural bed are cultivated on the substrata such as 2m × 2 m nets (20-cm mesh) made of either nylon or coir (obtained from coconut husks) and on the 10-m long ropes. For seeding, about 5 g of fronds is inserted or sandwiched between twists of rope at a distance of 10 cm in the longline or at each mesh in the 2 m^2 nets and attached to floating rafts or bottom-set fixed structures in the sea, especially protected bays, lagoons or shallow coast. Other method includes broadcasting seaweed fragments thallus in ponds, raceways and tanks or shallow sea bottom. The fragment culture method is simple and gives quick results.

In India, reproductive propagation of seaweed (*Gracilaria edulis*) was experimentally done by liberating carpospores on different substrata like nylon-twine, cement blocks, HDP rope and old-fishing net. The spores were allowed to grow to germling stage in a nursery and then transplanted to natural environment during favourable period of growth. The spores reach germling stage within 13-17 days and attach to substrata. Three consecutive harvests can be made from the same seed after 105 days till 135 days of culture period. Though the technology for sea-farming has been developed, it is yet to be commercialized. Raw material for seaweed-based cottage industries is only from natural harvests and not from farming. Recently, village-linked seaweed farming programmes were initiated in the villages around Mandapam by MS Swaminathan Research Foundation (MSSRF) with technical help from the CMFRI, and commercial farming of *Kappaphycus alvarezii*, a carageenan-yielding seaweed, has been started in 100 ha in Palk Bay by a private company.

There is a high demand for seaweeds, mainly from cottage industries. Approximately 2,000 tonnes (dry weight) of agarophytes and 12,000 tonnes of (dry weight) of alginophytes are required, but current yield is only 800 to 1,100 tonnes and 3,600 to 5,400 tonnes respectively. Grazing of farm crops by fishes, low returns from monoculture of seaweeds, inconsistent yields and non-availability of seaweed seed-stock with high yield of colloids are major constraints in seaweed-farming in India.

Farming of sea-cucumbers

Sea cucumber is a high-valued marine product, famous for processed product *beche-de-mer*, a delicacy in South-east Asian countries.

It has high medicinal properties and is used for treating weakness, impotence, debility of aged, constipation etc. It is a rich source of polysaccharide conroitin sulphate; well known to reduce arthritis pain. Price per kg of *beche-de-mer* is about US $ 370/kg. Breeding and seed production technology of sea cucumber *Holothuria scabra* has been developed.

26. Soil and Water Quality Management in Aquaculture

In the recent years, intensification of aquaculture practices have posed question regarding maintenance of optimum nutrients in the culture system as well as impact of practices on the surrounding environment. The new approach for nutrients management in the ponds gives due attention to organic decomposition, residual accumulation, microbial processing possibilities, fertilization strategies to suit different kinds of ponds; and to biofertilization and biofiltration to achieve increased productivity, sustainability and environment upkeep. Aquatic environmental management is crucial when efforts are being made to increase mean national fish production through aquaculture to at least 4 tonnes/ha/year; diverse nutrient resources are available for recycling and utilization in fish culture.

Since most of the potential areas for inland aquaculture have already been explored in India, additional production can only be achieved through successful manipulation of available resources that influence productivity of various aquaculture systems. One of the main ways is through maintenance of adequate nutrients levels in the ponds. In fish culture, pond management is mainly concerned with fertilization requirements and strategies; and with good pond soil and water quality management. High quality water and suitable bottom soil are essential for successful pond aquaculture. Some problems with pond soil and water quality are related to site characteristics. Bottom soils may have undesirable properties such as potential acid sulphate, high organic-matter content and excessive porosity. Water may be of poor quality -highly acidic, rich in nutrients and organic matter, high in suspended solids or polluted with industrial or agricultural chemicals. However, even if a good site is available, large inputs of nutrients and organic matter as a result of feeding may very often lead to poor water and bottom soil. Therefore, soil and water quality problems are common in aquaculture ponds, and many methods are used for improving pond soil and water.

Water quality and its management

Fish are in equilibrium with potential disease organisms and their environment. Changes in this equilibrium, such as deterioration in water quality (environment) can result in fish becoming stressed and vulnerable to diseases. It is, therefore, important to know water-quality parameters and their management that influence on growth and survival of aquatic organisms.

Dissolved oxygen

This is the most critical and limiting factor in intensive aquaculture. Oxygen enters water through photosynthesis by aquatic plants, principally phytoplankton, and by diffusion at the air-water interface. Diffusion occurs when oxygen in water is below saturation; and greater is the deficit between oxygen concentration in the water and saturation concentration, greater is the rate of diffusion. In ponds, diffusion is promoted by wind and wave action and by artificial aeration. Oxygen is lost from water through respiration by fish, plankton and other organisms, and by aerobic decay of organic matter. There are distinct diurnal fluctuations in oxygen; with concentrations lowest just after dawn, and increasing during daylight hours. This is because of the photosynthetic production of oxygen (there is also usually more wind during day) to a maximum in late afternoon before decreasing again during night.

The optimum dissolved oxygen (D.O.) content of pond-waters should be in the range of 5 mg/litre to saturation level for good fish growth. Following are some guidelines for dissolved oxygen for fish production.

- 5.0 mg/litre–optimum for normal growth and reproduction in tropical waters;
- 1.0–5.0 mg/litre–may have sub-lethal effects on growth, feed conversion and tolerance to disease;
- 0.3-0.8 mg/litre–lethal to many species if sustained for a long period.

Oxygen depletion in water is rectified by following aeration methods.

- Manual–In this, water surface is splashed with bamboo-sticks. This helps in dissolving atmospheric oxygen in water.
- Mechanical–A diesel water-pump is operated through this method. Water is pumped out and simultaneously sprayed in again into the water-body. This helps in dissolution of atmospheric oxygen.
- Aerators–Aerators are mechanical floating devices. Their rotating blades churn water helping in dissolution of atmospheric oxygen in water. Depending upon the concentration of oxygen in water, number and placement of aerators are determined.

Other steps taken to control oxygen level are as follows.

- Care should be taken to feed fish in the afternoon or evening in heavily stocked pond systems as oxygen requirement in fish after feeding increases and dissolved oxygen is minimized in the pond during early morning.
- Organic manure application in a water-area should be done carefully, as during decomposition, organic material consumes oxygen. Therefore, quantity of manure should be calculated taking into consideration availability of dissolved oxygen during the 24 hr period, to avoid oxygen depletion risk.
- During collapse of phytoplankton bloom, decomposition occurs, and in the process, oxygen requirement of microorganisms increases. Thus, special care has to be taken during this time.
- Special care has to be taken as fish requires more oxygen with increased temperature.

Temperature

Fishes are ectotherms as heat is obtained from outside the animal, unlike endotherms (e.g. mammals) that generate their own body-heat. Usually, body temperature of ectotherms is close to their surroundings; they are often described as poikilothermic (having variable temperature).

Temperature sets the pace of metabolism by controlling molecular dynamics (diffusibility, solubility, fluidity) and rate of biochemical reaction. Fish metabolic rate doubles for every rise of 10°C. Therefore, temperature has a direct effect on the important factors–growth, oxygen demand, food requirement and food-conversion efficiency. Higher is the temperature, greater will be the requirement for oxygen and food and faster will be the growth rate. During winter when water temperatures are low, carps will require less food and have slower growth rate. At temperatures below 10°C, fish may enter a state of torpor (a sluggish inactivity or inertia), with greatly reduced appetite and activity. In spring and summer, as water temperature increases, fishes require larger quantity of food owing to increased metabolic rate. Temperature also has a crucial role in stimulating gonadal maturation of carps and in spawning activity. Common carp can be induced to breed in hatcheries when water temperature rises above 20°C.

Temperature partly determines oxygen concentration in water. Oxygen solubility decreases with increased temperature, and so O_2 concentrations are usually lower in summer.

Under favourable conditions, optimum temperature range for many coldwater and warm water fishes is 14-18°C and 24-30°C respectively. Water temperature can be adjusted to optimal levels in controlled system such as hatcheries. It is difficult to adjust water temperature in large water-bodies. Aerator during calm and warm afternoon helps break thermal stratification by mixing warm surface water with cool subsurface water. Tree planting to give shade on pond-banks will reduce stratification but at the same time will reduce beneficial effects of wind mixing and will restrict solar energy for photosynthesis.

Salinity

Total concentration of all ions in the water is its salinity. Freshwater fishes exhibit a range in salinity. Many commercially important species (e.g. channel catfish, *Ictalurus punctatus;* largemouth bass, *Micropterus salmoides*; tilapia, *Oreochromis* spp.) survive and grow well in slightly salty water; and smelt, salmon and trout can also tolerate salt water. Salinity not only affects osmoregulation, but also influences concentration of un-ionized ammonia. During the planning stage of an aquaculture operation, salinity should be measured and water's appropriateness should be determined.

Turbidity

It is a very general term that describes cloudiness or muddiness of water. Many substances including microscopic algae (phytoplankton), bacteria, dissolved organic substances that stain water, suspended clay particles, and colloidal solids make water turbid. Although turbidity can be a problem in many different types of water, turbidity caused by suspended clay tends to occur most often in soft, poorly buffered (low alkalinity) waters.

Some substances that cause turbidity are desirable in fish culture or recreational farm ponds than others. Phytoplankton is a desirable form of turbidity because it provides food for microscopic animals (zooplankton) and filter-feeding fish, and improves water quality by producing dissolved oxygen and removing potentially toxic compounds such as ammonia. Turbidity caused by clay particles is generally undesirable, as it hinders light that penetrates into the water required for algal growth. At very high concentrations, clay particles can also clog fish-gills or smother fish-eggs. From aesthetic standpoint, turbidity may be objectionable by pond owners.

Runoff from clear-cut or overgrazed watersheds, road or building construction, pond-bank erosion by wave action, excessive aeration or feeding activities of certain bottom-dwelling fishes such as common carp, are some of the sources of clay turbidity.

Clay turbidity affects dissolved oxygen. Dissolved oxygen in sport fish or farm ponds normally widely fluctuates during summer. During day, plant photosynthesis increases oxygen concentration in the water; during night, plant and fish respiration reduces oxygen concentration. Clay turbidity reduces magnitude of daily fluctuations in dissolved oxygen concentrations, so that it gets neither very high nor very low. However, muddy water tends to have a lower average concentration of dissolved oxygen than water with a green phytoplankton bloom. Clay turbidity sometimes develops quite suddenly, when heavy storm runoff enters pond or high winds churn water and cause bottom soils to be resuspended. In such cases, oxygen may decline to critically low levels and make it necessary to aerate pond.

Turbidity also causes off-flavoured fish. As clay particles limit penetration of light into water, good amount of algae cannot grow in muddy water. Blue-green algae are adapted to dim-light waters of moderately turbid ponds. Unfortunately, some of these algae can cause off-flavour in fish, which could be reason enough to clear water of clay turbidity.

Chemistry of colloid clay suspensions: This is not completely understood, primarily as fairly complex physical and chemical processes are involved. Clay particles are extremely small; some are even smaller than bacteria. Therefore, they will not settle readily, even in still water. These small-size particles have extremely high surface area relative to volume of the particles. A clay particle can be envisioned as a flat plate covered with a negative electrical charge that attracts positive ions in water. Positive ions that are immediately adjacent to clay particle are said to be adsorbed, while others that are farther away are less strongly attracted. In water, clouds of positively charged ions surround negatively charged clay particles. When these particles, surrounded by their ion clouds, come close to one another, they are repulsed, much the same way as similar poles of two magnets. The cumulative effect of the repulsion of a huge number of small particles prevents their aggregation into larger, heavier particles that would settle readily. This explains why small-size particles remain in suspension.

Flocculation and coagulation: Flocculation is a way of controlling clay turbidity by adding substances to water that facilitate formation of bridges between particles, allowing them to combine into groups of small particles called flocs. Metal salts make good flocculants, depending on *p*H. These hydrolyzed metal compounds destabilize colloids by shrinking layer of positively charged ions surrounding clay particles, which increase attraction of one particle to another (coagulation). Hydrolyzed metals also can be adsorbed onto the surfaces of clay particles and create bridges to other particles (flocculation). As these particles begin to settle, they entrap other particles, become progressively heavier, and settle much more readily from the suspension.

In general, effectiveness of coagulants increases with charges on the metal ion– sodium (Na^+) in sodium chloride (NaCl) is not an effective coagulant; calcium (Ca^{2+}) in gypsum ($CaSO_4$) is more effective as it carries +2 charge. Aluminum (Al^{3+}) in alum and ferric-iron (Fe^{3+}) in ferric sulfate are more effective as they carry +3 charge. Some companies manufacture various synthetic polyelectrolytes, which are large, long-chained molecules with even more charges than metal-salt coagulants.

Alum: One of the most effective coagulants is alum or aluminium sulphate, which has been used to clarify muddy-waters since the time of early Egyptians (2000 BC). Although alum is not always available from farm-supply businesses, many companies selling industrial chemicals have it. A dose of 15 to 25 mg/litre (60 to 110 kg per acre or 0.4 ha) should be sufficient to remove turbidity from most waters. Lower concentrations should be used for moderately turbid (less than 12-inch or 30.5-cm visibility) waters and higher concentrations for highly turbid (less than 6-inch or 15.2-cm visibility) waters. If the visibility is more than 12 inch, then the dose should be proportionately lesser than this. Alum makes water acidic. In ponds with low alkalinity (less than 60 mg/litre as $CaCO_3$), it can reduce water *p*H to the levels that may affect fish growth and survival. In low alkalinity ponds, add ½ part hydrated lime for every part of alum applied to maintain *p*H.

Alum should be applied in calm weather as excessive turbulence will slow flock settling. The key to success with alum is to thoroughly and quickly mix coagulant with water. This can be accomplished by releasing a mixture of 10 parts water to 1 part alum in the prop wash of a boat as it is driven back and forth around the pond. Or slurry of alum and water can be spread over pond surface. In ponds equipped with aerators, releasing slurry of alum and water in front of the aerator will quickly distribute it. Users should wear a particle (dust) mask when mixing dry chemical with water. If the dose is sufficient, water should be noticeably clearer within hours, although full effect may not be apparent for several days.

Other coagulants: Although not nearly as effective as alum, gypsum can also be used to control turbidity but without loss of alkalinity. Gypsum must be added to achieve a concentration of 100 to 300 mg/litre for effective turbidity control. For most ponds, gypsum application rates will range from about 400 to 1,200 kg per acre or 0.4 ha. If the visibility is more than 12 inch, then dose should be proportionately lesser than this. In hard-water ponds (calcium hardness greater than 50 mg/litre), water is nearly saturated with calcium, and gypsum may be ineffective. In that situation, alum only will be an effective coagulant.

All the coagulants mentioned, can remove phosphorus from water. As phosphorus is an essential plant nutrient, it may be necessary to fertilize pond after treating it for turbidity. On certain occasions, phytoplankton and clay may mutually coagulate, so fertilizing to start a phytoplankton bloom, may clear water of suspended clay particles.

Organic matter such as chopped hay or cottonseed meal can reduce clay turbidity in farm-ponds. However, larger amounts of material need to be added to the pond, which may deplete dissolved oxygen. It may also be difficult and costly to transport and uniformly distribute large amounts of organic matter.

Prevention is the best control method: Coagulants should be applied after the cause of the turbidity is corrected. Watershed protection and soil conservation practices should receive highest priority. If a watersheds is to be clear-cut, leave butter strips (stream-side management zones) about 50 to 100 feet or 15.24 to 30.48 m wide along with each side of feeder streams. These strips can trap large quantities of sediments running-off cleared slopes. If pond layout permits, divert turbid feeder streams around the pond or direct them through a sedimentation basin upstream from the pond. If a watershed is in pasture, balance livestock stocking rates with availability of forage to minimize overgrazing. Within pond, maintain grass cover along levees and pond margins. Deepen pond edges to minimize sounding of shallow edges by wave action. Windward levees in ponds with a long fetch (maximum length) oriented to prevailing wind are subject to erosion by waves. Protect windward banks with riprap consisting of large boulders placed at the shoreline or log booms (logs linked with chain) placed along the base of the levee. Shallow sediments of old ponds may be periodically resuspended by wind-drive waves. Renovate old ponds after about 10 to 15 years by removing accumulated sediments. Spread and compact excavated materials on the pond levee. Finally, if practical, limit livestock access only to a small section of pond, preferably at the shallow end.

Ammonia

Total ammonia concentration in water comprises two forms, namely NH_3 = unionized ammonia (Free ammonia) and NH_4^+ = ionized ammonia. They maintain equilibrium as per the equation: $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$.
Unionized ammonia fraction is more toxic to fish and the amount of the total ammonia in this form depends on the *p*H and temperature of the water. As a general rule, the higher the *p*H and temperature, higher is the percentage of total ammonia present in the toxic unionized form. Following are guidelines for unionized ammonia levels for fish growth.

- 0.02-0.05 mg/litre–safe concentration for many tropical fish species;
- 0.05-0.4 mg/litre–sub-lethal effects depending on the species; and
- 0.4-2.5 mg/litre–lethal to many fish species.

There are a number of measures to maintain safe ammonia concentration in pond-water. Normally at high dissolved oxygen and high carbon dioxide concentration, toxicity of ammonia to fish is reduced. Some recommended measures to reduce effects of ammonia are as follows.

- Aeration will increase dissolved oxygen concentration and decrease *p*H; thereby reducing toxicity.
- Healthy phytoplankton populations remove ammonia from water. Care should be taken while using fresh manure with high ammonia content. The manure should be dried to allow ammonia-gas to escape before application to pond.

- Biological filters may be used to treat water for converting ammonia to nitrite, and then to harmless nitrate through nitrification process.

Nitrite

Nitrite is an intermediate product in the biological oxidation of ammonia to nitrate, a process called nitrification. In most natural water-bodies and in well-maintained ponds, nitrite concentration is low. In water-bodies with high organic pollution and low oxygen concentration, nitrite concentration may increase. Guidelines for nitrite value for fish growth are as follows.

- 0.02-1.0 mg/litre–sub-lethal level for many fish species;
- 1.0-10 mg/ litre–lethal level for many warm water fish species.

Measures to maintain safe nitrite level in water are as follows.

- Correct stocking, feeding and fertilization practices should be maintained. Ponds should be kept well oxygenated.
- Biofiltration should be done through special filters by which biological conversion of nitrite to harmless nitrate occurs.

Hydrogen sulphide

Freshwater fish-ponds should be freed from hydrogen sulphide (H_2S). Hydrogen sulphide is produced by chemical reduction of organic matter that accumulates and forms a thick layer of organic deposit at the bottom. Unionized hydrogen sulphide is toxic to fish, but ions resulting from its dissociation are not very toxic. Guidelines for hydrogen sulphide value for fish growth are as follows.

- 0.01-0.5 mg/litre–lethal to fish and any detectable concentration of hydrogen sulphide in water creates stress to fish;
- 0.1-0.2 mg/litre–prawns lose their equilibrium and may create sub-lethal stress;
- 3 mg/litre–prawns die instantly.

Measures to rectify increase in hydrogen sulphide levels include following.

- Frequent water exchange to prevent building-up of hydrogen sulphide in water-body.
- When liming increases *p*H of water, toxicity of hydrogen sulphide decreases.

Redox potential (oxidation-reduction Eh)

It is an index indicating status of oxidation or reduction. It is correlated with chemical substances such as O_2, CO_2 and minerals composed of aerobic layer; H_2S, CO_2, NH_3, H_2SO_4 and others comprising anaerobic layer. Microorganisms are correlated with the status of oxidation or reduction. With the degree of Eh, it is indicative of one of the parameters that shows supporting ability of water and soil to fish and prawn biomass.

In semi-intensive culture, photosynthetic bacteria play an important role through absorption and conversion of organic matter into minerals and nutrients as the secondary production, compared to primary production of algal population. PSB exist particularly due to low oxygen level and high intensity of light, and can significantly improve culture environment.

*p*H

It is a measure of hydrogen ion concentration in water and indicates how much acidic or basic the water is. The *p*H scale ranges from 0 to14 with 7 as neutral. When there are more hydrogen ions (H^+) present the *p*H will be lower than 7 and the water will be acidic. Water is basic (alkaline) when there are more hydroxyl ions (OH^-).

Carbon dioxide has an acidic reaction in water. The *p*H in ponds rises during day because phytoplankton and other aquatic plants remove carbon-dioxide from the water during photosynthesis. It decreases at night because of respiration and production of carbon-dioxide by all organisms.

Water *p*H affects metabolism and physiological process of fish; it also exerts considerable influence on toxicity of ammonia and hydrogen sulphide as well as solubility of nutrients and thereby water fertility. Guidelines for *p*H value for fish production are given in Table 26.1.

Table 26.1. Effect of *p*H on fish

*p*H	Effect
4	Acid death point
4-6	Slow growth
6-9	Best for growth
9-11	Slow growth, lethal to fish over long period of time
11+	Alkaline death point

Signs of sub-optimal *p*H are as follows.

- increase of mucus on gill surface
- damage to eye lens and cornea
- abnormal swimming behaviour
- fin fray
- death
- poor phytoplankton and zooplankton growth.

Effects of sub-optimal *p*H are as follows.

- stress
- increased susceptibility to disease
- low production levels
- poor growth

Causes of sub-optimal *p*H are as follows.

- acidic water and soils
- acid sulphate soils
- poorly buffered water, i.e. low alkalinity (<20 mg/litre)
- waters having high alkalinity and low hardness
- acid rain

Measures for rectifying alkaline and acidic water-bodies are as follows.

Alkaline waters

- Ensuring good water management may rectify rapid fluctuations in *p*H, caused by excessive phytoplankton populations. Water-body should have an alkalinity of more than 75 mg/litre as $CaCO_3$.
- Application of acid-forming fertilizers.

Acidic waters

- Calcium carbonate ($CaCO_3$), calcium hydroxide ($Ca(OH)_2$), calcium oxide (CaO) or dolomite is used to rectify acidic water-bodies depending upon the *p*H.

- Salt water like sea-water may be flushed through water-bodies of coastal farms to neutralize acidity.

Total alkalinity

Alkalinity refers to the total amount of bases in water, expressed in mg/litre of equivalent calcium carbonate. A base is a substance that releases hydroxyl ions (OH^-) when dissolved in water. In most waters, these bases are principally bicarbonate (HCO_3^-) ions and carbonate ions (CO_3^{2-}). These ions are buffers in water; that is they buffer water against sudden changes in *p*H. They can do this by absorbing hydrogen ions when the water is acidic and releasing them when water becomes basic. Waters of low alkalinity (<20 mg/litre) are poorly buffered, and removal of carbon dioxide (CO_2) during photosynthesis results in rapid rise in *p*H. Waters with greater than 20 mg/litre alkalinity have greater buffering capacity and prevent large fluctuations in *p*H during photosynthesis.

Guidelines for alkalinity for fish growth are as follows.

- 300 mg/ litre–create stress to fish;
- 75–300 mg/ litre–ideal for fish;
- <75 mg/ litre–create stress to fish.

Total hardness

Hardness is the concentration of metal ions (primarily calcium and magnesium), expressed in mg/litre of equivalent calcium carbonate. Alkalinity and hardness values are normally similar in magnitude because calcium, magnesium, bicarbonate, and carbonate ions in water are derived in equivalent quantities from the solution of the limestone in geological deposits. However, in some waters alkalinity may exceed its hardness and vice versa. If alkalinity is high and hardness low, *p*H may rise to very high levels (greater than 10.5) during rapid photosynthesis.

Waters are often categorized as follows according to degrees of hardness.

- 0-75 mg/litre – soft
- 75-150 mg/ litre – moderately hard
- 150-300 mg/ litre – hard
- over 300 mg/ litre – very hard

Guidelines for hardness value for fish growth are given as follows.

- 60 mg/ litre–satisfactory for pond productivity and helps protect fish against harmful effects of *p*H fluctuations and metal ions;
- <60 mg/ litre – creates stress to fish.

Alkalinity and hardness are not much affected by biological activity or aquacultural operations, and the initial concentrations in ponds are determined by their levels in the water supply; any changes are largely the result of rainfall and evaporation. Desirable levels for fish culture generally fall within the range of 75-300 mg/litre. If total alkalinity and total hardness are too low, liming may raise them. However, there is no practical way of decreasing alkalinity and hardness when they are above desirable levels. As a general rule, the most productive waters for fish culture have a hardness and alkalinity of approximately the same magnitude. For example, water with an alkalinity of 100 mg/litre and hardness of 10 mg/litre is not as good for fish culture as the water in which alkalinity is 100 mg/litre and hardness is 100 mg/litre. Greater production does not result directly from higher levels of hardness and alkalinity per se, but from the higher concentrations of phosphorus and other essential elements that increase along with hardness and alkalinity.

Water hardness also affects fish health because it influences osmoregulation. Being open systems, fish are affected by make-up of the surrounding water. As a consequence of osmosis, freshwater fishes are subjected to a continuous influx of water, while marine fishes live with a continuous outflow of water.

Against this continuous movement of water into or out of the body, fishes have to maintain a constant internal body fluid concentration – a process called osmoregulation. The greater the difference in concentration between fish's body fluids and surrounding water – the greater is the osmotic effect. As hard water is more concentrated than soft, there will be less difference and therefore less water influx > and consequently fishes will not be stressed hard at osmoregulation. This is particularly important in cases of bacterial ulceration, where water can flood into open tissues.

Carbon dioxide

It is present in the atmosphere in very small quantity. For this reason, in spite of its high solubility in water, its concentration in most water-bodies is low. It occurs in water in three closely related forms– (*a*) free carbon dioxide, (*b*) bicarbonate ion (HCO_3^-), and (*c*) carbonate ion (CO_3^{2-}). Each form amount present depends on the *p*H of water. For example, in neutral or acidic waters, high concentrations of free carbon dioxide, i.e. toxic form is frequently found. Guidelines for carbon dioxide value for fish-ponds are as follows.

- 12-50 mg/litre – sub-lethal effects include respiratory stress and development of kidney stones (nephrocalcinosis) in some species;
- 50-60 mg/litre – lethal to many fish species with prolonged exposure.

Measures for controlling high carbon-dioxide concentration include the following.

- Repeated aeration of water;
- Increasing *p*H of water by hydrated lime that can control high carbon-dioxide concentration. Experiments have shown that 1.0 mg/litre of hydrated lime can remove 1.68 mg/litre of free CO_2; and
- Correct stocking, feeding and fertilization should regulate phytoplankton population and organic loading in a water-body.

Iron

In surface waters, iron occurs in ferrous state II (soluble compounds) or ferric state III (mostly insoluble compounds) forms. Ratio of these two forms depends on the oxygen concentration in the water, *p*H and on other chemical properties of water. Poorly oxygenated waters with low *p*H, where iron is mainly in the form of soluble compounds, may harm fishes. Because gill surface of the fish tends to be alkaline, soluble ferrous iron can be oxidized to insoluble ferric compounds, which then cover gill lamellae and inhibit respiration. At a low water temperature in the presence of iron, iron-depositing bacteria multiply rapidly on gills, and further contribute to oxidation of ferrous-iron compounds. Their filamentous colonies cover gills; at first they are colourless but later precipitated iron gives them brown colour. The precipitated iron compounds and tufts of iron bacteria reduce gill area available for respiration, damage respiratory epithelium and may thus suffocate fish. In a similar toxic action, iron compounds precipitate on the surface of fish-eggs, which die owing to lack of oxygen.

Many groundwaters contain elevated levels of dissolved iron. When exposed to air, this iron interacts with oxygen, becomes insoluble, and forms red deposit. Small clumps of iron produced can settle on fish gills, causing irritation and stress. Problems can be avoided if iron-bearing water is exposed to air and resultant iron clumps are removed by settling or filtration before water enters culture system.

Lethal iron concentration for fish is not easy to measure because it depends to a large extent on the physico-chemical properties of the water. In cyprinid culture, it is generally accepted that concentration of iron soluble ionized forms should not exceed 0.2 mg per litre; for salmonids, this limit is 0.1 mg per litre.

Chlorine

To control bacteria, municipal water supplies are treated with chlorine at 1.0 mg/litre. If municipal waters are used to culture fish, residual chlorine must be removed by aeration with chemicals such as sodium thiosulphate, or filtration through activated charcoal. Chlorine levels as low as 0.02 mg/litre can stress fish.

Plankton, blue-green algae and macrophytes

Plankton comprises all microscopic organisms that are suspended in water and include small plants (phytoplankton), small animals (zooplankton) and bacteria. When there is enough plankton in the water to discolour it, water is said to contain plankton bloom. Because plankton forms base of food-web; there is a strong relationship between plankton abundance and fish production. Plankton bloom is a common feature of fish-culture ponds.

Types of phytoplankton include green algae, yellow-green algae, blue-green algae and diatoms. In summer, phytoplankton blooms contain blue-green algae, which can form scums at the surface. These scums absorb heat during day and may cause shallow thermal stratification. During night, heavy plankton blooms consume large amounts of dissolved oxygen and may cause oxygen depletion before next morning. Plankton may suddenly die, decompose, and cause oxygen depletion. Factors causing this include exhaustion of available nutrients, increased clay turbidity and changes in water quality (e.g. cold change, cloudy and rainy days). Excessive phytoplankton blooms can also cause large diurnal fluctuations in water quality variables (e.g. very high *p*H and NH_3 levels) in mid-afternoon; such conditions are stressful to fish.

Blue-green algae can cause other problems in aquaculture besides fluctuating water quality parameters. They can produce toxic substances that are lethal to some fishes. They can also produce compounds that impart a strong off-flavour to fish. Fish from these ponds may be off-flavoured to be unmarketable. This is why it is important to clean or purge fish by placing them in clean water before sending them to market.

The larger aquatic plants or macrophytes include pondweed and milfoil. They are undesirable in fish-ponds because of the reasons given here.

- interfere with fish management such as seining, feeding and harvesting;
- compete with plankton for nutrients;
- Provide shelter for undesirable fish;
- contribute to oxygen depletion and high ammonia levels when they decompose;
- contribute to water loss through evapotranspiration.

Management options to reduce macrophyte growth include the following.

- drying and desilting of ponds every 1-2 years;
- mechanical harvesting;
- increasing phytoplankton turbidity (fertilizing);
- herbicides application.

Water colour

Fish farmers pay much attention to colour of pond-water. In other words, they give more importance on the promotion of phytoplankton in pond-water. Five following objectives associated with water colour can be identified: (*i*) to increase dissolved oxygen and to decrease CO_2, NH_3, H_2S and CH_4 in pond-water, (*ii*) to stabilize water quality and to lower content of toxic compounds, (*iii*) to make use of plankton as a natural feed, (*iv*) to provide shade and to decrease cannibalism, (*v*) to increase and stabilize water temperature.

Seven types of water colour that can occur in pond are as follows.

- **Reddish-brown or pinkish-red:** Blooming diatoms cause this colour. Algae species *Chaetoceros, Navicula, Nirzschia, Skeletonema, Cyclotella, Synedia, Achnanthes, Amphora* and *Euglena* are often found in pond-water of this colour, especially the first three species. This colour is quite difficult to achieve. Diatoms, excepting *Biddulphia,* are generally nutritious to fish and prawns.
- **Light or bright green:** This colour is due to green algae, especially *Chlorella.* In addition, *Dunaliella, Platynons, Carteria, Chalmydomonas* are also present. Water of this colour is usually stable. Fish and prawns grow very well in this pond type. Therefore, water of this colour should be the target of farmer.
- **Dark green:** When pond-water temperature gets too high or organic materials accumulate too fast, blue-green algae blooms faster than green algae. Blue-green algae *Oscillatoria, Pharmidium* and *Microcoleus* dominate. Although fish and prawn survival rate in the ponds is not affected but growth rate declines.
- **Dark-brown colour:** Poor pond management such as over-feeding or using large amount of trash fish causes rapid growth of dinoflagellates and brown algae and consequently result in formation of this water colour. Such water conditions are undesirable, and it is recommended to change pond-water partially if this colour appears.

- **Yellowish colour:** Yellow water formation is due to Chrysophyta growth. In addition, green flagellates may also grow moderately. Because all these algae are very small in size, they cannot be used directly as natural foods. Fish and prawns growth is inhibited in this kind of water. In many cases, mortality may be very high.
- **Turbid water:** Turbid water formation may be due to suspension of zooplankton, clay particles or detritus. This kind of water can be beneficial or harmful depending on the quality and quantity of suspended materials.
- **Clear water:** This water is transparent. This may be owing to lack of nutrients, presence of heavy metal, pollution of copper, manganese, iron and acid bottom clay (*p*H 5.5 or lower). Under these conditions, no organisms can grow properly. This kind of water is not ideal for culture of fish and prawns.

Following are some guidelines for water colour for fish growth.

- Some types of water colours are desirable, some are not. To achieve a particular colour, fertilizers may be used.
- It is suggested that ammonium salts are good for green algae growth while urea is good for brown algae (i.e. diatoms).
- When colour becomes undesirable owing to over-blooming, bacteriocides, insecticides and algaecides are to be used.
- Increasing aeration and/or partial replacement with clean water may also be helpful in changing water quality.
- Feeding greatly influences water colour and water quality. Over-feeding should be avoided. Too much trash fish use may cause blooming of flagellates that are not desirable.

Bottom soil management

The role of the bottom soil in determining productivity of a pond is well documented. The production of various primary food organisms depends largely on the availability of different nutrients. Dynamics of availability of most of these nutrients, in turn, is determined by the condition prevailing in the bottom soil. Considering this significance, bottom soil is designated as the chemical laboratory of the pond. However, suitable soil problems are common in aquaculture ponds, and therefore, many methods are used for improving soils of pond.

Texture

Nature and properties of the parent material forming soil determine soil texture. Many important physico-chemical properties for fertility of fish-ponds are influenced to a great extent by the proportion of different size fractions of soil. An ideal pond soil should not be too sandy to allow leaching of nutrients or should not be too clayey to keep all nutrients adsorbed. When the pond is constructed on the sandy soils, heavy doses of organic manure are essential to control seepage loss of water. In general, raw or composted farmyard manure dose varies from 10,000 to 15,000 kg/ha/year.

Soil acidity

Soil may be acidic, alkaline or neutral; the ideal range of *p*H is 6-8. Water passing over acid soil tends to be acidic with low alkalinity and hardness. High concentration of metal ions particularly aluminium and iron may also be present. Acid ponds do not respond well to fertilization. Liming is the only way to improve water quality in ponds with acid soils, and it is the *p*H of the soil that must be corrected for lasting effects, rather than *p*H of water.

Acid sulphate soils

Acid sulphate soils from mine spoils and coastal mangroves contain high levels of pyrite (FeS_2 1-6%). As long as sediments containing pyrites are submerged and anaerobic, they remain reduced and change little. However, as they are drained and exposed to air, they oxidize and form sulphuric acid. Sulphuric acid reduces water *p*H when pond is filled. In ponds, problems with acid sulphate soils usually originate in pond-dykes. Pond bottoms are usually flooded and anaerobic, so sulphuric acid does not form. However, dykes dry and sulphuric acid formed during dry period enters pond through run-off water after rains. Acidity on dykes can be controlled by liming (0.5-1.0 kg/m^2) and by establishing good cover with an acid-resistant grass species.

A procedure for rapid reclamation of ponds with acid sulphate involves drying and filling of soil to oxidize pyrite, filling pond with water and holding water till *p*H drops to below 4, and then draining pond; repeat procedure till *p*H stabilizes at or above 5, and then lime pond with 500 kg of calcium carbonate per hectare.

Bottom-soil oxidation

Dissolved oxygen cannot move rapidly into water-saturated soil, and pond soils become anaerobic below the depth of a few millimetres. Aeration and water circulation are beneficial in improving bottom-soil oxidation, but the surface layer of the soil may still become anaerobic in intensive fish culture ponds. When redox potential is low at the soil surface (anaerobic conditions), hydrogen sulphide and other toxic microbial metabolites diffuse into pond water. Sodium nitrate can serve as a source of oxygen for microbes in poorly oxygenated environments; the redox-potential will not drop low enough for formation of hydrogen sulphide and other toxic metabolites.

Drying pond bottoms

When pond bottoms are dried between crops, evaporation of water from soil-pores and cracking of soil enhances aeration and favours microbial decomposition of soil-organic matter. Excessive drying makes soil too dry for even microbial activity; a drying period of 2-3 weeks is usually adequate. Tilling of dry soil with a disk harrow can improve aeration, but tilled bottoms of aerated ponds should be compacted before refilling to reduce tendency of erosion.

Good practices for bottom-soil management

Major concerns in pond bottom-soil management are low soil *p*H, high soil-organic

Table 26.2. Good management practices for pond bottom-soil quality

Problem	Preventative measure
Low soil *p*H	• Neutralize acidity of new pond bottom-soil before initiating aquaculture • In old ponds that have never been limed, apply agricultural limestone according to the soil *p*H (*see* text) • Use urea and ammonium fertilizers conservatively as they are acid forming • Monitor total alkalinity of pond-waters and soil *p*H to assure that total alkalinity is above 75 mg/ litre in fish-pond and soil *p*H is above 7 • After initial correction of soil *p*H, apply agricultural limestone to bottoms of empty ponds at 1,000 kg/ ha during fallow period between crops. If ponds are full, apply to water
High soil organic matter	• Select sites without organic soil • Where soils are organic, apply agricultural limestone and urea (200 to 400 kg/ha) to encourage degradation of organic matter during fallow periods. Repeat after each crop • Use moderate stocking rates to avoid high inputs of nutrients and organic matter in fertilizers, manures and feeds • Dry ponds between crops, apply agricultural limestone according to soil *p*H (*see* text), and till heavy-textured soils to encourage oxidation of organic matter by bacteria • In areas where pond bottom soils cannot be dried, apply nitrate fertilizer at 20 to 40 g/ m^2. • Monitor soil organic matter concentrations annually. More than 3% organic carbon (about 6% organic matter) suggests excessive organic matter
Loss of oxidized layer	• Practice preventive measures for avoiding accumulation of organic matter in soil listed above • Where a surface layer high in organic matter has developed in bottom soils, use turning plough to bury this layer and expose higher quality soil • Monitor appearance of soil. The upper few millilitres should be of natural soil colour or brownish. A gray or black colour at surface indicates reduced (anaerobic) conditions • Use a rake or chain to scarify surface soil during crop if it appears anaerobic • Remove accumulation of organic matter from corners of ponds • Maintain adequate plankton to restrict light and prevent mats of benthic algae. • Remove soft sediment from ponds as suggested below
Excessive accumulation of soft sediment	• If water supply has high concentrations of suspended solids, pass water through a settling basin before putting it in ponds • Establish grass cover to minimize erosion on watersheds and embankments of ponds • Use proper side slopes and compaction when constructing new ponds or renovating old ones • In ponds with mechanical aeration, install aerators to prevent water currents from eroding insides of embankments • If sites of active erosion are observed, measures for lessening erosion should be installed. These measures may include installation of rip-rap, proper sloping and compaction, grass cover, etc • When ponds are empty between crops, remove sediments from deep areas and place them on areas from which eroded. Proper sloping and compaction, establishment of grass above water level, or installation of rip-rap will lessen erosion potential • Do not leave ponds empty longer than necessary during rainy season to prevent erosion of soil from shallow area with deposition of soil in deeper areas • If bottoms of heavily aerated ponds are tilled between crops, compact bottoms with heavy roller before refilling • Do not allow livestock to walk on pond embankments or wade in shallow water-edges • Avoid operating equipment that will cause ruts and other inundations in pond bottoms • Monitor pond bottoms for soft sediment and remove such sediment periodically instead of waiting until a severe problem develops

matter, loss of oxidized layer, and accumulation of soft sediment. Although procedures outlined above can be used to correct soil-quality problems; pond-managers should still strive to prevent development of severe soil problems. Soil deficiencies should be identified and treated in new ponds instead of waiting until poor bottom-soil quality develops later. For example, if soil in a new pond is acidic, it should be limed before initiation of aquaculture. And liming material should be applied in a moderate quantity after each crop to maintain acceptable soil *p*H. In older ponds with impaired soil quality, problems should be corrected and prevented from recurring. Some good practices for protecting soil quality are provided in Table 26.2.

Liming in fish-ponds

Fish-farmers adopt liming in fish-ponds for improvement of pond condition. As water quality is more or less a reflection of the soil condition within certain limits, so liming is usually done on the basis of the soil properties. Moreover, alkaline waters in the *p*H range of 7.5-8.5 with an acid combining capacity of more than 50 ppm are considered suitable for various physiological processes of fishes. Such favourable water conditions are feasible only when soils have *p*H in the range of 6.5-7.5. Besides, the deleterious effects of *p*H on the environmental conditions affecting aquatic animals, other harmful effects developed during culture operations are also reduced or corrected through liming. So knowledge of various liming materials, their efficiency and suitable doses are desirable for maintaining a healthy aquatic environment for successful carp-culture practices.

Liming materials: They are substances containing calcium and magnesium compounds capable of neutralizing acidity. Accordingly, the most common liming materials are oxides, hydroxides and carbonates of calcium and magnesium having higher percentage of calcium compared to magnesium. Besides these, a number of industrial wastes containing appreciable percentage of CaO, viz. basic slag, cement factory wastes, and paper-mill sludge, have also been found suitable for use as liming materials with reduced expenditure. However, large-scale uses of these materials have not yet been undertaken. Rock phosphate containing calcium besides phosphorus may be used as a source of phosphorus in acid soils, but only to a limited extent due to its effectiveness under moderately acid conditions, which is rather undesirable for fish-ponds.

Chemical changes due to different liming materials, which occur, may be represented as follows.

$$CaO + 2H^+ \rightarrow Ca^{2+} + H_2O$$
$$Ca(OH)_2 + 2H^+ \rightarrow Ca^{2+} + 2H_2O$$
$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2O + CO_2$$
$$CaMg\,(CO_3)_2 + 4H^+ \rightarrow Ca^{2+} + Mg^{2+} + 2H_2O + 2CO_2$$

Liming materials' effectiveness depends on their neutralizing capacity, particle size and physical properties. Neutralizing power is the ability for neutralizing acidity. Pure $CaCO_3$ is considered to have a neutralizing value of 100%, and is used as the standard.

Particle size of less than 0.25 mm (100-mesh) is considered 100% efficient, and particles retained by 8 mesh are rated as zero % efficient. Quicklime and slaked lime are fine powders, so they are very efficient compared to others. Dolomite, calcite, basic slag and rock phosphate are efficient when applied in finely powdered form.

Benefits of liming: Liming establishes a strong *p*H buffer system, and thereby prevents sudden fluctuation in environment, that is considered detrimental for aquatic life. Liming with low alkalinity will increase morning *p*H values and alkalinity. Limed ponds have reduced *p*H fluctuation.

Carbon dioxide availability for photosynthesis also increases due to liming. Lime reacts with carbon dioxide and as a result, excess CO_2 present in the water is removed to form carbonates and bicarbonates according to the equation.

$$CaO + CO_2 \rightarrow CaCO_3$$
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$
$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2H_2CO_3^-$$
$$CaMg\,(CO_3)_2 + 2CO_2 + 2H_2O \rightarrow Ca^{2+}\ Mg^{2+} + 4HCO_3^-$$

Thus, CO_2 fixed through liming is available for future use by plants in photosynthesis in the absence of CO_2. Plants and phytoplankton also use bicarbonate and carbonate as a source of CO_2. Hence, application of lime also competes with plants for CO_2 and may reduce photosynthesis temporarily.

Liming counteracts poisonous effect of excess magnesium, potassium and sodium ions. Calcium content of lime displaces certain other elements from organic colloidal system, thus making available greater quantities of such material as K^+ and PO_4^{3-} when they are applied as manure in the pond. The *p*H of acidic soils raised by liming increases microbial activity, and thus favours mineralization of nitrogen and other nutrients through decomposition of organic matter. Humic acid and sulphuric acid produced during decomposition of organic matter are also neutralized with the application of oxides and hydroxides of lime. Toxic and caustic actions of liming materials kill bacteria as well as fish parasites in their various stages of life-cycle, and thus render fishes less liable to diseases. Lime reduces turbidity caused by suspended silt and clay particles and humic substances.

Lime requirement: For ponds, it depends on the texture and *p*H of soils. Heavy soils need more lime than sandy soils and the amount of lime required increasing with increased acidity. Agricultural procedures based on soil *p*H and soil texture for determining lime requirement have been followed by various workers. Doses of lime recommended for fish-ponds at different *p*H values for soils having texture neither too sandy nor too clayey are presented in the Table 26.3. The amount may be modified depending on the mechanical composition of soil. Accordingly, dose is increased about 50% for clayey soils while percentage is reduced for sandy soils. Use of chemical fertilizers, organic manure, artificial feed and other

Table 26.3. Lime doses at different *p*H values of soils

*p*H	Soil condition	Dose of lime (kg/ha)
4.0-4.5	Highly acidic	1,000
4.5-5.5	Medium acidic	700
5.5-6.5	Slightly acidic	500
6.5-7.5	Near neutral	200

management practices reduce *p*H of bottom soil. To neutralize this, liming at 200 kg/ha/year is recommended even at near neutral to slightly alkaline soil *p*H.

Method of application of liming materials: Among different forms of liming materials (oxide, hydroxide and carbonate), agricultural limestone is generally used in fish-ponds. It is low-priced and does not create any harmful effects, compared to oxides and hydroxides, which are used under specific conditions for control of diseases.

Lime may be applied either to the pond bottom after draining or to the water at the inlet, or spread on the water surface. Quicklime should, as far as possible, should be applied to ponds after draining. Liming should be applied on to pond bed when it is desired to improve pond bottom or to control parasites. But for controling diseases or precipitation of organic substances and removal of turbidity in acid water, liming materials are broadcast on the water surface. In certain cases, oxide or hydroxide form of lime is applied to ponds for control of diseases but the same should be avoided in nurseries. Newly constructed ponds should be limed prior to filling with water. Maintenance of desired soil *p*H is rather difficult by liming due to relationship between reserve and exchange acidity of soil; so frequent applications of lime in split doses are considered effective to achieve desired results.

Fertilization of fish-ponds

Natural productivity of a fish culture system depends largely on the availability of the natural food organisms, on the favourable environmental conditions, and on the optimum doses of fertilizers.

Fertilizer management in freshwater aquaculture

In India, potential areas for inland aquaculture have already been explored, and additional production can only be achieved through successful manipulation of available resources that influence productivity of various aquaculture systems. This can be achieved is through maintenance of adequate levels of nutrients in the pond environment.

Fertilization requirements of fish-ponds: Phytoplankton that give water its green colour is the first step in the food-chain of fish-ponds. Other organisms also feed on them and multiply, increasing availability of natural foods for fishes stocked in the pond. In addition to carbon dioxide (CO_2), water and sunlight for carbohydrate synthesis, phytoplankton need mineral elements, including nitrogen, phosphorus, potassium, calcium, sulphur, iron, manganese, copper and zinc for growth and nutrition. Pond soil plays an important role in regulating concentration of nutrients in the pond water. Knowledge of the nature and properties of pond soil can help a farmer to develop efficient management practices that will boost production. The most important chemical properties of bottom-soil influencing nutrient management practices of ponds are as follows.

Properties of pond soils: The most important chemical properties of bottom-soil influencing nutrient management practices of ponds are as follows.

Soil reaction (pH): Soil *p*H is one of the most important factors for maintaining

pond productivity since it controls most of the chemical reactions in the pond. Near neutral to slightly alkaline soil *p*H (7 and a little above) is considered ideal for fish production; if too low (strongly acidic), this can reduce availability of key nutrients in the water and lower pond fertility.

Organic carbon content: Organic carbon acts as a source of energy for bacteria and other microbes that release nutrients through various biochemical processes. Pond soils with less than 0.5% organic carbon are considered unproductive while those with 0.5-1.5% and 1.5-2.5% have medium and high productivity respectively. Organic carbon content of more than 2.5% may not be suitable for fish production, since it may lead to an excessive bloom of microbes and oxygen depletion in the water.

Carbon : nitrogen ratio: This ratio of soil, influences activity of soil microbes. This, in turn, affects rate of release of nutrients from decomposing organic matter. The rate of breakdown (mineralization) is very fast, moderately fast and slow at the C:N ratio in the range of less than 10, 10-20 and more than 20 respectively. In general, C:N ratio between 10 and 15 is considered favourable for aquaculture and of 20:1 or narrower gives good results.

General nutrient status: Nitrogen, phosphorus and potassium are major nutrients required by phytoplankton. Inorganic fertilizers can be applied to provide these nutrients. The appropriate dosage depends on the amount of individual nutrients present in the pond soil in available form. Generally, relatively small amounts of potassium are needed in fish-ponds. However, newly constructed ponds or those situated on poor soils may need potassium also. The single most critical nutrient for maintenance of pond productivity is available phosphorus content of soil and water. Pond soils with 30 ppm, 30-60 ppm, 60-120 ppm and more than 120 ppm available phosphate (P_2O_5) are considered to have poor, average, good and high productivity, respectively. Ponds with less than 250 ppm available soil nitrogen are considered to have low productivity while concentrations in the range 250-500 ppm and above 500 ppm are considered to be medium and highly productive.

Fertilization schedule of nursery ponds: Natural productivity of nurseries is often unsatisfactory due to deficiency of one or more of nutrient elements in the soil and water, which may be caused by other environmental conditions. Correction of deficiencies by application of manures or fertilizers containing these nutrients in suitable form and in optimal amount is necessary to accelerate biological production and for enhancing productivity. Accordingly, small shallow ponds are preferred for nurseries for easy management and manipulation of environment.

Organic manures use: Both organic manures and chemical fertilizers are widely used for improving productivity of nurseries. Cow-dung is the most widely used organic manure in many areas, and is typically applied at 5,000-15,000 kg/ha in one installment well in advance of stocking with spawn, preferably at least a fortnight prior. Amount is reduced to 5,000 kg/ha when *mahua* oil-cake is used as a fish toxicant in shallow nursery ponds. Sometimes, to hasten the process of decomposition of added manures, nurseries are limed ($CaCO_3$) at 250-350 kg /ha after manure application. Sometimes spaced manuring with cow-dung at 10,000 kg/ha 15 days prior to stocking, followed by subsequent application of 5,000 kg/ha, seven days after stocking has been practised for sustainable production of zooplankton in nurseries. When more than one crop is raised, nurseries may be manured with cow-dung at 5,500 kg/ha immediately after removal of first crop. Besides, cow-dung, a combination of mustard oilcake, cow-dung and poultry manure in 6:3:1ratio at 1,100 ppm has been successfully used for culturing zooplankton for carp spawn.

Inorganic fertilizers: These fertilizers containing a fixed percentage of individual nutrient elements or a combination of more than one element are also able to enhance productivity of nurseries. Nitrogen: phosphorus (N : P) at 4:1 is considered most effective for increased production in nurseries. Weekly application of nitrogen: phosphorus: potassium mixture (N : P : K) in 8:4:2 ratio is suitable for increased production of fish food organisms. N : P : K in 18:8:4 ratio at 500 kg/ha after liming at 200 kg/ha is effective in enhancing production of slightly acidic and unproductive soils used for nurseries.

Nitrogenous fertilizers containing different forms of nitrogen (amide, ammonium-cum-nitrate and ammonium) are suitable for management of nurseries. Three forms of fertilizers (e.g. urea, calcium ammonium nitrate and ammonium sulphate) are effective for slightly acidic to neutral, moderately acidic and alkaline soils respectively, and rate of 80 kg nitrogen/ha is most suitable for rearing rohu spawn in the nurseries.

Combined organic and inorganic fertilization: Combined fertilizer use is another strategy for increased production of either fish food organisms or fry. Combination of mustard oilcake and 6:8:4: N: P: K inorganic fertilizers on equivalent nutrient basis (at 12 kg nitrogen/ha) is suitable as compared to either organic or inorganic fertilizers for nutrient management of nurseries. However, on an equivalent nutrient basis (N: P: K), organic manure (cow-dung) is most suitable compared to either inorganic fertilizer or combined use of organic and inorganic fertilizers.

Fertilization of rearing and stocking ponds: Acidic pond soils reduce microbial activity and availability of nutrients in pond water and may render fertilization ineffective. Therefore, lime application is the first step of management for all stages of fish culture. Liming raises soil *p*H to a desirable level (near neutral) and establishes a strong buffer system in the aquatic environment, improving effectiveness of fertilization.

Liming stimulates microbial decomposition of organic matter, supplies calcium to pond, increases nitrate content in pond and maintains sanitation in pond environment. Generally, ground limestone is extensively used and spread over dry bed or broadcast over water surface in a single dose at least 15-20 days before stocking. On the basis of soil *p*H, lime dosages are applied to ponds. Besides initial application, some compensatory applications of lime in the range of 100-200 kg/ha may also be made in the stocking pond from time-to-time to neutralize acidity developed through application of acid-forming inorganic fertilizers and organic manures and also when fishes are diseased or distressed.

In India, organic manures are more commonly used than inorganic fertilizers. A variety of agricultural wastes, including cow-dung, poultry droppings, pig manures and biogas slurry can be used as organic manures. In rearing ponds, application of raw

cow-dung or biogas slurry is observed to give better results. Depending on the organic carbon content of pond soil in the rearing pond, application of raw cow-dung or biogas slurry in the range of 3-7 or 5.5-12 tonnes/ha respectively and addition of 2.5-5 tonnes/ha/year of cow-dung or 10-30 tonnes/ha/year biogas slurry or 5-15 tonnes/ha/year poultry droppings, respectively, in the stocking ponds give good results. In rearing ponds, usually 50% of the total requirement is given 15-20 days prior to stocking of fry and the remaining in two equal monthly splits during rearing period. In stocking ponds, on the other hand, 20% of the total requirement is applied initially and the rest is given in equal monthly splits. But if the ponds are treated with *mahua* oilcake to eradicate unwanted fishes, initial application of organic manure can be dispensed of in both the culture systems.

Efficiency of nitrogen fertilizers in enhancing productivity of ponds depends largely on their forms. Commonly used nitrogen fertilizers are urea, ammonium sulphate and calcium ammonium nitrate. Among these, urea is suitable for slightly acidic to neutral soil, ammonium sulphate for alkaline soil and calcium ammonium nitrate for acidic soil. Depending on the available nitrogen content of the pond soil, application of 50-70 kg nitrogen/ha (i.e. 108-152 kg urea/ha; 200-280 kg calcium ammonium nitrate/ha; 250-350 kg ammonium sulphate (ha) in rearing ponds and 75-150 kg/ha/year (i.e. 163-326 kg urea /ha/year; 300-600 kg calcium ammonium nitrate /ha/year; 375-750 kg ammonium sulfate/ha/year) in stocking ponds give good results. Fertilizer should be applied in equal monthly splits alternately with organic manure with a gap of about a fortnight.

Single superphosphate (SSP) is the most commonly used phosphate fertilizer in the fish ponds. Depending on the available phosphate content of the pond soil, application of 25-50 kg phosphate (P_2O_5) /ha (i.e. 156-312 kg SSP/ha) and 40-75 kg P_2O_5/ha/year (i.e. 250-468 kg SSP/ha) in the rearing and stocking ponds, respectively, gives good results. To get better utilization efficiency, phosphorus fertilizers should be applied in weekly intervals and the first installment should be given seven days after initial organic manuring.

Muriate of potash (potassium chloride, KCl) and sulphate of potash (potassium sulphate, K_2SO_4) are commonly used as potassium fertilizers in fish-ponds. Application of 10-20 kg K_2O/ha (i.e. 16-32 kg KCl/ha or 20-40 kg K_2SO_4/ha) and 25-40 kg K_2O/ha/year (i.e. 41-66 kg KCl/ha or 52-83 kg K_2SO_4/ha/year) in the rearing and stocking ponds, respectively, gives good results. The fertilizer should be applied in equal monthly splits. If thick green or blue-green blooms of algae develop in the pond, to avoid oxygen depletion, manure and fertilizer applications should be suspended.

Careful use of organic manures and chemical fertilizers in combination is a sound strategy. Occasional development of unhygienic conditions in the ponds may be avoided by using pre-decomposed organic manure. Use of excessive amounts of raw organic manure can result in excessive blooms of microbes during aerobic breakdown, which can also cause oxygen depletion.

Fertilizer management in brackishwater aquaculture: Soil and water quality for brackishwater aquaculture is almost similar to freshwater aquaculture, excepting water salinity. Salinity represents quantity of dissolved salt in a given unit of water, and is usually expressed in g/kg of water (ppt). In brackishwater ponds, salinity usually ranges between 0.5 ppt and 30 ppt, depending on the distance from sea and seasonal variations due to monsoon precipitation.

The effect of salinity on the growth and availability of fish food organisms may be due to its direct influence on the physiological processes or due to its effect on the transformation of nutrient elements. Most of the brackishwater species of commercial importance are euryhaline in nature, which is related to their osmoregulatory adoptions. However, effect of salinity on the survival and growth of *Penaeus monodon* has been studied widely for its importance in global market. Though, it is euryhaline in nature, high mortality and poor growth rate were found at salinities lower than 10 ppt. The salinity, which supports normal growth of *P. monodon*, is between 15 and 30 ppt. However, *P. monodon* could also survive and grow well at lower salinities and can tolerate freshwater for a month.

In India, culture fisheries resources of brackishwater sector surpass in magnitude to those pertaining to freshwater ponds. However, in comparison to freshwater sector, production in brackishwater fish-ponds is comparatively low. Lack of presence of sufficient fish food organisms has been considered one of the major reasons for such low productivity, and to increase productivity, use of fertilizers and manures has been suggested. Benthic algae form principal food item for all non-carnivorous brackishwater fishes and prawns. These algae grow on the surface of the bottom soils and derive their sustenance either directly from soil or from soil-water interphase. Concentrations of nutrient elements in either case are largely governed by the amount of water soluble and exchangeable ions present in the surface layer of the bottom soils. Considering this phenomenon, fertilization of brackishwater fish-ponds is radically different in concept and practice from that of freshwater ponds. Since the purpose of fertilizing brackishwater fish-ponds is to increase growth of benthic algae, fertilizers in such culture system should be applied at the bottom of the ponds. Response as well as behaviour of different pond-fertilizing materials in brackishwater ponds, therefore, depends largely on their transformation in the pond soils. In addition, widely changing water salinity levels of brackishwater fish ponds also contribute to availability of nutrient elements in such a culture.

Role of soils: Productivity of brackishwater ponds is directly related to nutrient content of the soils. Physico-chemical conditions of the soils of the brackishwater ponds are different from freshwater ponds. Brackishwater soils are characterized texturally by high clay content, chemically by high percentage of sodium and alkaline reactions and physically by low permeability. Acid soils may also pose a problem for brackishwater aquaculture in some states – Kerala, Goa, and West Bengal etc. Considering low organic- carbon content of most of brackishwater soils, use of organic manure may be beneficial for increasing productivity of these ponds. High calcium carbonate content of these soils may be useful in counteracting some of the harmful effects of organic manuring under submerged conditions.

Among different nutrient elements, phosphorus is generally most important because of its striking effects in increasing fish yield. Photosynthesis of fish-food organisms is

directly related with rate of phosphorus absorption in salt-water system. In general, brackishwater pond soils contain fairly good amount of available phosphorus. Although, such availability of phosphorus may be considered beneficial to growth of fish-food organisms, yet large amount of chloride ions in such a environment may affect utilization of this nutrient element due to its antagonistic effect with uptake of chlorides; information in this respect is still meagre.

Nitrogen forms the second important nutrient element in aquaculture. Productivity of brackishwater ponds is directly related to the amount of available nitrogen in their soils. The amount of easily available form of nitrogen is comparatively lesser in brackishwater pond soils. Between two readily available inorganic forms – ammonium and nitrate – ammonium content is comparatively higher due to anaerobic conditions prevailing in submerged soils. Ammonium nitrogen could be beneficial for brackishwater aquaculture since this form remains adsorbed in the soil in exchangeable form that can be utilized readily by benthic algae.

Sea-water, which is utilized for brackishwater aquaculture under different dilutions, contains considerable amount of micronutrient elements. Hence, brackishwater pond soils are not likely to be micronutrient deficient. Such pond soils are fairly well supplied with available Fe, Cu, Mn and Zn, and the magnitude and availability of these elements is influenced considerably by texture, *p*H, electrical conductivity and $CaCO_3$ values of the pond soils.

Behaviour of fertilizers: Among different pond fertilizing elements, nitrogen and phosphorus are generally considered of prime importance in aquaculture. In addition to inorganic fertilization, organic manuring is also done in these ponds not only to provide a steady source of different nutrient elements but also to improve physico-chemical properties of the soils. Nitrogenous and phosphate fertilizers along with organic manure are useful in enhancing production of brackishwater fish-ponds

Nitrogen: Efficiency of nitrogenous fertilizers depends largely on the form in which they are applied. As is well known, nitrates are highly soluble in water, and NO_3^- ions unlike NH_4^+ ions, are not adsorbed by the soil exchange complex and, therefore, are liable to be lost in leaching. Moreover, when the NO_2^- ions enter into lower reducing zone of the pond soil, much of them may be reduced to NO_3 form and ultimately lost as elemental N_2 by the denitrifying bacteria, which function efficiently in anaerobic environment; as exists in the reducing zone of the pond soil.

The ammonium carriers may generally be considered as better fertilizers than nitrate for use in brackishwater fish-pond condition since loss of nitrogen due to leaching and denitrification is much less in this form. Following application of ammonium-bearing fertilizers in the ponds, most of the NH_4^+ ions are likely to be adsorbed by the exchange complex of the bottom, and remain strongly bound there. This behaviour of ammonium carrying fertilizers has been considered of special significance for brackishwater aquaculture since benthic algae derive their nutrients either directly from the soil or from soil water interphase and may be benefited by this form of available nitrogen.

Water salinity of the brackishwater ponds varies within a wide range in different seasons of the year; assuming highest values during summer due to high rate of evaporation and lowest values during monsoon period owing to high precipitation. These changes in water salinity levels may exert profound influence on the transformation of nitrogenous fertilizers in such ponds. Applied nitrogen could be in water soluble form in comparatively higher amount under higher water salinity levels. The loss of added nitrogen through denitrification could also be less under higher water salinities, and this phenomenon attributes towards lower rate of nitrification under higher water-salinity levels.

Considering this behaviour of nitrogenous fertilizers, it may be summarized that ammonium-carrying fertilizers may be considered of greater value for brackishwater ponds and fertilization period should be made short so that influences of changing water salinity levels, loss of nitrogen through dentrification and production of free ammonia under existing high *p*H values may be minimized.

Phosphorus: Among different pond-fertilizing elements, phosphorus is generally considered most important because of its striking effect in increasing fish yield. It is the available form of phosphorus and not the total amount that is important for productivity of ponds. Under natural conditions, fish-ponds usually contain a low concentration of available phosphorus, which often plays the role of a limiting factor in the development of primary productivity in the food chain of fish-ponds. To correct this deficiency, when phosphorus is added to ponds in the form of water-soluble fertilizers, it has been found to disappear rapidly from the available phase by forming different insoluble compounds. The influence of the nature of the bottom soil has a significant role in transformation of applied water-soluble phosphorus in fish-ponds. The increase in different inorganic forms of phosphorus depends on the reaction of the soil. In general, increase in the amount of iron phosphate could occur in the pond soil with acidic reaction while increase in the amount of calcium phosphate could occur in the alkaline soil. Fixation of the total amount of added phosphorus in the soil is maximum in alkaline soil and minimum in neutral soil.

Besides alkaline reaction of the pond soils, behaviour of the applied phosphorus in brackishwater fish-ponds is affected greatly by highly saline water also. This water contains large amounts of calcium that may react readily with applied phosphorus and render it into unavailable form. The large amount of applied water-soluble phosphorus precipitates through formation of calcium phosphate under higher water salinity levels of brackishwater fish-ponds with consequent decrease in amount of available phosphorus into insoluble forms under brackishwater environment. Thus, phosphate fertilizers should be applied in small spilt doses in such ponds.

***Organic manure*:** In India, considering low amount of organic carbon in brackishwater fish-pond soils, application of organic manures is advocated for increasing productivity of such ponds. Beneficial effect of organic manuring on production of penaeid prawns in these brackishwater fish-ponds has also been reported by various workers.

Nature of transformation of organic matter in brackishwater fish-ponds is different from that in other pond conditions. The anaerobic environment of the pond soils influences character of microbial population that governs mineralization of organic matter in the soils. Decomposition of organic matter is carried out only by some facultative and obligate anaerobic bacteria. Anaerobic decomposition of organic materials produce enormous amount of CO_2 with large amount of CH_4, different organic acids, alcohols, etc. depending on the extent of reduction reaction in soils. High concentrations of these may severely affect production of fish-ponds, especially in soil and soil-water interphase. A considerable decrease in the amount of bottom macro fauna generally occurs in brackishwater fish-pond soil immediately after application of organic manure in the form of raw cow-dung.

However, decomposition of organic matter is comparatively slower under submerged conditions, yet it has been observed to increase considerably amount of available nitrogen and phosphorus in the soils. Anaerobic bacteria work at a lower energy level and hence synthetic activity and thereby nitrogen consumption by these bacteria is comparatively low. This results in increased release of available form of nitrogen from unit organic matter decomposed. Decomposition of organic manure creates an intense reducing condition in the pond soil and reduces ferric form of iron to more soluble ferrous form and thus prevents phosphorus to precipitate as insoluble ferric phosphate. Formation of different organic acids through anaerobic decomposition is also known to increase availability of phosphorus through acid extraction.

Wide fluctuations in water salinity levels also largely influence behaviour of organic manures in brackishwater fish-ponds. The rate of decomposition of organic manure in brackishwater pond soil generally declines with increase in water salinity levels. This behaviour may probably be attributed towards lowering of bacterial populations in the soils under higher salinity levels. Considering slower rate of decomposition of organic manures under submergence with highly saline tidal water, well-decomposed organic manure will be beneficial to be used in brackishwater fish-ponds.

Fertilization: In the fertilization programme, application of lime at 200 kg/ha at the initial phase could also be advocated (Table 26.4). However, under any circumstances lime and single superphosphate (SSP) should not be applied at a time. Pre-decomposed organic manure use is likely to be more efficient in brackishwater ponds. Secondly, in view of the existence of a highly dynamic water exchange system of brackishwater ponds, use of inorganic fertilizers may be so scheduled in small split doses so that waste of nutrients due to water removal remains restricted.

Table 26.4. Fertilization schedule for brackishwater ponds*

Fertilizer/ manure	Quantity (kg/ha)	
	Initial	Fortnightly
Cow-dung +	750	75
Poultry manure+	250	25
Urea	50	10
Single super phosphate++	50	10
Rock phosphate ++	150	25

*To modify depending on the basic properties of bottom soil; + one of them; ++ one of them.

Micronutrients and aquaculture

Pond fertilization is to supply certain essential nutrients, which stimulate growth of natural fish-food organisms in the pond. The more abundant is the food in the pond, the quicker is the fish growth. In addition to organic manures, nitrogen and phosphatic fertilizers are mainly used in India for plankton production. Although a general relationship exists between plankton and fish production, resultant effects of fertilizers applied to ponds are mainly governed by a number of intervening factors like soil, water, complex food chains and meteorological conditions. In spite of these, judicial application of fertilizers to fish-ponds for raising level of fish production in the country can be beneficial. Copper, zinc, manganese, cobalt, boron and molybdenum are known as micronutrients, which are needed in small amounts for plankton production.

Micronutrients' role in aquaculture: Zinc, cobalt, manganese and copper play a significant role in aquaculture.

Zinc: Essential function of zinc in living organisms is based on its role as an integral part of a number of metalloenzymes and as a catalyst for regulating activity of specific zinc-dependent enzymes such as carbonic anhydrase, alkaline phosphatase and alcohol dehydrogenase. Addition of zinc can be highly beneficial for fish growth; growth of silver carp and *Catla catla*, in particular. Its recommended doses are as follows: 30 kg zinc sulphate for soil having 0.50 ppm available zinc, 20 kg zinc sulphate for soil with 0.50-0.75 ppm available zinc and 10 kg zinc sulphate per hectare per year for the soil with 0.75-1.00 ppm available zinc. Water soluble, organically bound and to a less extent, exchangeable forms of zinc could principally contribute to pool of available zinc in the sediment.

Zinc is required for the synthesis of DNA and RNA, and is, therefore, essential for cell proliferation. It is essential due to its vital structural and /or catalytic importance in more than 300 proteins that play important role in piscian growth, reproduction, development, vision and immune function. For fish, zinc is second in quantitative importance, next only to iron. At the same time, excessive environmental zinc can have severe impacts upon the survival and growth of aquatic organisms. For example, an experiment conducted at the Central Institute of Freshwater Aquaculture indicated that *Cirrhinus mrigala* advanced fry exposed to 0.10 and 0.15 mg zinc/litre showed a reduction in growth (weight) of 11.1 and 38.8% to that of control (0.01 mg/litre) respectively after 30 days of exposure. Those exposed to 0.03 and 0.06 mg/litre showed an increase in growth of 27.7 and 33.3%, respectively, compared to control. This study clearly showed that waterborne zinc in the range of 0.03 to 0.06 mg/litre could stimulate fish growth.

Cobalt: It plays an important role in nitrogen fixation by rhizobium and it is also a constituent of vitamin B_{12}. Cobalt @10 kg cobalt chloride/year as micronutrient fertilizer could be highly beneficial for fish growth; application is highly beneficial for growth of silver carp and mrigala, in particular. Higher survival of fish spawn could also be achieved by addition of cobalt chloride @ 0.01 ppm per day per fish with supplementary feed. Pond sediment having higher capacity to adsorb cobalt was having higher capacity to desorb cobalt from overlying waters. An experiment conducted at the Central Institute of Freshwater Aquaculture demonstrated that cobalt (as cobalt chloride) exposure @ 0.10 and 0.20 mg/litre showed positive effect on fish growth.

Manganese: It plays an important role in photosynthesis and heterotrophic growth of phytoplankton. Application of manganese increased plankton to about 15% by weight, and the degree of response was found independent of manganese status of soil and water. Manganese activates an essential part of enzyme system that metabolizes protein and energy in all animals. Manganese is also involved in mucopolysaccharide formation, needed for healthy joint membrane. It concentrates in mitochondria and is present in higher concentration in the tissues rich in mitochondria.

Manganese concentration in natural surface water seldom reaches 1.0 mg/litre and is usually less than 0.2 mg/litre; while sea-water typically contains approximately 2 mg manganese/litre. Manganese may be found in deep-well water at concentrations as high as 2-3 mg/litre. Manganese is essential for the growth of aquatic animals but at the same time, at a higher concentrations is toxic to aquatic organisms. It may act as enzyme inhibitors if its concentrations differ from actual physiological requirements, which may lead to either a toxic effect or a growth inhibition. For example, an experiment conducted at the Central Institute of Freshwater Aquaculture indicated that *Macrobrachium rosenbergii* juveniles exposed to 0.3 mg/litre total manganese showed reduction in growth (weight) to 21.3% to that of the control (0.01 mg/ litre) in 60 days of exposure. The same experiment also indicated that feed utilization of *M. rosenbergii* exposed to 0.3 mg/litre lowered significantly to 10.3% to that of control.

Copper: Copper is commonly applied to aquaculture ponds to control algal blooms, to kill organisms, which produce odourous compounds responsible for off-flavour in fish and shrimp and to control fish diseases. Bottom mud adsorbs a significant amount of applied copper. A study on the distribution of different copper forms in the bottom mud revealed that majority of copper is contained within silicate minerals. However, there is a possibility of pond bottom pollution since some of the copper exists in exchangeable or weakly and moderately adsorbed forms, and may, therefore, be desorbed into the water in the course of time. The maximum admissible copper concentration in water for the protection of fish is in the range of 0.001 to 0.01 mg / litre, depending on the physical and chemical properties of the water and on the fish species.

Copper acts as a cofactor for a number of key proteins (i.e. superoxide dismutase, ceruplasmin). As with iron, copper's flexible redox state plays a vital role in cellular respiration, with cytochrome-c oxidase being an important copper protein. Copper is thus an essential element, and its daily dietary requirements for fish are in the region of 15-60 μ mol (1-4 mg) Cu/kg dry mass. However, in excess, copper is toxic. High concentrations of water-borne copper affect bronchial function, the main toxic action being impairment of sodium homeostasis. Thus, if the concentration of copper differs from the actual physiological requirements, it may lead to toxicity or growth inhibition. For example, an experiment conducted at the Central Institute of Freshwater Aquaculture indicated that *Cirrhinus mrigala* fry exposed to 0.10 mg/litre showed reduction in growth (weight) of 10.3% to that of control (0.02 mg/litre) in 60 days of exposure. The same experiment also indicated that feed intake of *Cirrhinus mrigala* exposed to 0.10 mg/ litre lowered significantly to 11.6% compared to that of control.

Factors responsible for availability of micronutrients: Water *p*H, alkalinity, hardness and dissolved matters and pond sediment *p*H and redox potential could play a significant role in availability and uptake of these micronutrients by fish.

Fish quality reared with micronutrients: Zinc, cobalt, copper or manganese addition as micronutrient fertilizers in the fish-pond did not increase their concentrations in fish muscle. Though there were increased concentrations of these nutrients in the liver, kidney or gills; these parts are generally not consumed. Judicious application of micronutrients could increase spawn survivability and fish production. Therefore, in fish-pond fertilization schedule, micronutrients should be included along with major nutrients (nitrogen and phosphorus) for optimum fish production. Therefore, an understanding of chemical and biological condition of pond soil and water through regular monitoring systems and adoption of efficient and careful management practices will lead to enhanced production of fish-food organisms, and thereby increase growth and survival of fish.

Sustainable pond productivity

Nutrient removal

It is possible to precipitate phosphorus from pond-water by applying sources of iron, aluminium or calcium ions. These ions precipitate phosphate as insoluble iron, aluminium or calcium phosphates. Alum (aluminium sulphate) and ferric chloride are commercially available sources of aluminium and iron respectively. Alum is low-piced and more widely available than ferric chloride. Gypsum (calcium sulphate) is a good source of calcium, because it is more soluble than liming materials. Treatments rates of 20-30 mg of alum/litre and 100-200 mg of gypsum/litre lowered phosphorus concentrations in pond-waters. Alum is acidic and more suitable for use in waters of 500 mg/litre total alkalinity and above. Gypsum is better for use in low alkalinity waters.

Phytoplankton removal

Algaecides are used to reduce abundance of phytoplankton in intensive fish culture ponds. Copper sulphate is recommended for reducing phytoplankton abundance and abundance of blue-green algae in particular. The usual recommendation is to apply a dose of copper sulphate equal to 1/100 of the total alkalinity. The best approach to phytoplankton control is to regulate nutrient inputs by moderate stocking and feeding rates, but it may be feasible to use alum or gypsum to precipitate excessive concentrations of phosphorus.

Chlorination

Hypochlorus acid and hypochlorite (free chlorine residuals) are responsible for disinfecting power of chlorine products in pond-water. But, chlorination of waters containing fish or prawn is dangerous and unbeneficial. It is possible to disinfect bottoms of empty ponds and water in newly filled but unstocked ponds by applying

chlorine products. When this is done, enough chlorine should be applied to overcome chlorine demand and to provide 1 mg/litre or more of free chlorine residuals. The residuals will detoxify naturally in a few days so to stock ponds safely.

Water exchange

There are reasons to exchange water in specific instances such as to reduce salinity, to flush-out excessive nutrients and plankton or to reduce ammonia concentrations. However, daily water exchange usually does not improve water quality in ponds; pumping cost is a liability. Ponds are highly efficient in assimilating carbon, nitrogen and phosphorus inputs not converted to fish or prawn flesh, but if water exchange is high, these substances are discharged from ponds before they can be assimilated. Thus, pollution potential of aquaculture ponds increases as a function of increasing water exchange. From both economic and environmental perspectives, water exchange should only be used when necessary.

Ammonia toxicity in aquafarming

Sources of ammonia in ponds: In ponds, ammonia is produced by excretion of fishes, crustaceans; microbial decomposition; supplementary feed etc.

Excretion of ammonia by fish and crustaceans: Ammonia, which accounts for 40-90% of the nitrogenous excretion from fish and crustaceans, is released continuously during their growth. Most of the ammonia is excreted through gill epithelium.

Microbial decomposition: Microbial decomposition of organic materials accumulates ammonia in the pond environment. Additionally more of nitrogen is released to the environment as ammonia when a substance with low C:N ratio decomposes.

Urea and ammonium fertilizers: Urea and ammonium fertilizers, if used at higher rates, increase ammonia level in the pond environment.

Supplementary feed: In ponds where fish in high densities is given supplemental feeds, ammonia concentration may increase to undesirably high levels.

Municipal wastewater: When municipal wastewater is used in aquaculture, ammonia is discharged in enormous quantities to the environment.

Ammonia-ammonium equilibrium

Ammonia has an oxidation state of 3^- and is the reduced form of inorganic nitrogen in surface water. The term total ammonia refers to sum of ionized (NH_4^+) and unionized (NH_3) forms. The unionized form of ammonia exists in equilibrium with ammonium ion as per the following equation:

$$NH_3+H_2O=NH_3.\ nH_2O\ (aq.)=NH_4+OH+(n-1)\ H_2O$$

The concentration of unionized ammonia depends primarily on *p*H and to a lesser extent on temperature (Table 26.5). Although the concentration of dissolved solid, salinity and pressure may also influence unionized ammonia levels, such affects are inconsequential in most surface waters compared to those of *p*H and temperature.

Table 26.5. Per cent unionized ammonia in aqueous ammonia solutions

pH	Temperature (°C)								
	16	18	20	22	24	26	28	30	32
7.0	0.30	0.34	0.40	0.46	0.52	0.60	0.70	0.81	0.95
7.2	0.47	0.54	0.63	0.72	0.82	0.95	1.10	1.27	1.50
7.4	0.74	0.86	0.99	1.14	1.30	1.50	1.73	2.00	2.36
7.6	1.17	1.35	1.56	1.79	2.05	2.35	2.72	3.13	3.69
7.8	1.84	2.12	2.45	2.80	3.21	3.68	4.24	4.88	5.72
8.0	2.88	3.32	3.83	4.37	4.99	5.71	6.55	7.52	8.77
8.2	4.49	5.16	5.94	6.76	7.68	8.75	10.00	11.41	13.22
8.4	6.93	7.94	9.09	10.30	11.65	13.20	14.98	16.96	19.45
8.6	10.56	12.03	13.68	15.40	17.28	19.42	21.83	24.45	27.68
8.8	15.76	17.82	20.08	22.38	24.88	27.64	30.68	33.90	37.76
9.0	22.87	25.57	28.47	31.37	34.42	37.71	41.23	44.84	49.02
9.2	31.97	35.25	38.69	42.01	45.41	48.96	52.65	56.30	60.38
9.4	42.68	46.32	50.00	53.45	56.86	60.33	63.79	67.12	70.72
9.6	54.14	57.77	61.31	64.54	67.63	70.67	73.63	76.39	79.29
9.8	65.17	68.43	71.53	74.25	76.81	79.25	81.57	83.68	85.85
10.0	74.78	77.46	79.92	82.05	84.00	85.42	87.52	89.05	90.58
10.2	82.45	84.48	86.32	87.87	89.27	90.56	91.75	92.80	93.84

From Table 26.5, it is apparent that percentage of unionized ammonia greatly increases with increase of *p*H and temperature. To obtain unionized ammonia concentration, the percentage of unionized ammonia value for the appropriate temperature and *p*H is multiplied by the total ammonia nitrogen concentration and then divided by 100. For example a water sample at *p*H 7.0, 30°C, and 2 mg/litre total ammonia nitrogen contains 2 mg/litre × 0.81/100=0.0162 mg/litre of unionized ammonia, whereas the same water at *p*H 9.0 contains 2 mg ×44.84/100 = 0.8968 mg/litre of un-ionized ammonia. Unionized ammonia, which has high lipid solubility and is able to diffuse quite readily across the cell membrane, is far more toxic to fish while the ammonium ion is relatively non-toxic. Ionized ammonia (NH_4^+) may also be toxic presumably as a result of the competition inhibition of Na^+ transport by it, especially at lower *p*H, when the portion of it is very high.

Toxic effects to aquatic organisms

Mode of action: If ammonia concentration increases in pond-water, ammonia excretion by fish decreases but the level of ammonia in blood and tissue increases. The result is an elevation in blood *p*H and adverse effects on enzyme-catalyzed reactions and membrane stability. High unionized ammonia concentrations in the water reduce internal ion concentrations of fish. Ammonia also increases oxygen consumption by tissues, damages gills and reduces ability of blood to transport oxygen. Histological changes occur in kidneys, spleen, thyroid tissues and blood of fish that is exposed to sub-lethal concentrations of ammonia. Exposure to sub-lethal concentrations of ammonia probably increases susceptibility of fish to diseases. Ammonia toxicity can also limit production of intensive fish and crustacean aquaculture.

Toxic levels of ammonia to aquatic organisms: Unionized ammonia is regarded

as highly toxic to most species of aquatic invertebrates and fish, with 96-h LC_{50}'s typically ranging from 0.1 to 0.5 mg/litre. Also toxic concentration of ammonia for short-term exposure is considered between 0.6 and 2.0 mg/litre of NH_3-N for most of the species.

Factors influencing ammonia toxicity

Besides, *p*H and temperature, some other parameters are also having indirect effects on the ammonia toxicity – (*i*) ammonia is more toxic when dissolved oxygen concentration in fish-ponds is low; (*ii*) toxicity of ammonia decreases with low *p*H and increased carbon-dioxide concentration in fish-ponds; and (*iii*) toxicity of ammonia decreases slightly by high concentration of calcium.

Measures to control ammonia toxicity

Following practices can be used singly or in combination to overcome ammonia toxicity in pond-culture operations.

(i) Water exchange can reduce ammonia concentrations in fish and shrimp ponds. From both economic and environmental perspectives, water exchange should only be used when necessary.

(ii) 'De-odorase' made from plant (*Yucca shidigera*) extract with its major active ingredients, and glycocomponents as the ammonia-binding agents, can remove ammonia. De-odorase, even at lower levels of usage, can significantly reduce ammonia in sea-water. Even in the high ammonia conditions, it can increase survival rate of shrimp at 0.5 mg/litre, applied three times at 6 hr intervals.

(iii) Formalin can be used to remove ammonia from fish-ponds.

(iv) Zeolite, an aluminosilicate mineral with ion exchange properties, can absorb ammonium. While this is technically true, a very large amount of zeolite would be required to significantly lower ammonia concentration.

(v) A high quality feed that contains no more nitrogen (crude protein) and phosphorus than actually needed by fish should be used in ponds; overfeeding should be avoided.

(vi) Excessive liming should be avoided as it raises *p*H and high *p*H favours ammonia toxicity to aquatic animals.

(vii) Moderate levels of shrimp and fish production should be maintained.

Proper pond management practices such as liming, fertilization, aeration, water exchange and bottom soils drying and oxidation are the key to improve soil and water quality of ponds and to reduce volume and pollution potential of pond effluents.

The best method for preventing soils and water quality problems in aquaculture ponds is to select a site with good soil and with an adequate supply of high quality water, and to maintain moderate levels of prawn and fish production. If this is done, liming, fertilization and aeration can prevent most soil and water quality imbalances. However, in some instances, sedimentation basin may be needed to prevent ponds from filling in, and water exchange may be required periodically. In intensive aquaculture ponds, bottom soil treatment, viz. drying and liming between crops, phosphorus precipitation, turbidity removal and oxidation of bottom soils with sodium nitrate may be beneficial. Some treatments are either ineffective or potentially hazardous to the stock.

Therefore, proper pond management is the key to sustainability in aquaculture, and enhancing sustainability of pond aquaculture can improve soil and water quality in ponds and reduce the volume and pollution potential of pond effluents. Proper procedures for pond management will improve environmental conditions, sustainability and profits.

27. Aquaculture Engineering

Aquaculture engineering is basically concerned with the development of aquaculture industry, aiming primarily to build and maintain environment congenial for aquatic life. In fact, aquaculture requires considerable technical assistance from engineering field. On the aquaculture engineering, the Indian National Commission on Agriculture 1976 noted, "The work load would comprise planning, designing, cost estimating and constructing some of the works pertaining to fish-seed farms. New farming units are to be developed by reclamation from freshwater swamps after restoration of connecting channels and by reclamation of brackishwater tracts aided by construction of stable dykes capable of withstanding tidal impacts. These works require considerable skill in the field of engineering which has so far been neglected aspect of fish farming in India". Growth of aquaculture enterprise is limited by several constraints; the primary among them is lack of sufficient scientific and engineering knowledge to make commercial culture of many of the species practically and economically feasible. Application of engineering in aquaculture, in fact, starts right from the initial stage of selection of the site for construction of aquaculture facilities, up to the end of the activities of aquaculture industry, i.e. harvesting, handling, transportation and marketing of crop; hence, aquaculture engineering has to play a crucial and important role. It is to be recognized that modern aquaculture is a major development in the interface of science, engineering and social sciences, particularly economics.

Due to climate change, there are indications that all surface waters of oceans with some geographical variations are warming up and increasing in salinity. Global sea level has risen due to climate change, and the rate has accelerated after 1993. Many lakes have also shown indications of warming; there is likelihood that wetlands would be drying gradually. Increase in temperature due to climate change will have much stronger impact on aquaculture productivity and yields. To adapt to sea-level rise, one should promote agri-aqua farms by integrating aquaculture with agriculture. Sea-water can be converted to potable water through mariculture-cum-agroforestry. To mitigate impacts of climate change in aquaculture development, there is a need for appropriate handling of many issues, and they all in a way involve aquaculture engineering.

Selection of the site for aquaculture

Success of an aquaculture project depends largely on the proper selection of a site that is to be developed into a farm; following are the important factors that need to be considered–water supply, soil type, topography, and biological and operational, economic and social factor.

Water supply

An assured water supply of sufficient quantity is very important. Therefore, investigations for a proper water source should be thoroughly conducted. Source of water supply can be a river, canal, reservoir, lake, spring, rainfall run-off and shallow or deep wells. For a pond built in a suitable soil, minimum water supply throughout the year from it should be 5 litres/sec/ha. If rainfall run-off is to be used, and stored in a reservoir to supply into ponds; a ratio of 10 to 15 ha of catchment area to 1 ha of pond is required if catchment area is pasture; a slightly higher ratio is needed for woodland and less for land under cultivation. Flood discharge of an area can be calculated by the following expression providing information on the peak flow.

$$Q = R.A.P.$$

where Q, total run-off in C ft/sec; R, intensity of maximum rainfall in inch per hour; A, drainage area acres contributing run-off; P, factor of imperviousness, which may be as per the following.

Area type	P value
Steep bare rock	0.90
Rock, steep but wooded	0.80
Ordinary rocky ground, bare	0.70
Clayey soils, steep and bare	0.60
Clayey soils, slightly covered	0.50
Loam; slightly cultivated/covered	0.40
Sandy soil, slight growth	0.20
Sandy soil, covered heavy bush	0.10
Forest area	0.10-0.20
Parks, lawn, garden, cultivated areas	0.05-0.10
Residential areas, not densely built up with metalled roads	0.50-0.70
Suburbs with gardens, lawns and moored roads	0.20

An equation to calculate approximate amount of water required for a pond/farm on an average per year is as follows.

$$Q = v_f + v_{rf} + l_e + l_s + l_c - v_{ra}\ (m^3)$$

$$\text{Or}\quad Q_r = \frac{V_f + V_{rf} + L_e + L_s + L_c - v_{ra}}{86{,}400 \times T}\ (m^3/sec)$$

where Q_r, Annual water requirement (m^3/sec); V_f, the pond volume to be filled (m^3); $V_{rf} = n_o \times v_f$, the pond volume to be refilled (m^3); M_o, number of refilling in a year; $L_e = A \times E$, water loss from evaporation (m^3), A, average water surface area of pond (m^2), E, mean annual evaporation (m); $L_3 = A \times T \times S$, Seepage loss in the pond (m^3), S, Seepage co-efficient (m/day), T, operational time in days; $L_c = A_c \times 1.2 \times E$, transmission loss in earthen channel (m^3), A_c, water surface area in feeder channel (m^2); $V_{ra} = A_{eff} \times r_a$, water inflow from rainfall to pond (m^3), R_a, mean rainfall (m), A_{eff}, total area of pond including the dykes affected by rain (m^2). (*Source:* Kovari, 1984)

Important climatological data like temperature, rainfall, evaporation, humidity etc., should be obtained from the nearest meteorological station of the site. Hydrological data like discharge yield, floods and water elevations should be collected from the irrigation department or other water authorities for the existing water sources like rivers, irrigation canals, reservoirs, springs etc. If the wells and deep wells are to be

used, groundwater investigations of the area are required to be carried out for proper design of the well. Adequate depth for good aquifer should be available so that required quantity of water can be availed from well/deep well. Information on the groundwater may also be obtained from the Central Ground Water Board/Geological Survey of India/concerned department of the State Government. Quality of the proposed source of water also should be investigated by analyzing water samples for physical, chemical, biological and microbiological properties including health hazards. Water characteristics for freshwater aquaculture ponds are well known.

Soil characteristics

The soil must be able to hold water. Soil profile should contain sufficiently impervious and thick layer of material to prevent high losses through seepage; otherwise expensive sealing procedures will be required. Potential seepage losses from ponds and canals connected there to; stability and performance of low dykes surrounding ponds and feeder canals are the main problems encountered by soil engineers for a fish farm.

Seepage occurs through interspaces or pores of the soil, and soil porosity is reduced if soil contains good percentage of fine particles (clay). According to the Indian Road Congress (IRC), the particle sizes of soil are as follows: gravel: above 2mm; coarse sand: 2 to 0.2 mm; fine sand: 0.2 to 0.02 mm; silt: 0.02 to 0.002 mm; clay: under 0.002 mm.

Soil classification as per U.S. Bureau of soils is given in Table 27.1. Silty clays are excellent for fish-pond construction. Clay loam, silty clay loam and sandy clays are usually satisfactory. Coarse-textured sands and sand-gravel mixture are highly pervious and generally are unsuitable.

Table 27.1. Soil classification by U.S. Bureau of Soils

Class	% sand	% silt	% clay	Remarks
Sand	80-100	0-20	0-20	
Sandy loam	50-80	0-50	0-20	
Loam	30-50	30-50	0-20	
Silty loam	0-50	50-100	0-20	
Sandy clay loam	50-80	0-30	20-30	Name denotes constituent predominating in the composition
Clay loam	20-50	20-25	20-30	
Silty clay loam	0-30	50-80	20-30	
Sandy clay	50-70	0-20	30-50	
Clay	0-50	0-50	30-100	
Silty clay	0-20	50-70	30-50	

Source: Khanna (1966)

In general, a site is suitable for construction of fish-ponds if soils below the proposed pond bottom (minimum about 1.0 m depth) have a co-efficient of permeability $k=5\times10^{6}$ m/sec. Areas with a layer of organic soil over 0.60 m thickness are unsuitable; they neither retain water nor permit compaction. Proper soil investigations are to be made before a site is procured. If soil conditions are found undesirable for pond construction, alternate sites may have to be found.

Soil investigation techniques used for engineering purposes vary from relatively simple visual inspections to detailed subsurface explorations and laboratory tests. Visual inspection of the site is an essential preliminary step. To provide data on the subsurface soils, test pits (usually 0.80 m × 1.50 m × 2.00 m) are dug. Depths of these pits may vary according to the elevation of the water-table. Frequency of these pits depends upon the occurrence of significant changes in the soil profile. However, in general one pit in each hectare of land may be taken up. Digging of test pit permits visual examination of soil and also makes it possible to obtain disturbed and undisturbed samples of soils encountered in different layers below the ground level. A general and convenient field test is to take a handful of moist soil from the test pit and to compress it into a firm ball. If the ball does not crumble after a little handling, soil contains desired clay for the purpose. To find out water-holding character of a soil, laboratory tests may be carried out. A record or log of each test pit should be made showing location, depth and classes of materials encountered.

To obtain detailed information, following parameters are required to be studied: soil type with mechanical properties to ascertain soil profile with sub-soil characteristics; co-efficient of permeability; angle of repose; bearing capacity of soil; *p*H; available nutrients such as phosphorus, potassium, organic-carbon,nitrate etc.

Topography

For the purpose of constructing an aquaculture farm, it is better to look for a land that is fairly levelled. Avoid steep hilly topography with sharp rises and falls, however, a gentle slopping (not steeper than 2%) land is advantageous for laying water supply and drainage network. Land elevation with reference to flood levels is also an important factor to be considered. A complete topographic survey of the site is necessary. Cross-section surveys for embankments and spill-way locations are also to be undertaken carefully. In fact topography guides for the cost of construction.

From economic point of view, a pond should be located where largest storage volume can be obtained with the least amount of excavation or earth-fill. For one single pond construction, an ideal situation would be a saucer-shaped area which may provide an appreciable quantity of water. Impoundment after a small amount of earth work indicates that building of diversion ponds is easy if alluvial plain is slightly inclined. Contour survey determines elevations of the proposed site.

For brackishwater aquaculture farm of tide-fed system, ground elevation should be sufficiently below the mean spring tide high-water level and above low-water level, so that entire farm could be filled up and emptied by gravity during rising and falling of tide. The tidal range should also be sufficiently large for an efficient water exchange system.

If the relative land elevation and tidal rise of the site preclude the possibility of a tide-fed farm as the gravity-fed ponds require lowering of pond bottom, which requires high development cost. Culture ponds in that case are to be fed by pumping. This system is generally called pump-fed system, and in this system, location of the intake is also very important.

Biological and operational factors

- Species to be cultured
- Sources and availability of stocking material
- System of culture to be adopted
- Operational method and production target
- Estimated size of the area required

Economic and social factors

- Development plan for the project area
- Ownership, availability and cost of land
- Availability of electricity and unit power cost
- Availability of construction material and equipment
- Cost and availability of operation materials, labour, equipment etc.
- Demand and market of the product
- Amenities (school, hospital, shopping, facility etc.) for permanent staff

Fish culture ponds, their sizes and depths

The majority of the fish culture throughout the world is in ponds. Ponds are the bodies of the water created by the construction of a dyke or an embankment across a water-course or by excavating a pit by digging. As the culture systems prevailing in India, ponds may be classified into three types: (*i*) nursery ponds, (*ii*) rearing ponds, and (*iii*) stocking ponds.

Pond shape: For aquaculture purposes, ponds of various shapes are in use, but rectangular shaped ponds are preferred. Square or round ponds may be cheaper in construction for its shorter length of dyke, but not preferable because very wide ponds are difficult to net. Moreover, construction of a number of round ponds in an area will cause wastage of some land in-between. In general, stocking ponds should be longer so that fishes have sufficient space for healthy growth. Width of the stocking ponds does not normally exceed 50 m, and so relatively smaller net and limited number of men would be sufficient for catching fish.

Pond depth: In fish farming, size and depth of a pond means water surface area. Size depends mainly on the prevailing culture practices, and depth is very important for biological production. Depth depends on the penetration of the sunlight in the water (turbidity), which in turn influences temperature and circulation pattern of water, and thereby photosynthetic activity. In shallow ponds, sunlight penetrates up to the bottom of the pond. This warms up the total water volume, which increases primary productivity and photosynthetic activity. However, ponds shallower than 1 m depth often get over-heated during tropical summers and affect survival of fish and other organisms. Water depths greater than 4 m are rare for fish culture and are also less productive. Deeper ponds are also difficult to net.

Engineering standards of the Soil Conservation Service, USDA, indicated that fish-ponds should be at least of 0.1 ha, excepting ponds that are constructed as a special-purpose ponds; may have a minimum size of 0.025 ha. Pond depth should be between

1.3 and 4.0 m. In China, 0.7 ha is commonly used as the standard size but desirable depth is between 2 and 2.5 m while for fry-rearing, desirable depth is 1.5 to 2.0 m. Predominant size of fish-ponds in Indonesia is 0.3 to 1.0 ha; in Hawaii, prawns are reared in earthen-ponds of 0.2 ha to nearly 2 ha. Pond bottoms are usually slopped with depth varying from 0.75 m at the shallow end to 1.4 m at the deep-end. In India, common size of seed rearing pond is 2.5 m having a depth of 1 to 1.5 m. Rearing ponds should preferably be 0.06 ha to 0.1 ha in size and 1.5 m to 2.0 m in depth. Size and depth of stocking ponds vary from 0.2 ha to 2.0 ha and from 2.0 m to 2.5m respectively. However, a preferable stocking pond size is between 0.4 ha and 1.0 ha.

Aquaculture farm-design criteria

First step for designing a fish farm is to study survey reports, maps and drawings concerning soil quality, topography, water supply source, water requirement of farm, and intended practices for management and operation of farm. General considerations for freshwater fish farm design are as follows.

(i) Compare farm water requirement with the quantity of water available from different sources.
(ii) When water source is perennial, no reservoir for water storage is required.
(iii) If the water source does not provide adequate quantity of water throughout the year, but total quantity of water available in a year is enough, then a reservoir may be required, and under such a condition, two following situations may arise.
   (a) Source provides varying quantity at different times
   (b) Source is completely empty at times

The size of the reservoir, the height of the main embankment, the spillway etc. would be depending upon the above factors.

Spillway requirement: All ponds formed by putting an embankment or a dyke across a water course require protection by constructing a carefully designed spillway or a combination of spillways. Spillway function is to pass storm, run-off around and under the embankment to prevent overtopping. It must also convey water from pond safely to stable outlet below, without damaging down-stream slope of the embankment. The spillway must discharge peak flow with a non-erosive velocity to a safe point of release.

In a spillway, water flows through a weir and falls over an apron in which water energy is dissipated. The flow of water passes through weir opening, drops to an approximate level apron or stilling basin and then passes into down-stream channel. If the reservoir has fishes then spillway weir-opening is provided with screens to avoid loss of fish stock.

Embankment or dyke: The dyke must be stable and water-tight. While designing a dyke, stability should be checked by drawing hydraulic gradient or the line of saturation, which must pass through the base of the dyke and there should be a clear cover of at least 0.3 m between the line of saturation and the toe of the dyke (Fig.27.1). Hydraulic gradients for different types of soils are: 1 in 3 for good clay; 1 in 4 for good compacted soil; 1 in 5 for average soil (sandy loam); 1 in 6 for fine silt.

If required, berm of sufficient width may be provided for stabilizing slopes. Ideally

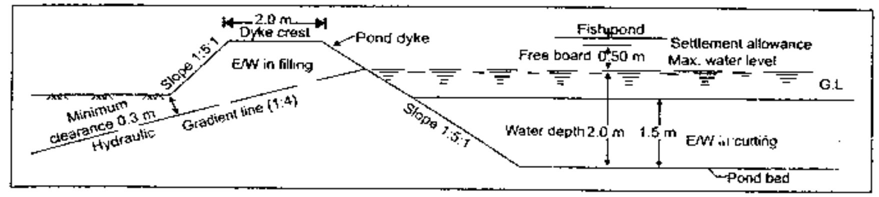


Fig. 27.1. Typical cross-section of a pond dyke.

dyke should have 2-m top width, but the dyke of 1-m width at the top is also good enough to facilitate operational work. If the top of the embankment is to be used for a roadway, the top width should be at least 4.5 m.

A minimum of 0.3 m freeboard should be maintained for small ponds and 0.5 m for large ponds. A settlement or shrinkage allowance of 10-15% should also be provided. The recommended minimum top widths of earthen-dykes of various heights are given in Table 27.2.

Table 27.2. Recommended top width of earthen-dykes

Height of dyke (m)	Minimum width (m)
Under 2.5	2
2.5-5.0	3
5.0-8.0	4

Side slopes of a dyke primarily depend on the stability of the fill material. Greater the stability of the fill material means steeper side slopes. The recommended size slopes of various materials are given in Table 27.3.

Table 27.3. Recommended side slopes for earthen dykes

Fill material	Side slope
Good clay and silty clay	1 in 1.5 (1 vert : 1.5 hor.)
Sandy Clay	1 in 2 (1 vert : 2 hor.)
Sandy loam	1 in 2.5 (1vert : 2.5 hor.)
Loose and wet earth	1 in 3(1 vert : 3 hor.)

vert., Vertical; hor., horizontal.

The dyke should be built on a solid water-tight foundation. Satisfactory foundation consists of a thick layer or relatively impervious consolidated clay. If a suitable layer is at or near the surface, no special measure is needed excepting removing top soil and disking to provide a bound with the material in the dyke. If the foundation consists of pervious materials at or near the surface, seepage in the pervious stratum must be reduced to prevent possible failure. Usually a cut-off joining impervious stratum in the foundation with the base of the embankment is needed. The material to be used for construction of a dyke should also be stable and water-tight. Earth from salt-affected areas should be avoided; sand and peaty earth also should not be used for construction of a dyke. Earth obtained from pond digging is generally used for dyke construction. If good earth is not available locally, a clay core or a puddle clay core should be provided to make dyke water-tight. Fig. 27.2 gives details of cut-off and clay-core of a dyke.

Water inlet: All ponds should be provided with a water inlet, which provides required and controllable water supply and prevents entry of undesirable fishes into the pond. Details of an inlet structure are shown in Fig. 27.3. Water inlets can be constructed either to provide inflow for each pond or for a group of ponds. To ensure

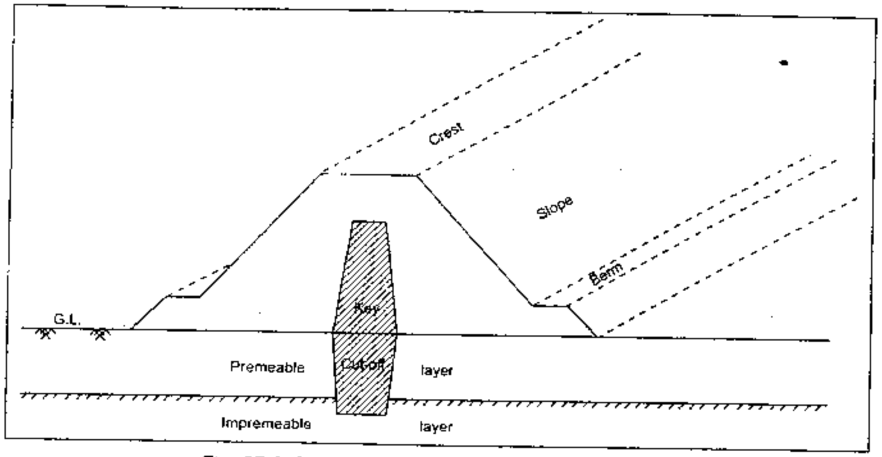


Fig. 27.2. Details of cut-off and clay-core of a dyke.

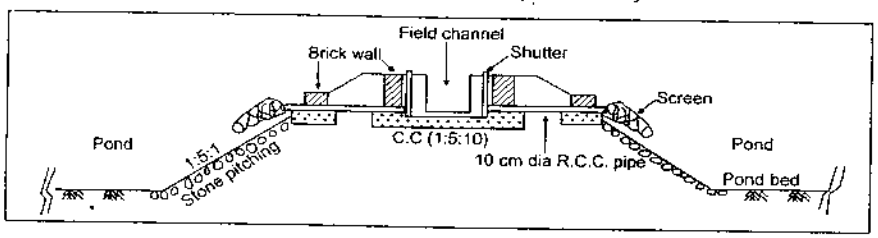


Fig. 27.3. Details of inlet structure from field channel.

regular and controllable flow into the ponds, vertical sluices may be installed. In well-laid fish-farms, furrow-type inlets made of brick masonry or concrete with control boards and screens have been used in the Central East Africa. The structure depicted in Fig. 27.3 and executed in pond outlays in the CIFA, Bhubaneshwar, has advantage of providing additional aeration by putting bag-type screen with the pipe. Control of flow is easy with this, and less maintenance is required for this inlet type.

Drainage arrangement and water exchange: The ponds should be provided with a suitable drainage arrangement so that the same can be emptied/dried at will. In a fish-farm, the drainage arrangement may be independent for each pond or may be interconnected for a group of ponds. For proper drainage arrangement, pond bottom should be above groundwater table and the pond bottom should have a gentle slope towards outlet.

Drainage arrangement for a fish-farm can be provided either by constructing suitable drainage channels or by laying drain pipes. The drainage channels or drain pipes should be connected with ponds through easily controllable sluices or monks. Sizes of drain-pipes or drainage-channels depend upon the pond size and the quantity of water required to be passed through.

In intensive fish-farming, more animals are cultured in a limited area and

considerable quantity of feed and fertilizers are applied for rapid growth of fishes resulting in more deposits of metabolites at the pond bottom. Water exchange from such ponds helps in removal of excess metabolites. Drainage arrangement of these ponds can be connected with a specially designed device, and the pond with the water supply arrangement from the inlet ensures water exchange of the pond when operated from both inlet and outlet structures simultaneously. The tiger prawn hatchery of the Odisha Shrimp Seed Production, Supply and Research Centre at Gopalpur on sea, implemented such water-exchange structures for its broodstock ponds. These are unique structures and have been constructed for the first time in India, mainly with PVC pipes. The structure is capable of draining water both from surface as well as from the bottom of ponds, effecting efficient water exchange, removing excess fecal matters from pond bottom. Fig. 27.4 illustrates such water exchange-cum-drainage structure.

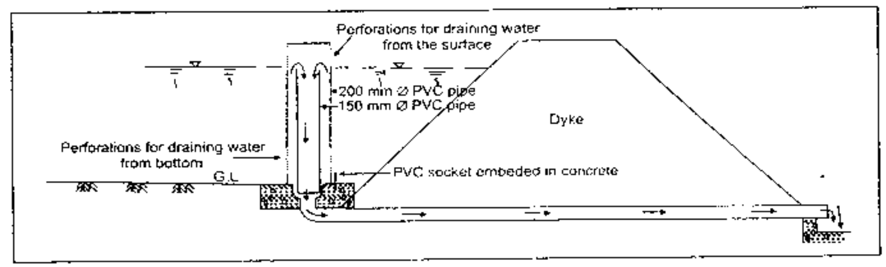


Fig. 27.4. Drainage-cum-water exchange structure for draining water both from surface as well as from the bottom of the pond.

The layout

Ponds layout should be prepared as per the land configuration and contours. The deeper ponds should be positioned in the lower contours so that lesser earth-work is involved. For economic design, earth-work available by excavation should, as far as practicable, be equal to earth-work required in filling or raising dykes. While preparing layout due consideration should be given for easy water supply and drainage arrangement.

The ratio of water areas among nursery, rearing and stocking ponds in a fish-farm depends upon the farm use. In fish-seed farms, only nursery and rearing ponds are constructed with a nominal area for stocking ponds, to be used for raising breeders and donor fishes. It has been estimated that for production of 10 million spawn, yielding a crop of 5 million fry and 1.6 million fingerlings, water-area requirement would be 1.0 ha for stocking ponds, 1.0 ha for nursery ponds and 7.0 ha for rearing ponds. But fish-production farm, only stocking ponds may be constructed to produce table-size fish from fry/fingerlings stocked.

For a self-sufficient fish-culture farm, the ratio has to be as per the intended production expected from the nursery, rearing and stocking ponds. It may be necessary to sell-out part of the seed produced in the farm for want of stocking space inside the farm or as a matter of policy. Typical layout of a 10-ha fish production farm is shown in Fig. 27.5.

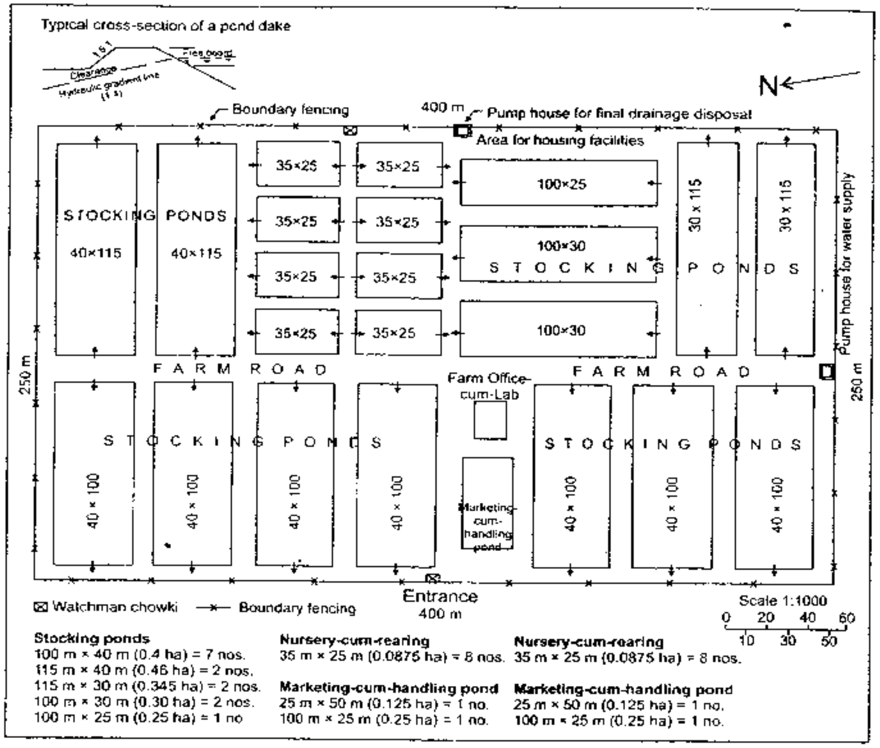


Fig. 27.5. Typical layout of a 10-ha freshwater fish farm (plan at ground level).

Main principles for designing a fish-farm layout are: (*i*) cost of construction should be as minimum as possible, as such the earth-work in excavation should be almost equal to the earth-work required in filling of dyke construction; (*ii*) water supply layout and drainage network should be prepared according to the contours so that as far as possible, water supply and drainage arrangement can be accomplished by gravity; (*iii*) shallower ponds may be located in comparatively high elevation areas while deeper ponds may be located in low-elevation areas; (*iv*) other infrastructural facilities like roads, electricity, office, watch and word facilities, residential quarters, stores, fish selling and marketing area should be appropriately located so as to facilitate operation and management of the farm.

Visual resources design

People generally prefer water-spread scenery. Therefore, when ponds are created, they can enhance visual resource if water view is emphasized. A visual design objective is to focus views towards permanent pool and reduce visual focus effects of structural elements. Excavation areas are to be shaped and blend with natural surrounding topography to the extent possible. In most landscapes, ponds will automatically predominate if other elements are visually designed to be subordinate.

Hydraulics in designing aquaculture systems

Application of hydraulics is very important for designing aquaculture systems. Some important hydraulic formulae being used in aquaculture system designs are as follows.

Design formula for open-channel flow

Manning's formula, $v = 1/n\ R^{2/3}\ s^{1/2}$ (m/sec)

where V, average velocity (m/sec); *R*, A/p , hydraulic radious (m), *A* , cross sectional area for the channel (m^2), *P*, wetted perimeter of the channel (m); *S*, slope of the channel; *n*, roughness coefficient.

Discharge, $Q = A.V. = A/n\ R^{2/3}\ s^{12}$ (m^3/sec).

Table 27.4. Values of roughness coefficient, n

Channel condition	Value of n
Good wood, metal or concrete surfaces with some curvature, vε y small projection, slight moss growth or gravel deposition	0.014
Rough brick, medium quality cut stone surface, wood with algae or moss growth, rough concrete, riveted steel	0.015
Very smooth and straight earth channels, free from growth stone rubble set in cement, deteriorated brick wall	0.017
Well-built earth channel covered with thick uniform silt deposits, accumulated debris	0.018
Smooth well-packed earth, rough stone walls, channels excavated in solid, soft rock	0.020
Small, man-made-earth channels in well-kept condition, straight natural streams with clean bottom	0.025

Source: Simon, 1976 *in* Kovari, 1984.

Dissolved oxygen and aeration

Dissolved oxygen (D.O.) present in the aquaculture environment is the most important factor in water quality. Unless sufficient D.O. is maintained animals will be in stress, becoming vulnerable to diseases and mass mortality. Though limited level of oxygen concentration depends on the genetic make-up of the fish, water temperature, level of activity and stress experienced. It is generally stated that oxygen concentrations below 3 mg/litre will not support fish for a long period, and concentrations below 1 mg/litre will kill almost all fish species. Aquaculture ponds receive oxygen mainly from the process of photosynthesis and from the atmosphere through absorption; whereas the primary loss of D.O. from ponds is through respiration by plankton and other organisms and diffusion of oxygen into air.

Mechanics of aeration: Atmospheric air contains about 21% oxygen, and surface water contains about 15 ppm or 0.0015% oxygen. Oxygen transfer from air to water is strictly a diffusion process. The rate of diffusion from one phase to the other depends upon the concentration gradient existing in each phase. Oxygen has a low rate of solubility in water; consequently insufficient amount of oxygen enters water through normal air-water interface. To meet respiration and oxidation demands of high density aquaculture, ponds need aeration which increases rate of gas exchange between air and water by increasing air-water interface.

Oxygen transfer is a function of surface area available across which transfer can occur, oxygen concentration gradient, magnitude of liquid-film coefficient and turbulence. Mathematically these parameters can be expressed as follows:

$$dc/dt = K_L\,(A/V)\,(C_s - C) = K_{LA}\,(C_s - C)$$

where dc/dt , rate of change of oxygen concentration with respect to time (mg/litre/hr); K_{LA}, the overall oxygen transfer rate = $K_L(A/V)$–(hr^{-1}); K_L, oxygen transfer coefficient-cm/hr; A , area of gas liquid interface (cm^2);C_s - C , concentration gradient (mg/litre); V, volume of water (cm^3).

Critical period for aeration: Depletion of D.O. may be caused by decomposition of organic matter, sudden phytoplankton die-off or due to high rate of respiration during night with heavy plankton bloom. Combination of warm weather and cloudy days in the late summer can result in low oxygen level in fish-ponds. The critical period is likely to be just after sunrise when over-night demand depletes oxygen storage in water and resupply by photosynthesis has not yet been activated.

Mixing by aeration: It is important to realize that amount of oxygen added to a pond through aeration is insignificant relative to the amount added through photosynthesis by a healthy phytoplankton bloom. Consequently, aeration is not done in the day-time to add oxygen, but rather as a mixing method to move highly oxygenated surface water to bottom for breaking stratification. Aeration as a means of gas exchange probably would not be cost-effective unless pond water is less than 70% saturated. Mixing of water helps in getting oxygenated water at the pond bottom, which will allow bacterial decomposition to proceed aerobically so that waste products can be oxidized quickly and without formation of toxic gases. Maintenance of aerobic pond bottom also encourages development of bottom organisms, which can feed on bacteria, organic matter and plankton.

Aeration devices: These utilize an energy input to increase liquid surface area available for oxygen transfer and ensure that water of low oxygen concentration is brought into contact with air or oxygen. Increase of liquid surface area or air-water interface can be achieved by dispersing water in air, and dispersing air into water.

Gravity aerators: Gravity aeration depends on increasing air-water interfacial area caused by turbulence at the down-stream side as the result of the loss of elevation. Natural streams having turbulent flow make surface water continually changed and thus improve oxygen transfer rate. Water falls are very effective natural aerators. Gravity aerators are inexpensive and can be easily constructed in a culture system. They are most economic when a natural head exists.

Table 27.5. Test results of a few gravity flow-type aeration devices

Device	Flow rate (Lps)	SOTR (g/hr)	OTE (kg/kwh)
Cascade type	0.76	11.95	2.59
Bucket dissipater type	0.75	9.50	2.10
Hydraulic jump basin type	0.73	9.05	2.01

Studies conducted on the gravity flow type of aeration (Table 27.5) have shown that the cascade-type aerator is the most economic device, providing standard oxygen transfer rate (SOTR) of 11.95 g/hr and oxygen transfer efficiency (OTE) of 2.59 kg/kwh. Such aerators are also very convenient to be installed at the inlets of the aquaculture systems.

Surface aerators: They agitate water surface, creating turbulence and break water into droplets for higher oxygen transfer rates. Paddle-wheel aerator provides theoretical aeration efficiency of about 1.7 kg/kwh. The amount of oxygen transferred by a paddle-wheel aerator can be increased by increasing submergence depth, rotor/paddle speed and rotor/paddle diameter. The paddle-wheel aerators are used quite satisfactorily in many aquaculture ponds, particularly prawn-culture ponds having depth of 1 m.

Water pumped through a nozzle with a very high velocity is another type of surface aerator and can be used effectively for emergency aeration. Two nozzles of 10 mm to 4 mm and 10 mm to 4.4 mm have been observed to enhance D.O. concentration up to 4.81 mg/litre in one hour of operation attaining about 57.4 % saturation concentration.

A simple cascade-type aeration device made by 4 used bamboo baskets of about 1.2 m diameter and 0.15 m depth, placed at about 0.40cm interval, vertically in a bamboo-frame fixed in the fish-pond (Fig.27.6) was tested in the Kakdwip fish-farm of the Central Inland Fisheries Research Institute, Barrackpore, during 1985 and 1986, in the prawn-culture ponds that gave good results with increased prawn production. Aeration was affected by circulating pond-water through device. The water was pumped with an ordinary agriculture pump from the bottom of the pond and circulated through the device caused water to break into droplets and gradually fall through bamboo baskets, thereby increasing air-water interfacial area and effecting sufficient diffusion of oxygen into water. The oxygen transfer efficiency (OTE) of the device in pond tested at the Central Institute of Freshwater Aquaculture (CIFA), Bhubaneshwar, was found to be about 0.4 kgO_2/kwh.

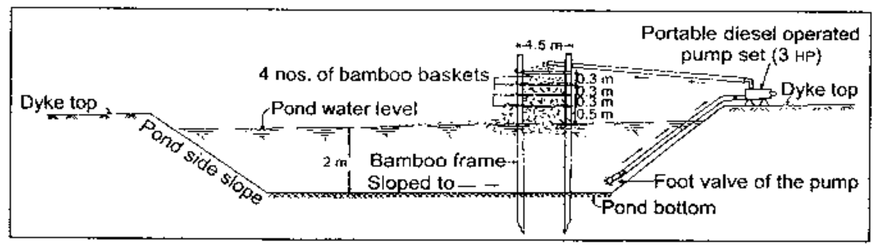


Fig. 27.6. Installation of a bamboo basket aerator (Cascade type) in a semi-intensive aquaculture pond.

Sowerbutts and Forster in 1981 quoted the work of Colt *et al.* and informed the following transfer efficiencies of aerators under pond condition.

Aeration method	Transfer efficiency kgO_2/kwh
Surface aerators	0.25-0.50
Fine-bubble diffused air	0.25-0.42

Diffuser aerators: These devices inject air or oxygen into the body of the water in the form of bubbles, and oxygen is transferred from bubbles to water by diffusion.

Efficiency of these aerators depends on bubble diameter and depth of submergence of the diffuser. Oxygen transfer is maximized producing as many bubbles as possible. In this system, air is generally pumped down through pipes near the pond bottom and allowed to come up through perforations in the form of bubbles.

Pumps

Pumps are machines that can add energy to fluids. Aquaculture enterprise often needs movement of fluid from a lower to a higher point against a gravitational gradient. So correct pump selection is important in the aquaculture enterprise as pumping expenditure is one of the major costs for many aquaculture operations. Poor pump selection can double or triple pumping cost and can significantly increase operation cost. There will also be risk of pump failure at critical times due to poor selection.

Pump selection: Selection of a correct pump for a particular application requires knowledge of pump characteristics, system's requirement in terms of total head and discharge, and characteristics of fluid that is to be pumped. Draw-down characteristics of the well must be known before a pump is selected.

Pump selection requires knowledge of total head required; discharge required; suction lift required; characteristics of the liquid to be pumped; whether the service is continuous or intermittent; type of power source to be used; space, weight and other limitations; and special requirements, if any.

The pump should be selected at or near its highest efficiency to minimize energy cost. Under normal conditions, low head, high discharge pumps are considered suitable for aquaculture purposes. In general, centrifugal pumps meet this requirement. However, in cases, where head requirement is less than 4 m, use of propeller pumps is considered suitable; as the propeller pumps have relatively higher efficiency for the head up to 4 m.

Power requirement: This requirement for pumping is a function of the specific weight of the fluid, volume of the fluid, head against which it is delivered and pumps's efficiency. To estimate power requirement in watts, following equation may be used.

$$POP = r\,Q\,h$$

where POP , Power output of pump (w); r , specific weight of fluid (N/m^3); Q , flow rate (m^3/sec); h , head (m)

Brake power is the power required to drive a pump.

$$BP = POP/e$$

where BP, break power input to pump (w); e, efficiency of pump;

By combining both the equations, we get $BP = r\,Q\,h/e$

Power requirement in horse-power, $HP = rQh/e.75$

It is also important that power must be delivered to a pump at the desired speed and in an efficient manner. Electric motors and internal combustion engines are common sources of power for pumps.

Pond-sealing or lining

Ponds constructed on a permeable soil have heavy seepage losses. The methods for sealing ponds built on permeable soil include soil compaction, clay blankets, chemical additives and water-proof lining. Each has a specific use and may require certain range of conditions for its successful use.

Compaction: Compaction alone can sometimes seal a pond. Pond-sealing by compaction is relatively inexpensive. However, its use is limited to soils having a wide size of particles, from coarse sand to fine clay. Sandy loam and silt loam are usually suitable for compaction. Minimum compacted depth should be 20 cm.

Bentonite clay: It is a fine-textured colloidal clay that absorbs water several times its own weight and at complete saturation swells 8 to 20 times its original volume. Sufficient bentonite in coarse soil will expand when wet, to fill soil pores and form a pond-seal. Bentonite shrinks when it dries, causing crack formation. Thus it is rarely satisfactory as a sealing material for ponds with widely varying water levels, particularly for fish-ponds, which have to be dried periodically.

Chemical additions: Soils with high percentage of fine-grained clay and silt sometimes aggregate by clumping of particles. Aggregate particles which usually form a honey-comb structure act as a large particle, forming an open porous soil structure. Application of small amount of certain chemicals to these aggregates may result in collapse of open structure and arrange effective soil particle size back to the size of the individual clay or silt particle. These chemicals are called dispersing agents.

The most widely used chemical-dispersing compounds contain sodium. Adding a sodium dispersing agent to a calcium soil produces ion exchange when sodium ions of the chemicals replace calcium ions. As a result, additional sodium ions are absorbed by the soil. A following simplified equation illustrates ion exchange when a dispersing agent, sodium carbonate is added to calcium.

$$Ca^{++}\text{ (Soil particle)} + Na_2CO_3 = Na^{+}\text{(soil particle) } Na^{+} + CaCO_3$$

The common dispersing agents are sodium tripolyphosphates, sodium hexamataphosphate and sodium carbonate. Sealing fish culture ponds with chemicals requires consideration of effect of chemicals on the fish. The chemical must be nontoxic and should not leach into the water.

Water-proof linings: Polyethylene, vinyl and butyl rubber membranes are gaining acceptance as pond-linings. These linings reduce seepage losses to zero provided they are not broken or punctured. Black polyethylene films are less expensive than vinyl and butyl rubbers and have better aging properties than vinyl. Vinyl is superior to polyethylene to sustain impact damages.

In soils not coarser than silty sands, recommended film thickness is 0.20 mm or more for polyethylene or vinyl and 0.38 mm for butyl rubber. Minimum thickness of film for placing over silty or clayey gravels is 0.38 mm for polyethylene or vinyl membrane and 0.76 mm for butyl rubber.

The black polyethylene sheet of 0.25 mm thickness proved effective in stopping seepage in ponds for shrimp seed production, Centre (MPEDA) of Gopalpur Hatchery of Odisha, which had sandy soils.

Filters

Filtration is accomplished by identifying properties of materials to be separated.

Material properties useful for filtration are: density, particle size, electrical properties, chemical properties and magnetic properties.

Different types of filters are available. Selecting the correct one for specific application requires knowledge of various types of filters and their principles of operation. Filters may be classified as mechanical, gravitational, chemical or biological.

Mechanical filters: In aquaculture systems, mechanical filters are primarily used for separation of liquids and solids. They are usually simple in operation and easy to maintain, if correctly used. They extract all particles larger than specified size.

Stationary screens: Probably screens are the most widely known mechanical filters. A stationary screen placed across the fluid flow is the simplest form. Stationery screens are rarely used for particles smaller than 1.5-mm in diameter. Screen mesh sizes are available from several centimetres down to a few microns. Screens are available in materials ranging from carbon steel, brass, stainless steel and plastics to cloth fabrics.

Rotary screens: Where screen plugging is a problem, rotary screens are used. They are rotating screens constructed in such a way that screen operates only partially submerged in water, and submerged section filters water passing through it. Continuous rotation causes a section of screen to alternately filter and be above water surface, where it passes in front of a backwashing system. Since backwashing is continuous, screen can operate continuously with low head loss and low labour requirement.

Sand filters: They consist of a layer of sand and or other particulate materials through which water is passed. This is a mechanical process where particles too large to pass through spaces between sand grains are trapped. The maximum particle size that will pass depends on the sand-grain size. The larger the grain size, the larger the particle will pass through. Normally the sand grain sizes vary between 2.0 mm and 0.02mm. However, stone, coal, gravel or other materials may extend particle size to a desired larger size and clay or similar materials may reduce particle size to micron level. Backwashing of filter bed is required at regular intervals to avoid clogging.

Gravity sand filters: In these filters, water containing particulate material enters at the top and passes down through the filter bed by gravity. In most cases filter material consists of a top layer of sand, middle layer of gravel and a bottom layer of large stone ballast. At bottom clean water is collected either through perforated pipes or through perforated floor.

The rate of flow through a gravity filter may be described by Darcy's equation,

$$U=K \cdot h/d$$

where U, average velocity of flow through sand filter (m/sec); K, permeability constant (m^3 per sec per m^2 surface area); d, depth of the filter (m); h, head, i.e. pressure (m).

$$\text{The flow rate, } Q = AU \ (m^3/sec)$$

$$= A.\ K.\ h/d$$

where Q, flow rate (m^3/sec); A, top surface area of filter (m^2).

The Central Institute of Freshwater Aquaculture has constructed a filtration system at its main feeder canal with stone ballast of average size of 15mm to remove entry of unwanted fishes and debris from the irrigation canal water supply. A laboratory model filter with gravel size 10 mm was observed to achieve a high filtration rate with

reasonably good sediment removal.

Pressure sand filters: They are same as the gravity sand filters excepting that pressure sand filters are enclosed in the pressure vessels and the head is applied to the filters by pumps. Since the head is considerably higher, the flow rate is also higher.

Chemical filters: These filters are primarily absorption units. Absorption is the process of accumulation or concentration of substances at the surface or at the interface. In wastewater treatment, absorption usually occurs at a liquid – solid interface, such as in activated carbon-water or ion exchange resin water interface.

Biological filters: Biological filtration means bacteriological conversion of organic nitrogenous compounds into nitrates. Although nitrogen cycle begins with the conversion of nitrogen containing organic compounds into ammonia;this first step is usually complicated before the material reaches biological filter. However, some ammonification and deamination occur in all biological filters unless filter influent is from pure organic source. The primary purpose of the biological filter is conversion of ammonia to nitrite and nitrite to nitrate. This conversion is very important in aquaculture systems because ammonia is a highly toxic metabolic waste; discharged directly by many cultured organisms.

The first step of this process is accomplished by autotrophic bacteria of the genus *Nitrosomonas* as per the following reaction.

$$NH_4^+ = 1.5O_2 \ \textit{Nitrosomonas} \ NO_2^- + 2H^+ + H_2O$$

The second step of the nitrification process is accomplished by *Nitrobacter*

$$NO_2^- + 0.5O_2 \ \textit{Nitrobacter} \ NO_3^-$$

The biological filters usually consist of a porous solid phase on which nitrifying bacteria grow, bacteria extract required nutrients, oxygen and other materials for survival from the water passing over the solid phase. A box filled with rocks is a simple biological filter. The influent enters the top, passes down through the filter bed (rocks) and flows out through the under drains laid at the bottom of the box.

The CIFA, Bhubaneshwar, has developed and installed a Recirculatory System of Aquaculture through water recirculation and biofiltration (Fig. 27.7) and demonstrated a net production of 7.3 kg/m^3/3 months of Indian major carps. The biological filter

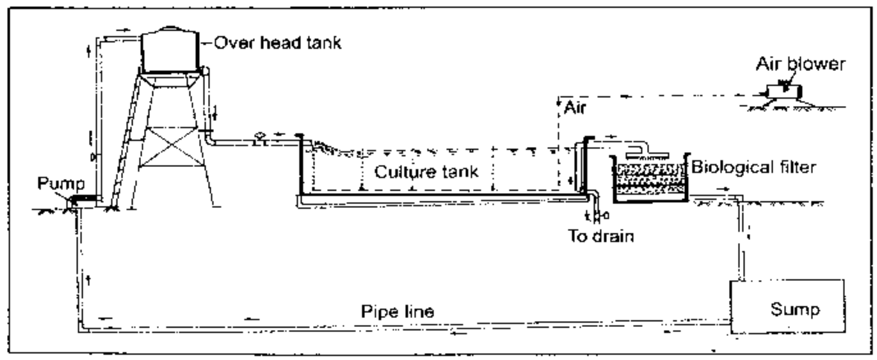


Fig. 27.7. Schematic diagram of a closed-loop recirculatory system.

used in the system is packed column filter with a total depth of 0.45 m by filter media of shells, charcoal and stone chips; the depth of each media being 0.15 m.

Aquaculture helps reducing water pollution, and in this direction the CIFA has developed Aquaculture Sewage Treatment Plant (ASTP). A pilot ASTP plant has been designed and installed at Matagajpur, Cuttack, Odisha, where one million litres sewage is treated daily through duckweed and fish culture over 0.56 ha. The raw sewage is partially treated in duckweed pond complex (18 nos, 0.36 ha) with two days retention period and thereafter passed on to fish-ponds (2nos, 0.2 ha), where it is retained for three days, and on the whole, continuous flow of water is maintained during the treatment. The ASTP runs satisfactorily having intake BOD level 140-152 with outlet BOD level 18-22, and average fish production of about 4 tonnes/ha/14 months.

28. Fish Genetics

Fisheries and aquaculture play a promising role in providing nutritional security to the growing global population. Fish genetic resource for food still comes from capture due to low domestication level in fisheries sector. Therefore, conservation of natural resource and enhancement in aquaculture production become equally important. Fish is the most important source of protein in the world, making up to 25% of protein intake in some developing countries and 10% in North America and Europe. Increase in demand for fish is being driven by the population growth – global population of 6 billion in 2000 reached at 6.8 billion by the end of 2010. Future increases in sea-food supply from capture fishery are unlikely. Over 50% of the oceans are fully exploited and 70% are in the urgent need for management. Contribution of worldwide aquaculture to fish production has increased from 2.2% to more than 35% in 50 years. Trend confirms that aquaculture will become more important in future than capture from the production perspective; and likely to take over capture by 2020. Another key trend is that aquaculture production is primarily concentrated in the developing countries, which is likely to continue through expansion programme. It is estimated that aquaculture will expand to 76 million tonnes in 2030. It is also predicted that production in developed countries will grow by 10% (7 million tonnes by 2030). Top aquaculture production species are Japanese scallop and Pacific oyster among the bivalves, and among finfish are grass carp, bighead carp, crucian carp, silver carp, Nile tilapia, Atlantic salmon and Indian major carps. Among crustaceans, the most important species is tiger shrimp. Indian major carps account for over 4.0% to world aquaculture production, and nearly 75% is contributed by Indian aquaculture. Asian aquaculture producers are responsible for 91.2% global production; followed by 3.9% by Europe, 2.0% by South America, 1.26% by North America, 0.89% by African aquaculture, and 0.28% by Oceania (Australia and New Zealand).

Over last 2 decades, Indian fisheries have grown 6.5 times. Freshwater aquaculture makes 95% of the total production. Production of carps and shrimps forms main area of activity. The major challenge for fisheries and aquaculture research is to enhance production while resources such as land, water and husbandry inputs will remain limited; means the thrusts need to be on enhancing productivity per unit of input. Fish-culture technologies developed so far are primarily based on husbandry and management practices. They have their own limitations, and beyond which they may not be economical. This makes development of improved strains of cultivable fishes; conservation and management of indigenous germplasm with its utilization and at the same time securing Intellectual Property Rights (IPRs), an utmost priority. Recent technological advancements in genetics and biotechnology have provided immense potential for their application in aquaculture to meet above challenges. Exploitation of genetic potential of the candidate species would be a practical possibility for further improvement in the production levels in a most sustainable manner. Genetic potentials have been, and are being extensively exploited and utilized in agriculture and also in the domesticated livestock, and these practices can be applied in aquaculture as well.

Cytogenetic/chromosomal studies in fishes

Majority of the fishes possess a diploid (2n) number, ranging usually between 48 and 50, and in some even above this. Approximately, 2,000 and odd number of fish species (marine and freshwater) have so far been analyzed for chromosomal investigations, mostly for diploid number, from different parts of the world. A chromosome atlas on Indian fishes depicting karyotypes of 128 teleosts found in Indian waters has been compiled by the National Bureau of Fish Genetic Resources (NBFGR), Lucknow. Till now, chromosomal information for more than 200 Indian fish species has been documented.

Some studies were also undertaken for comparative karyological analysis of parents and hybrids. In India, studies on hybrids were carried out in some major carps–catla-rohu, kalbasu-rohu, kalbasu-catla, rohu-catla, etc. Diploid number (2n) in hybrids did not differ from their parent species, but difference was there in number under each type. In hybrids between Indian major carps and common carp, diploid number reported was an aneuploid in most cases, ranging from 74 to76. Hybrid crosses between catla, rohu, mrigal, kalbasu have exhibited high rate of viability and fertility. Certain hybrid crosses did not yield any fertile progeny like hybrids between common carp and Indian carps and also between Chinese grass carp and bighead carp (triploids).

Chromosomal banding

C-banding, G-banding, Q-banding and NOR-banding studies have been carried out in some fish species. So far as Indian major carps are concerned, studies have shown presence of centromeric C-bands in all chromosomes of *Labeo rohita* with no intercalary C-band. In *Cirrhinus mrigala,* overwhelming majority of chromosomes indicated C-bands localization in or around centromere, while others either lacked or showed telocentric (terminal or interstitial) C-bands localization; different reports are available on C-banding pattern by different workers. G-banding studies in Indian carps did not meet with much success. NOR (nucleolar organizer regions) studies were also done in some fish species, including Indian major carps and endemic fish species from Western Ghats. In catla, minute NORs were terminal on the short arms of one sub-metacentric and sub-telocentric chromosome pairs.

In *L. rohita*, NORs are on the short arm of the medium-size submetacentric chromosomes. While in *Labeo rohita* and *L. calbasu*, the NORs are similar in size, and *L. bata* possesses bigger size NORs. NORs in *L. rohita* and *L. calbasu* were present on the 11th pair of chromosomes and in *L. bata,* they are located on the 9th pair. Banding studies help in identification of species and also of homologous pairs in the karyotypes. NOR banding also helps similarly, as they are present on specific chromosomes. NORs also help in identifying parentage of hybrids that occur in nature.

It appears that fish chromosome studies did not progress much, particularly, after the advent of biochemical and molecular genetic methods, mainly due to ease, accuracy and speed that is possible with these methods. Application of advanced techniques such as restriction endonuclease banding and fluorescent *in-situ* hybridization (FISH) can be used for development of species/stock specific molecular markers and identification of sex chromosomes.

Molecular markers and fish genomic resources

The genetic markers can detect genetic variations and they can be explained and analysed within the limits of the genetic principles. Based on their mode of transmission and evolutionary dynamics, genetic markers can be categorized into protein markers such as allozymes, and DNA markers. DNA markers are further characterized based on the location–nuclear DNA and mitochondrial DNA. Development of DNA amplification using polymerase chain reaction (PCR) technique has opened up possibility of examining genetic changes in fish populations over past 100 years or even more using archive material. In PCR reaction, a DNA sequence can be amplified many thousand folds to provide sufficient product for restriction analysis or direct sequencing. Once appropriate primers are available, large number of individuals can be assayed quickly thus facilitating large population screening for variability. Every type of marker has advantages and limitations. Therefore, application and suitability depends upon the objective of analysis. The basic properties of these marker types and their potential applications are explained in Table 28.1.

Molecular markers have varied applications such as species discrimination, phylogeny and taxonomy validation, population genetics and stock identification, and linkage mapping for selective breeding and functional genomics. In the present scenario, conserved MtDNA genes such as Cytochrome b, Cytochrome C oxidase I (COI) and 16SRNA are prominently used for phylogenic and taxonomic validation of fish species. Fast evolving genes such as partial Cytochrome b (307 bp) polymorphic region, ATPase 6, 8 genes are used to determine genetic structure population of wild fish populations, single or in combination with variable nuclear markers such as allozymes and microsatellites. Due to co-dominant inheritance and precision of analysis, allozyme and microsatellite DNA markers are preferred for study of population genetics. These markers can be analysed to have information for genetic bottlenecks, if there are in natural populations, and also for information on population size.

Over 24,000 microsatellite loci are known in teleost fishes. Majority are contributed from carps, catfishes, perches and salmonids. Considerable progress has been made to develop microsatellite DNA markers from Indian fish species for population genetics as well as for genomic applications. Species specific microsatellite DNA markers are developed through construction of partial genomic library for important species such as *Catla catla, Labeo rohita, Labeo fimbriatus, Chitala chitala, Pangasius pangasius, Channa marulius, Clarias batrachus, Tor putitora* and *Macrobrachium rosenbergii.* Conserved flanking sequences of microsatellite markers can be used to identify homologous microsatellite loci in closely related species through cross priming. Overall,

Table 28.1. Types of DNA markers, their characteristics, and potential applications

Marker type	Requires prior molecular information	Mode of inheritance	Type	Locus under investigation	Likely allele numbers	Polymorphism or power	Major applications
Allozyme	Yes	Mendelian, codominant	Type I	Single	2–6	Low	Linkage mapping, population genetics
Mitochondrial DNA (mtDNA)	No	Maternal inheritance	-	-	Multiple haplotypes	High and conserved (Depending upon MtDNA Region)	Population genetics, phylogeny and DNA barcoding
Restriction fragment length polymorphism (RFLP)	Yes	Mendelian, codominant	Type I or type II	Single	2	Low	Linkage mapping
Random amplified polymorphic DNA–RAPD (AP-PCR)	No	Mendelian, dominant	Type II	Multiple	2	Intermediate	Species discrimination, population genetics
Microsatellites (SSR)	Yes	Mendelian, codominant	Mostly type II	Single	Multiple	High	Linkage mapping, population genetics, pedigree analysis
Expressed sequence tags(EST)	Yes	Mendelian, codominant	Type I	Single	2	Low	Linkage mapping, physical mapping, comparative genomics single nucleotide polymorphism
Single nucleotide polymorphism (SNP)	Yes	Mendelian, codominant	Type I or type II	Single	2, but up to 4	High	Linkage mapping, population genetics
Insertions/ deletions (Indels)	Yes	Mendelian, codominant	Type I or type II	Single	2	Low	Linkage mapping

polymorphic microsatellite DNA markers are identified for nearly 40 Indian fish and shellfish species. For functional genomic studies, microsatellite DNA and single nucleotide polymorphism (SNP) have been considered as markers of choice. Expressed sequence tags (ESTs) represent transcript of expressed genes and have proved to be a powerful and rapid approach to identify new genes that are preferentially expressed in certain tissue or cell types and for their regulation. Polymorphic microsatellites within genes of known function would convert microsatellites into type I markers, and that conserved in a wide spectrum of species through evolution are useful for comparative gene-mapping. Thus, development and mapping of large numbers of gene-associated microsatellite type I markers will greatly enhance existing linkage maps, bringing application of genomics for genetic improvement of fish brood through analysis of quantitative trait loci and marker-assisted selection. In one of the pioneering studies at the NBFGR, over 1,900 ESTs were sequenced from *Clarias batrachus* spleen. Through annotation of genes, 14 genes responsible for immune response were identified and 200 microsatellites (type I) were identified. These microsatellites can provide useful resource for genotyping wild populations and families in domestication for linkage map development. In *Labeo rohita*, 702 ESTs have been identified from brain, liver and spleen at the CIFA, Bhubaneshwar.

Genetics in aquaculture

Different methods or approaches available for genetic improvement in fishes are traditional, selective breeding and hybridization, genome manipulation and hormonal sex reversal and gene transfer. The method to be applied usually depends on the species and its biological traits, its economic importance, and of course, on the available facilities. Selective breeding has been an effective method to improve number of quantitative or economic traits in a cumulative manner, i.e. improvement from generation to generation. But to maintain stock/group in a larger number to avoid inbreeding is a constraint. Negative effects of inbreeding are more or less directly proportional to genetic gain.

Genome manipulation (chromosomal engineering)

Genome manipulation or chromosomal engineering is another modern approach to produce gynogenetic and androgenetic inbred lines and polyploid individuals. Gynogenesis and androgenesis are effective tools to produce highly inbred homozygous lines of usually mono-sex individuals. These inbred individuals when crossed with normal heterozygous ones may produce offspring with heterosis, particularly for growth.

Gynogenesis

It is generally stated to be a specialized form of parthenogenesis. In gynogenesis, embryo develops solely with maternal genome wherein egg is activated by sperm without any genetic contribution from the latter. And the resulting zygotes are haploid. Restoration of diploidy may occur spontaneously in the natural gynogenesis or by chemical or variety of thermal/pressure shock treatments to the activated eggs in the artificial gynogenesis.

Natural gynogenesis: This occurs in nature. In some species of the fish of the family Poecilidae such as *Poecilia formosa* and Cyprinidae (*Carassius auratus gibelio*), gynogenesis is the reproduction method. Similar process of reproduction has also been reported in the members of the family Pleuronectidae.

Induced gynogenesis: Gynogenesis has been successfully induced in a number of fishes, including Indian major carps and Chinese carps by denaturing genetic maternal DNA of sperm through irradiation either by UV or gamma rays and activating eggs with irradiated milt. Diploidy is restored as mentioned earlier. Response differences in diploidization of activated eggs have been reported. In some species, diploidization was effective with cold shock treatments while in others, heat shocks gave better results. Among Indian major carps, diploidization of activated eggs was found better with heat shocks in catla and cold shocks in rohu and kalbasu. However, pressure shocks were reported to yield higher percentage of diploid-gynogens in many species. Gynogenesis usually results in all female-progeny production when female is homogamous–means female-fish that produces eggs with only x/x and not x/y. Most of the females in fishes produce homogamous eggs. Gynogenesis is of two types that can be induced in fishes. One is meiotic gynogenesis and the other is mitotic gynogenesis.

Meiotic gynogenesis: It is induced through retention of second polar body by administering early shock treatments to activated eggs. Diagrammatic description of the process is shown in Fig. 28.1.

Mitotic gynogenesis: It is induced by blocking first cleavage/the first mitotic division (endomitosis) by administering late shock treatments (Fig. 28.2).

However, the resulting products from meiotic gynogenesis may be heterozygous or homozygous. Again through meiotic gynogenesis, it may not be possible to achieve complete homozygosity in one generation, and may require to produce two to four generations of gynogens, whereas through mitotic gynogenesis, it is possible to produce homozygous individuals (100% homozygous at all loci) in one generation. Diagrammatic description of the process is shown in Fig.28.2. As mentioned above, both meiotic and mitotic gynogenesis are effective tools to produce inbred lines in fishes in a much shorter time compared to conventional means of sib-mating, which may take 10-12 generations to achieve complete homozygosity.

Hormonal sex reversal is also used for the production of gynogen males by administering androgens to a portion of meiotic gynogen-offspring. These sex reversed individuals are phenotypically males as they develop testes, but genotypically females as they produce sperms with X chromosome, so that when a gynogen female is crossed with this sex reversed gynogen male, resultant offspring are all females.

Androgenesis

It is also another form of parthenogenesis; it occurs in the nature and can be induced.

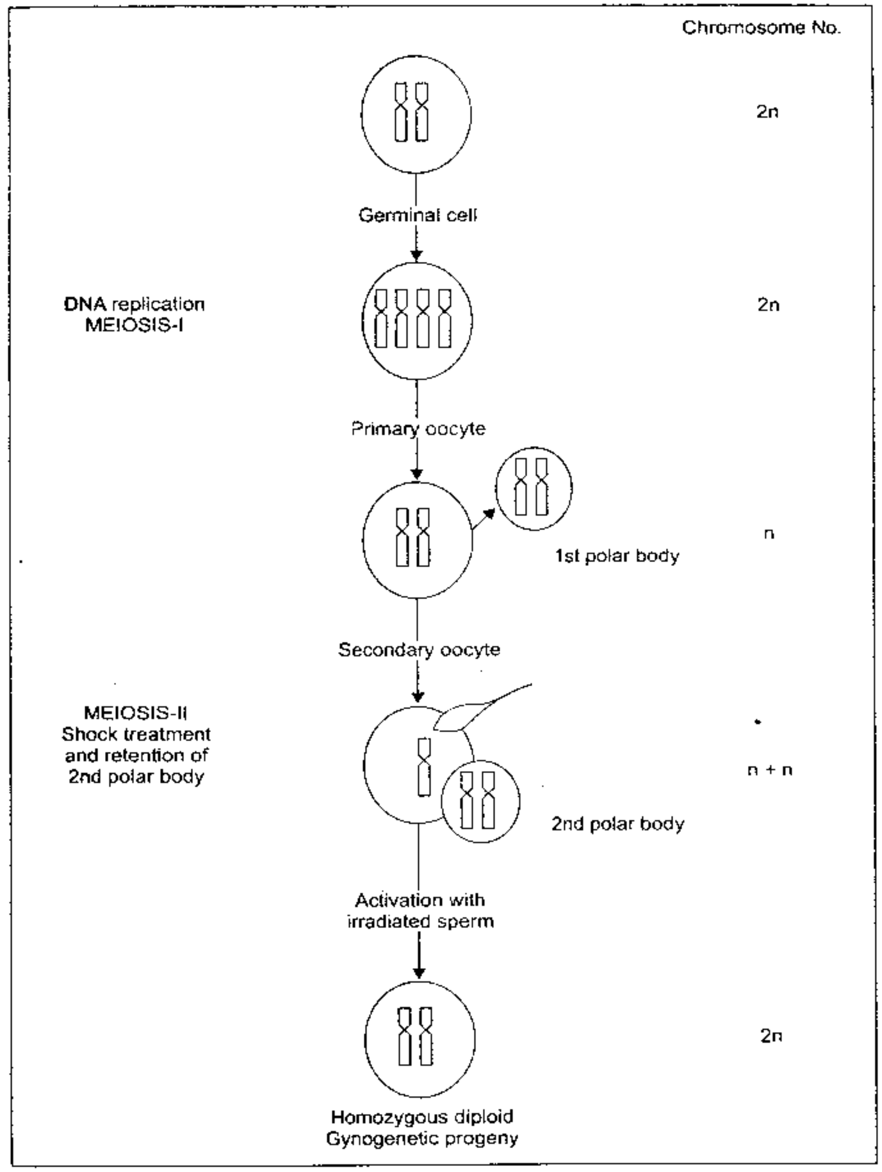


Fig. 28.1. Induction of meiotic gynogenesis by retention of 2nd polar body.

Natural or spontaneous androgenesis: This, though rare, has been found to occur particularly in some hybrid crosses, produced either between distantly related individuals or those with disproportionate or incompatible genomes, as is in the cross

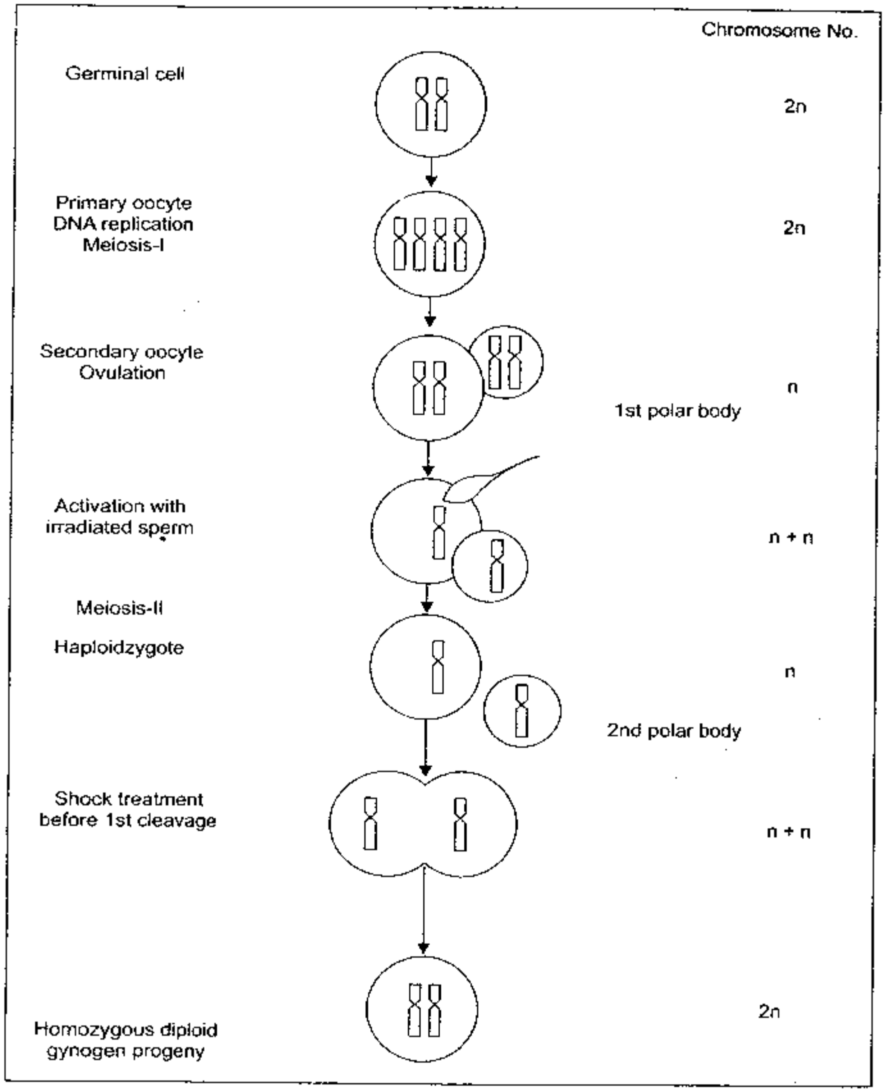


Fig. 28.2. Induction of mitotic gynogeneis by endomitosis.

of common carp female and grass carp male. However, the incidence or percentage of occurrence is very rare and low.

Artificial androgenesis: In this, genetically inactivated egg is activated by normal sperm of the species. And diploidization of the zygote is through administration of shock treatments as is done in artificial gynogenesis. For diploidization, dispermy or

other mechanisms are also employed. Nature of products resulting from androgenesis is different in the sense that unlike in gynogenesis, usually all males are produced.

Polyploidy

An individual is said to be polyploid if its ploidy consists of additional set(s) of chromosomes over normal diploid number. Polyploidy has been reported to occur in nature, as do gynogenesis and androgenesis. Increased level of ploidy can also be brought about by artificial means or through inducement.

Natural polyploidy: It has been observed in some fish species like common carp, trout etc. mainly due to chromosomal translocation. It may also appear in cross-bred progeny of very distantly related species. Thus, spontaneous triploidy was observed in the progeny of the cross between grass carp and bighead carp.

Induced polyploidy: Polyploidy can be artificially induced in the same manner as is done for artificial gynogenesis and androgenesis. In other words, shock treatments of the same nature and intensity and duration applied for inducing gynogenesis and androgenesis to a given species may also be effective to induce polyploidy. The difference is that to induce polyploidy, shock treatments are administered to normal fertilized zygotes and not to genetically denatured sperm-activated zygotes.

However, while triploidy (3n) is induced through retention of second polar body in the fertilized egg by giving early shock treatments; tetraploidy (4n) is induced by blocking first cleavage or mitotic division in the fertilized egg by administering late shock treatments (Fig. 28.3). Artificial induction of triploidy was successfully carried out in several species of fishes, including Chinese grass carp and common carp. The CMFRI, Kochi, has achieved success in producing triploid edible oyster, *Crassostrea madrasensis,* by treating newly fertilized eggs with 100 μM 6- dimethylaminopurine. This resulted in 67% survival, and triploid oysters exhibited significantly higher growth rate and meat content (126% higher dry weight, nearly 30% more glycogen, lipids and proteins) compared to diploid individuals. Among ornamental species, triploidy has been induced in *Betta splendens*, *Brachydanio rerio*, *Puntius conchonius* and *Poecilia reticulata* at the Madurai Kamaraj University. Some successful attempts have been made to induce triploidy/tetraploidy in Indian major carps—catla and rohu (Fig. 28.3). Triploids, particularly aneuploid individuals, are generally sterile. Sterility can be made use of in species like common carp and tilapia, which breed prolifically even under pond environment, to check unwanted reproduction leading to over-population that will hamper growth of other fishes in grow-out culture system for want of food and space. In some species, sterile triploids have been reported to grow significantly faster than normal diploids. But, like gynogens and androgens, teleost triploids are yet to be produced in a large scale in India to be used for aqua-farming. Induction of tetraploids resulted in heavy mortality, poor yield and survival. The known and assumed reasons for failure to induce live tetraploid fish are: mosaicism, aneuploidy, reduced cell surface, choosing wrong cytological events and/or high homozygosity. Tetraploid mammals and birds are not viable and are known

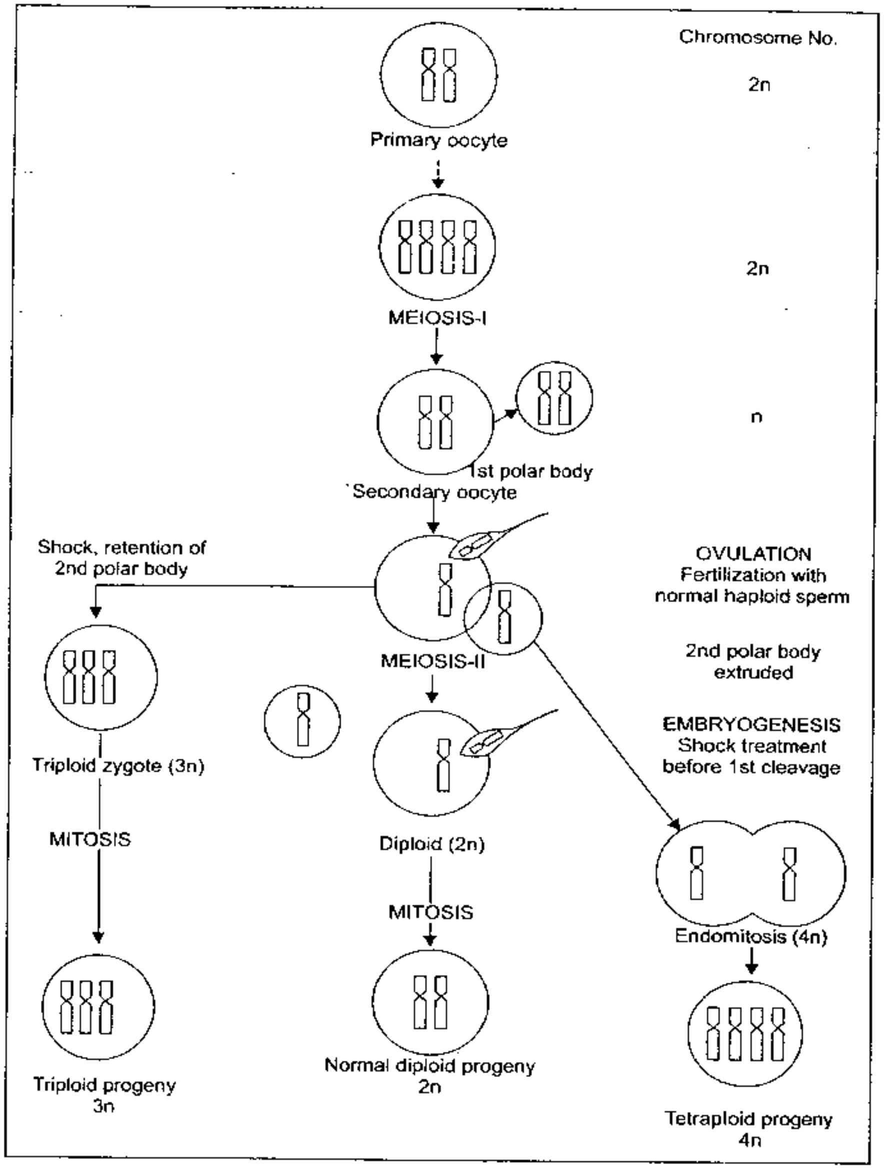


Fig. 28.3. Induction of polyploidy.

not to tolerate critical changes in the genome-cytoplasmic ratios. It was estimated that in comparison to diploids, cell number present in tetraploid grass carp, *Ctenopharyngodon idella*, was 54% only. Such a decrease in cell number and the

corresponding increase in cell volume would decrease cumulative cell surface available for physiological reactions, which may limit or inhibit cellular metabolism, leading to mortality of 4n individuals.

Hybridization

It is well known that hybridization refers to crossbreeding between either members of different races or strains of the species (intraspecific) or between two species of the same genus (interspecific) and between species belonging to different genera (intergeneric). Hybridization is usually aimed to combine positive traits of parent species in their hybrid offspring. The positive traits may include better growth, resistance to disease/changed environment, meat quality, early or late maturity, better fecundity and so on.

Intraspecific hybridization: Different races or strains of the same species from different geographical regions when crossed result in production of offspring with heterosis. Recently, even stocks from different hatcheries, when crossed yielded progeny that exhibited heterosis for growth. The most noteworthy is the interracial crossbreeding work in the erstwhile USSR, between cultivated common carp and wild carp from river Amur. The offspring of this cross known as 'Kursk carp' has a greater resistance to cold temperature than cultivated carp. This facilitated extending fish culture in the north and north-eastern region of the formerly USSR, which was hitherto nonexistent. Hungarian work on the hybridization of common carp produced useful strains.

Interspecific hybridization: This among Indian major carps has shown intermediate traits in some cases and negative traits in others. Cross and reciprocal cross between *Labeo rohita* and *L. calbasu* produced offspring with intermediate traits (partial heterosis) ; the hybrid exhibited faster growth than the slow-growing parent kalbasu. A slight improvement of the body colour from dark muddy to pale-red to reddish-brown of the hybrid was also a welcome trait over kalbasu with consumer's point of view. However, other crosses between members of genus *Labeo* (*L. rohita* × *L. bata*, *L. rohita* × *L. gonius*, *L. calbasu* × *L. bata* and *L. dussumieri* × *L. rohita*) did not exhibit any useful traits of interest for aquaculture.

Intergeneric hybridization: Intergeneric hybrids have more or less exhibited same characteristics as shown by interspecific hybrids. In Indian major carps, extensive work has been carried out to study growth patterns and food habits and also other phenotypic traits of the intergeneric hybrids in comparison to their parent species. Only a few of them are found to possess some traits useful for aquaculture–these are hybrids between *L. rohita* female and *C. catla* male; *C. mrigla* female and *C. catla* male; and reciprocal hybrids between *C. catla* and *L. fimbriatus*. These hybrids have exhibited faster growth than their slow-growing parents *L. rohita*, *C. mrigala* and *L. fimbriatus* respectively. Some of these hybrids have shown a wider feeding spectra over their parent species and are recommended for culture in reservoirs. The reciprocal hybrids of Asiatic catfishes *Heteropneustes fossilis* and *Clarias batrachus* and *H. fossilis* and *H. microps* have also been produced experimentally. Of all the interspecific and intergeneric hybrids produced so far in India, 'Naadan' produced between *Labeo rohita* female and *Catla catla* male has found acceptance by the farmers owing to small head and meat quality of rohu and fast growth rate of *Catla catla.* Utility of rohu × catla hybrid in composite fish culture is also enhanced by its higher flesh content (54%), phytophagic food habits and adaptability to artificial feed. 'Naadan' is produced in hatcheries of West Bengal and Andhra Pradesh for fish farming (Generally, while mentioning name of hybrids, name of female parent is written first, followed by the name of the male parent. For example, 'Naadan' is represented as rohu♀× catla♂).

Intergeneric cross between beluga and starlet, two economically important sturgeons (*Huso huso* and *Acipensor ruthemus*), combined quicker growth rate of beluga and early maturity of starlet. Hybrid crosses between some species of tilapia produced all male offspring. Some other hybrid crosses like Chinese carps produced either triploid progeny (grass carp × bighead carp) or gynogens (grass carp × silver carp). Others like hybrids between common carp × Indian major carps turned out to be mostly aneuploid and sterile. Thus, though not very common, sometimes hybridization may be useful to combine positive traits of parents in the offspring or in producing monosex progeny and also sometimes changing ploidy status, leading to sterile individuals in certain cases. The resultant traits in hybrid offspring of any particular cross may probably depend on the compatibility and interaction between genomes of two species involved in the cross.

Selective breeding

Selection of animals with useful traits has been one of the most effective means to improve quality of domesticated animals. This is the conventional application of genetics for enhancing domestication and production farming. Normally, selection has been for increasing yield, survival rate and resistance to biotic and abiotic stresses, and also for improving product quality. Selective breeding in nature is called 'natural selection'. In this process, the most strong and the fittest individual that can withstand variations or changing situations in their environment will remain and thrive and all others will get eliminated. Such individuals which can perform well or the best can also be developed through artificial selection, be it in plants or in animals, not only terrestrial dwellers but also aquatic organisms. Artificial selection is a classical approach, and the methods have been profitably utilized by man both in agriculture and veterinary animals. The process has already started its influence in aquaculture too.

There are different methods of selection – mass selection, family selection, within family selection, combined selection etc. In the case of fishes, most commonly followed methods are either family selection or mass selection. Most of the times, combined selection is also followed. While mass selection can be used only for a single trait, family selection/combined selection helps in selecting different traits such as growth, disease resistance, meat quality or reduced fat content etc. The selection methods act on the intraspecific variation available in the founder population and heritability of the desired trait. Here, for widening the base of variation, even wild stocks of animals or wild landraces of plants are important. The objective is to select for additive gene effects to enhance frequencies of favourable genes for target trait. Therefore, improvement through selective breeding depends upon the extent of additive genetic variation in the selected population.

In any selective breeding programme, individuals that perform more than the population average for the target traits are captive bred, and progeny is selected again for generations for breeding. Therefore, after generations of selective breeding, additive genetic variation increases in selective bred population, and is improved over unselected population for the desired trait. In the whole selection programme, caution is taken to avoid breeding of closely related individuals, which depress possible genes due to inbreeding. Aquaculture is dependent upon the low domestication level. It is estimated that productivity of farm animals has enhanced 3-4 times in the last 5 decades through selective breeding. To meet demand growth, aquaculture will need to contribute more in fish production. Moreover, key lies in improving aquaculture within the limits of critical resources such as land area, water and increasing costs for husbandry. In this scenario, need for development of improved breeds for aquaculture is a challenge. In aquaculture, genetic selection and hybridization have been used for improving fish species. The estimates of genetic variance reported for domestic fish stock suggest that selection for economically important traits could be effective. From captive breeding perspective, aquaculture species differ from livestock, yet principles of selective breeding can also be applied to their genetic improvement. Some of the successful examples of selective breeding programmes in aquaculture are Atlantic salmon in Norway, Nile tilapia in Asia, Channel catfish in the USA. Genetically Improved Farmed Tilapia (GIFT), growing 60% faster than parental strains; is one of the widely used improved fish in tropical aquaculture. The other important aquaculture genetic improvement programmes that are in progress include *Cyprinus carpio, Labeo rohita, Barbodes gonionotus, Megalobrama amblycephala, Penaeus monodon, Marsupenaeus japonicus, Fenneropenaeus chinensis, Litopenaeus vannamei* and *Macrobrachium rosenbergii* for traits such fast growth rate and disease resistance; and for smaller naupliar size (SNS) in *Artemia franciscana* and Indian strains of *Artemia.* The work on selective breeding of the Indian major carp, rohu at the Central Institute of Freshwater Aquaculture, Bhubaneshwar has resulted in the development of strains that exhibited over 40% selection response on an average at the 4th generation level. Genetic improvement of rohu (Jayanti) with 17% higher growth efficiency per generation has been reported

Marker assisted selection

With the advent of technologies to identify genomic resources such as high throughput sequencing and bioinformatics, prospects of targeting specific loci for desired traits have enhanced. The research requires development of molecular markers which are variable. Microsatellite DNA markers and single nucleotide polymorphisms (SNPs) have become markers of choice for development of linkage maps. Linkage maps have been used for various kinds of biological analyses, which include position-based cloning, quantitative trait locus analysis, comparative vertebrate genomics, detection of radiation-induced mutations and marker assisted selection (MAS).

MAS is an important strategy for genetic improvement and breeding programmes. In MAS, identified polymorphic markers are used to genotype families and progenies with desired trait data. The data is used to develop linkage maps to study linkage between markers and traits. Breeding plans are planned for families that show such linkages to achieve genetic improvement. In agriculture, such linkage maps are available for several crop varieties. Application of marker assisted selection is pursued in some aquaculture species – Atlantic salmon (522 microsatellite markers with 28 linkage groups); catfish (563 markers, AFLP, with 43 linkage groups); tilapia (550 microsatellite markers and 15 genes), rainbow trout (Two maps have been produced–476 markers segregated into 31 major linkage groups; 109 markers segregated into 29 linkage groups); olive flounder (149 microsatellite markers and 23 linkage groups); seabass (163 microsatellite markers and 25 linkage groups) and tiger prawn (189 markers with 36 linkage groups). In India, a programme to develop linkage map of *Labeo rohita* is being actively pursued. Hybrid mapping populations (rohu × kalbasu) and QTL mapping populations (growth-selected and unselected rohu) have been developed. With the available 75 microsatellite markers, 3 linkage groups of rohu have been generated.

Hormonal sex reversal

Administration of exogenous steroid hormones to control sex in fishes has been in use for aquaculture purposes. Hormonal sex reversal techniques are used for mass production of sterile monosex populations by interfering with genetic sex. Spawn or fry are treated at an early stage with androgens (male hormone) if all-male population is required and with estrogens for all-female population–treatment with androgen usually develops testes and with estrogen develops ovaries. Hormones administration is done either by mixing required quantity in the feed or dissolving in water medium (dip-treatment or immersion). The early stage of the fish for treatment should correspond with the initial genetic sex or gonadal differentiation. Success or effectiveness of hormonal sex reversal depends particularly on the time of treatment, dose of hormone, duration of treatment and also sometimes on the mode of treatment (dietary or water medium). In addition to producing monosex fish populations, hormone treatments are also carried out to produce sterile fish. Sterilization has been achieved in fishes such as rainbow trout, turbot and in salmonids like Atlantic, Coho and Chinook salmons. The most commonly used hormones for sterility are testosterone and methyl testosterone at a dose slightly higher than used for masculinization. Hormonal sex reversal is also used for production of gynogen males by administering androgens to a portion of meiotic gynogen offspring. These sex reversed individuals are phenotypically males as they develop testes, but are genotypically females as they produce sperms with X chromosome, so when a gynogenetic female is crossed with this sex reversed gynogenetic male, resultant offspring will be all females.

Hormonal treatments have been successfully used to sterilize genetically improved tilapia (through selective breeding) to prevent unauthorized production and sale of seed of these improved varieties. The technique is ideal for culture of exotic fishes to prevent them from establishing in natural waters, if they escaped from captivity.

Male sex hormones: Androgens, both natural and synthetic, are used for production of all-male fish population. Among androgens, 17α methyl testosterone (MT) is the most widely used hormone and has been tested on several species of fish belonging to Salmonidae, Cyprinidae, Anabantidae, Poecilidae and Cyprinodontidae. Production of 100 %t male tilapia had been done by administering a dose of 5 mg MT/kg diet during labile period lasting from 9 to 20 days after hatching. As already mentioned, time of treatment (labile period) is very important to achieve maximum results.

Female sex hormones: Estradiol 17β is mostly used to achieve feminization in fishes. Estradiol and estrone are two naturally occurring steroids. Estrogen preparations used for sex reversal include ethyl estradiol, which is a longer acting preparation. Different levels and periods of treatment had been used for feminization with estradiol 17β on salmonids. The dose requirements are different for different species.

Negative aspects of hormonal sex reversal: Some of the expected and suspected negative aspects of hormonal sex reversal are (*i*) residues of the administered steroids can be carcinogenic and may interfere with sex of consumer, who eats treated fish, (*ii*) sexual maturity is usually delayed in the sex reversed females and they may have reduced fecundity, (*iii*) it is a costly and time-consuming process, (*iv*) process has to be repeated every time whenever monosex/sterile population is required. In conclusion, though it is claimed with experimental proof that hormones from the treated fish body system will disappear after the treatment is suspended, use of hormonal manipulations has to be carried out with necessary caution. Hormonal manipulation followed by genomic manipulation could ensure production of all-male or all-female progeny in a successful manner in majority of the fishes.

Genetics in conservation of natural fish populations

Genetic diversity is one of the three fundamental levels of biodiversity, so it is directly important in conservation of biodiversity, though genetic factors are also important in conservation of species and ecosystem diversity. Conservation of genetic variability is important for the overall health of the populations, because decreased genetic variability leads to increased levels of inbreeding, and reduced fitness. Conservation genetics is an interdisciplinary science that aims to apply genetic methods for the conservation and restoration of biodiversity. Populations of most of the species are composed of subpopulations, also called genetic stocks. These subpopulations maintain genetic make-up or characters distinct from other subpopulations of the same species. This is the genetic variation within the species. This differentiation depends upon interactive forces like migration, selection, genetic drift etc that are acting on the species/population, ever since their evolution. Therefore, with the loss of a genetic stock, a species also losses animals adapted to a particular habitat and evolved as fittest to survive through selection. Interbreeding of non-native fish with different

29. Fish Physiology

Fish species occupy almost half of the present vertebrate kingdom. Their habitats range from high altitude lakes such as Titicaca Lake to abyssal depths of oceans, and from high temperature ambience at 37°C in African lakes to negative 2°C in Polar Regions. Fishes also exhibit wide diversity in size, feeding behaviour and digestive physiology. The successful existence of fishes in the course of evolution has mainly been attributed to their ability to utilize a wide variety of trophic resources and diversification in their feeding and digestion. Feeding and digestive structures of fishes are exceedingly diverse, which may be classified as follows based on the feeding habit (Fig. 29.1).

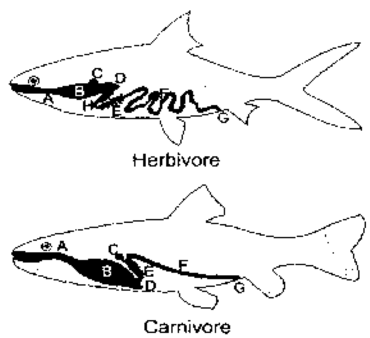
Herbivores: Feed largely on plant materials and often have special chewing structures to get maximum nutritional value from them by ultra-thorough grinding.

Detrivores: Feed largely on detritus (a mixture of sediments, decaying organic matter and bacteria).

Omnivores: Generally consume a mixed diet and have minimally specialized structure.

Carnivores: Consume only animal matter, usually fish and bigger invertebrates.

Fish may also be broadly categorized into ecological groups according to the niche they prefer for feeding – pelagic plankton feeders, benthos feeders etc. Pelagic plankton feeders can be further subdivided into surface and columnar feeders. Fish may also be classified based on the presence or absence of stomach as gastric (e.g. salmonid, catfish, eels, tilapia, groupers, barramundi etc) and agastric (e.g. carps).



(A) Esophagus (B) Stomach
(C) Gall bladder (D) Spleen
(E) Pyloric caeca (F) Intestine
(G) Anus (H) Gizzard

Fig. 29.1. Digestive system of carnivore and herbivore fishes.

Digestive system of fish

Alimentary canal in teleost fishes is broadly divided into two parts – Kopfdarm and Rumpfdarm.

Kopfdarm

It includes mouth, buccal cavity and pharynx and is essentially associated with predigestive processing of food–selection, seizure and orientation. Agastric fishes such as carps do not have teeth on jaws. Buccal teeth assist in food capturing and holding but do not assist in tearing of the prey, excepting in piranha. As an aid to initial processing, most stomach-less cyprinids have pharyngeal teeth which are modified to varying degree depending on the nature of the diet. These teeth help in crushing and

mastication of plant food particles. Some species are filter feeders, filtering surrounding water for phytoplankton and zooplankton, trapping organisms and ingesting them. Filtering apparatus is composed of gill rakers of selected gill arches, which are modified to form a fine sieve, e.g. silver carp and bighead carp. Most of the fishes do not have tongue, excepting some carnivorous fishes. The tongue supplements function of teeth in retention of prey, and may act as a sensory organ. Basement membrane of the buccal cavity is lined with stratified epithelial line which contains mucous cells and taste receptors.

Rumpfdarm

This part of the alimentary canal generally consists of the following parts.

Esophagus: At posterior, pharynx passes into a short, wide muscular tube esophagus. It is commonly known as gullet. It may not be clearly demarcated from stomach in gastric fish or from intestine in the case of agastric fish. Basement membrane of esophagus is lined with stratified epithelial cells, which contain different cell types such as club cells, taste buds and mucous cells. Esophagus is a muscular organ which has well developed both longitudinal and circular muscles. It performs functions of food storage, trituration and mucus secretion.

Stomach: Some fishes do not have stomach. Generally, stomach wall consists of a number of layers, and organization of these layers, from outside towards lumen, is as follows: serous membrane; muscularis: longitudinal muscle layer; circular muscle layer; mucosa: *i.* sub mucosa, *ii.* muscularis mucosa, *iii.* stratum compactum, *iv.* lamina propria, *v.* mucosal epithelium.

Stomach may be divided into two regions, anterior and pyloric. Gastric glands and musculature are more prominent in the anterior part. In some fishes, muscularis or pyloric part is modified to more thick muscularis, which is further reduced into submucosa having protected hard lining to act as gizzard; with compensatory function of dentition as observed in Mugilids.

Intestine: It is simple tubular structure that contains columnar epithelium lined with finger-like projections called villi, which are again divided into small finger-like projections called microvilli with brush-border that serve mainly as the absorptive area for nutrients. These microvilli increase surface area for absorption which allows greater contact of nutrients with cells and provides enhanced cell surface for better digestion and nutrient uptake. Intestine contains goblet cells. The anterior section (the area into which bile and pancreatic juices are received) is often characterized by large number of chylomicrons in the epithelial cells while distal portion of the intestine is characterized by pinocytic activity and cells that contain granules of absorbed nutrients.

The length of the intestine depends on the feeding habit. Relative gut length (RGL) is also an indication of different food habits of fishes (Fig. 29.2). Ratio of the length of the digestive tract to the body length is known as RGL. In general, herbivores have longer digestive tracts than carnivores – RGL is 0.2-2.5, 0.6 to 8.0 and 0.8 to 15 times of the body length in carnivores, omnivores and herbivores respectively (Table 29.1).

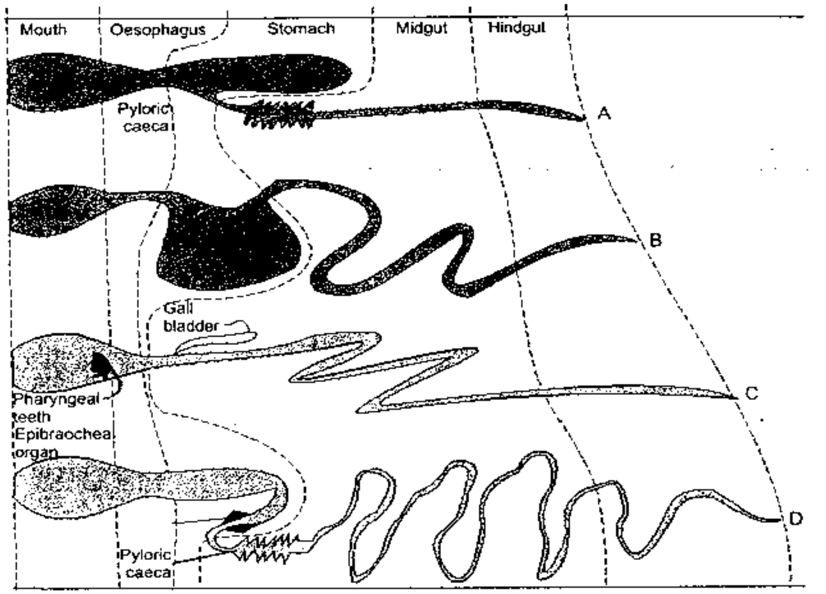


Fig. 29.2. Schematic diagram of relative gut length of four fishes in increasing order. A–Rainbow trout (carnivore), B–Catfish (omnivore, emphasizing animal sources of food), C–Carp (omnivore, emphasizing plant sources of food), D–Milk fish (microphagous, planktivore) (Adapted from *De Silva and Anderson, 1995*).

Table 29.1. Relative gut length (RGL) of selected fish species

Species	Feeding habit	RGL
Labeo calbasu	Algae, detritus	3.75-10.33
Cirrhina mrigala	Algae, detritus	8.0
Hypophthalmichthys molitrix	Phytoplankton	13.0
Catla catla	Periphytopn, plant, insect larvae	4.68
Ctenopharyngodon idella	Plants	2.5
Chela bacaila	Carnivores	0 .88

Rectum: The most distal part of the intestine possesses thicker muscular pore with higher number of goblet cells and granulocytes. Some extent of microbial digestion also takes place in rectum.

Pyloric caecae: It is also known as intestinal caecae. Its presence or absence and number vary with species. It is generally considered as an auxiliary organ or appendage having cellular structures similar to intestine. In some fishes, epithelium lining of pyloric caecae bears hair-like structures known as cilia.

Accessory organs: These organs of digestive system includes liver, gall bladder and pancreas. Liver is generally fused with pancreas to form hepato-pancreas. It is composed of a large number of polyhedral hepatic cells. Numerous bile ductules and blood capillaries are scattered in it. The secretory acini are composed of cuboidal exocrine cells with a large number of zymogen granules. Gall bladder is a narrow sac-

like structure present between the intestine and the right lobe of the liver, and is continued into a short bile duct opening into the intestine; a little behind the pylorus. Vertebrate alimentary canal and certain other organs contain large numbers of granulated endocrine cells. Two lines of these cells have been termed enterochromaffin (argentaffin) and enterochromaffin-like (argyrophil) cells. When supplied with amine precursor, these cells produce and store amines and are known as Amine Precursor Uptake and Decarboxylation (AUPD) or GEP cells (gastro-enteropancreatic cells.). The GEP cells synthesize low molecular weight polypeptides which act as hormones. Several gastrointestinal polypeptide hormones occur in fish such as, insulin, gastrin, secretin, cholecystokinin, and cerulean-like substance and histamine.

Digestive fluids and enzymes

Gastric secretion: Production of acidic gastric fluid occurs in most fishes, excepting in agastric fishes like myxinomids, chimaeroids and many teleosts. Large amount of gastric fluid, usually distinctly acid, is found in elasmobranchs. Maximal acidity is observed a few hours after food intake, and in the absence of food, gastric fluid may be weakly acidic or neutral. Hydrochloric acid makes gastric environment acidic, digests some part of the food, and converts pepsinogen into pepsin, which kills microorganisms from dietary source.

Pancreatic secretion: It is rich in enzymes (mostly as zymogens), which serve in digestion of proteins, carbohydrates, fat and nucleotides. It also contains bicarbonates that neutralize hydrochloric acid entering intestine.

Enzymes: Gastric fluid contains several types of proteases. It is secreted by gastric gland cells as zymogen called pepsinogen, which is inactive. Pepsin is an endopeptidase, which cleaves peptide linkages formed by amino groups of aromatic and acidic amino acids.

Proteases: Proteases such as trypsin, chymotrypsin, carboxypeptidase and elastase are stored in pancreatic cells as inactive zymogen (proenzyme) granules. Trypsinogen is transformed into trypsin by proteases produced by the intestinal mucosal cells (enterokinases).Other pancreatic zymogens are activated by trypsin. Trypsin is formed by removal of a hexapeptide from trypsinogen molecule as a result of hydrolysis of a lysine-isoleucine bond. It is an endopeptidase with optimal action at a neutral *p*H of 7. It cleaves peptide linkages whose carbonyl groups come from arginine or lysine. Aminopeptidase is an exopeptidase, which acts at the end of the polypeptide chain and removes terminal amino acid, possessing free amino groups.

Chymotrypsin: It is formed by the action of trypsin on chymotrypsinogen, and is an endopeptidase, which attacks peptide bonds with carbonyl from aromatic side chains (tyrosine, trptophan, and phenylalanine).

Elastase: It is formed when zymogen proelastase is activated by trypsin. This enzyme is especially active on the peptide bonds of the protein elastin.

Carboxypeptidase: They are exopeptidases, which hydrolyse terminal peptide bonds of their substrates. Carboxypeptidases A and B differing in their specificities are formed by activation of procarboxypeptidases by trypsin.

Amylase: Pancreatic and intestinal amylase probably is more important than gastric amylase in carbohydrate digestion.

Chitinase: It occurs in the digestive system of many fishes; notably in forms feeding on insects.

Lipases: These are esterases, which split ester bonds of fats. Triglycerides, fats, phospholipids and wax-esters are hydrolysed by lipases.

Other enzymes: Alkaline RNase and phosphodiesterase are found in the intestinal ceca of rainbow trout. In the gut of coral fishes, increased activity found of carbonic anhydrase is supposed to be an adaptation to ingest calcium carbonate.

Bile: It is produced by liver and stored in the gall bladder. Bile contains bile salts, cholesterol, phospholipids, bile pigments, organic ions, glycoprotein and inorganic ions. Fish bile is weakly alkaline and has high sodium and low chloride concentration. Bile emulsifies fat, maintains optimum internal *p*H for lipase activity, activates lipase and helps in excretion of toxins, heavy metal and different pesticides.

Intestinal enzymes: Digestive enzymes produced by the intestinal cells are located mainly in the brush border of epithelium. Enzymes produced by the intestinal mucosa include aminopeptidases, di and tripeptidases (formerly termed erepsin), alkaline and acid nucleosidase (which splits nucleosides), polynucleotidases (which splits nucleic acids), lecithinase (which splits phospholipids into glycerol, fatty acids, phosphoric acids and choline), lipase and other esterases and various carbohydrate-digesting enzymes: amylases, maltase, isomaltase, sucrase, lactase, trehalase and laminariase.

Digestion and absorption

Digestion is the process in which by the action of enzymes of digestive fluids and gut epithelial cells, proteins, polysaccharides, lipids and nucleic acids are degraded into smaller molecules that can be absorbed and assimilated.

Carbohydrates: Fishes ingest carbohydrates in the form of mono-, di- and poly saccharides. Monosaccharides do not need hydrolysis before absorption. Di- and polysaccharides are relatively large molecules and are to be hydrolyzed prior to absorption into monosaccharides. Only monosaccharides can be absorbed after digestion.

Mouth: Carbohydrates are digested to some extent in the mouth by amylase. Pancreatic amylase hydrolyzes α-1,4 linkages of carbohydrates, and produces monosaccharides, disaccharides and polysaccharides. It plays a major role in hydrolyzing starch and glycogen.

Digestion in the upper part of intestine: Most of the carbohydrate-digesting enzymes present in the brush border of the intestine are as given below.

$$\text{Disaccharides} \xrightarrow{\text{(Brush Border Enzymes)}} \text{Monosaccharides}$$

Exception in β-1, 4 bonds in cellulose

$$\text{Sucrose} \xrightarrow{\text{(sucrase)}} \text{glucose+fructose}$$

$$\text{Maltose} \xrightarrow{\text{(maltase)}} \text{glucose+glucose}$$

$$\text{Lactose} \xrightarrow{\text{(lactase)}} \text{glucose+galactose}$$

Information on glucose absorption in fishes is scanty. However, in goldfish, it has been shown that active transport of glucose is coupled with Na^+ transport as is the case with most of the mammals. It is generally believed that absorption takes place on the mucosal surface of the intestinal cells. It is an energy-requiring process which moves glucose across the membrane into the epithelial cells even if there is already a high concentration of glucose within that cell. Monosaccharides which result from carbohydrates digestion primarily consist of glucose, fructose, galactose, mannose, xylose and arabinose. Although rate of absorption of these sugars has been determined for many land mammals, similar information for fishes is not available. Diffusion may occur either as facilitated or as simple diffusion. Facilitated diffusion occurs where there is a career system that allows compound to move across an otherwise impermeable membrane. Fructose is an example of a compound absorbed into the intestinal epithelium in this manner. Facilitated diffusion does not require energy and will not move compound up a concentration gradient.

Proteins: Digestion of protein begins in stomach in gastric species. Endopeptidase activity of gastric juice renders proteins soluble and readily digestible by pancreatic and intestinal proteases. In the intestinal digestion of proteins, trypsin and chymotrypsin from the pancreas play a major role. Polypeptides formed by their interaction are further digested by pancreatic carboxypeptidases and intestinal peptidases. Protein degradation product is absorbed from the intestinal content as amino acids or peptides. Individual amino acids are readily absorbed against concentration gradient.

Lipids: Small intestine is the primary site for fat digestion. Fat is broken down to monoglycerides (MGs) and fatty acids (FAs) by lipase. Lipase can break only first and third ester bonds. Fatty acids, monoglycerides and glycerols are absorbed from intestine. Large fat droplets enter intestine after meal. Bile acids and lecithin emulsify fats into smaller particles. Lipase breaks down fat into fatty acids and monoglycerides. MGs and FAs are absorbed through villi *via* micelles and then transformed into triglycerides. Triglycerides aggregate and are combined with cholesterol, protein and phospholipids to form chylomicrons. Mixed micelles move to intestinal mucosal cells (enterocytes) and release contents near the cell. The bile salts are re-absorbed further down gastrointestinal tract (in the ileum), transported to liver, and finally recycled and secreted back into the digestive tract. Fatty acids, 2-monoglycerides, cholesterols and cholesterol-esters move down the concentration gradient (passive diffusion). And are repackaged in the intestinal cell for transport to liver. Some are reformed into triglycerides.

Chylomicrons: They are lipoproteins made by the intestine. Chylomicrons carry reformed triglycerides and cholesterol with a protein rich "shell" made of phospholipids. Once in enterocytes, glycerol and short-chain fatty acids directly enter mesenteric blood, whereas 2-monoglycerides and longer-chain free fatty acids are reformed into triglycerides, and then packaged with proteins to form chylomicrons. Phospholipids are hydrolyzed to form free fatty acids.

Gastric emptying time

Food eaten by the fish remains in the stomach for certain period that varies from

Table 29.2. Gastric emptying time of some fish species

Species	Temperature (°C)	Time to 100% evacuation (hr)
Sardinops caerulea	18	12
Salmo gairdneri	8	49-51
	11	46
	15	40
Ctenopharyngodon idella	9	7
Carassius auratus	12	36-48
	25	60
Cyprinus carpio	12	60
	23	48
Catla catla	28-30	18-54
Cirrhinus mrigala	28-30	18-60
Labeo rohita	28-30	24-54
Dicentrarchus labrax	16	36-74
Katsuwonus pelamis	23-36	14
Mugil cephalus	20-26	4-5
Tilapia nilotica	25	7-15
	27	15-27
Solea solea	10	72

Source: *Fish Physiology*, vol. VIII, Edited by Hoar, Randall and Brett, 1988.

species to species. And evacuation time also varies with species, depending on the size of the fish, type and amount of food as well as temperature. Environmental temperature significantly affects speed with which feed is processed. Evacuation rate of the stomach changes in proportion to $10^{0.035(t)}$, where t is the change in temperature in degree centigrade (Table 29.2).

Digestive physiology of shellfish

The unique characteristics of shellfishes in contrast to higher animals are emphasized to understand principal mechanism of their nutrition. Considering available information on the digestive physiology of giant freshwater prawn or cray fish, the following characteristics may be considered as unique features: Existence of moults; Reutilization of nutrients; Renewal of internal walls of digestive tract; Unique anatomy of mastication and absorptive organs; Existence of physiological fasting during moults; Specific mechanisms for digestion and absorption; and Involvement of digestive gland in various functions, in particular in the nutrient storage.

Digestive system: Digestive tract is classically divided into 5 parts – mouth, oesophagus, stomach, hepatopancreas, midgut and hindgut. Stomach in shellfishes resembles remotely to that of vertebrates; and digestive glands or midgut or hepatopancreas is neither a liver nor a pancreas. It is a diffused one where liver is penetrated by pancreatic acini.

Mouth: As in other arthropods, the mouth is surrounded by several pairs of appendages which are specialized for chemoreception, prey capture and mastication: maxilla, maxillulae, mandibules and maxillipedes. These appendages allow animal to bring food closer to mouth, especially in decapods, using maxillipede to sort particular

food size, which is right size for buccal cavity. In young larvae, antennae, antennules and mandibules are used primarily for swimming.

Esophagus: In crustaceans, walls of anterior as well as posterior parts of the digestive tract are covered by a thin layer of chitin, a major constituent of the exoskeleton. This cuticle is renewed during each moult. The esophagus thus appears to be a conduit with walls made-up of supple chitin-protein complexes. It is relatively short and straight in species important for aquaculture. Its cross-section is generally X-shaped.

Stomach: In crustaceans, stomach is like esophagus, forms part of the anterior gut in broad term. During larval development, hard structures (bristles, spines and brushes) are present on the internal walls of the stomach, which results in the 'Gastric mill' and masticate food in the same way as teeth do in vertebrates. The stomach is made up of two parts: cardiac chamber and pyloric chamber; that are separated by a marked constriction, a sort of valve. Like esophagus, the cross-section of the cardiac chamber is X-shaped as the result of folds in the form of grooves and thickening of walls. The antero-ventral part of this chamber contains a ridge with a row of hard, pointed projections called ossicules or teeth.

Digestive glands: The hepatopancreas is a massive organ made-up of two symmetrical lobes. It is situated in the dorsal part of the body, immediately below the heart, which opens into the pyloric chamber of the stomach. Within the tubules, as in the acini of secretory glands or in the intestinal villi of vertebrates, a distal zone can be distinguished in which there is cellular differentiation from embryonic cells. Four families of cells i.e. F, B, M and R, are present in proliferation zone. F cell secretes enzymes. At the subsequent stage B cells are the site of endocytosis. R cells contain subsequent amounts of lipids, glycogen, calcium, zinc and copper and play an important role in storage of nutrients originating either from food or from the destruction of animal's own tissue during biological cycle prior to moulting.

Midgut: The rectilinear part of the digestive tract extends from pylorus to rectum.

Hindgut: The distal part of the digestive tract is short and straight, and plays the role of a rectum. Its epithelial cells contain many mitochondria, as are found in the distal part of the fish intestine and helps in ionic regulation.

Digestive enzymes of shell fish

Pepsin is never present among proteases, while trypsin is synthesized in large quantities and represents about one-third of the soluble proteins in the digestive glands. Crustacean trypsin is more active on denatured proteins. Astacin, a metallo-protease is found in many crustaceans. Activity of these endoproteases is complemented by a group of exopeptidases, which are very similar to carboxypeptidases A and B and aminopdipeptidases. In lobsters, main proteolytic activity is due to cathepsins, lysosomal enzymes, which are released by lysis of digestive glands' cells. For carbohydrate digestion, there are four glucosidases: amylase, chitinase, laminarase and cellulase. Chitinase helps in partial digestion of chitin by shrimp that ingests moulted shells of individuals living in the same ecological niche, or on the integuments of other dead or living crustaceans. Cellulases are actively found in wood-boring crustaceans. Hydrolase activity is completed by enzymes that hydrolyse resultant dimmers: maltose is hydrolysed by maltase, chitobiose by a chitobiase and cellubiose by a cellubiase.

Lipase is the main digestive enzyme for lipid digestion. Lipase activity is similar to that of pancreatic lipase, but there are no bile salts in crustaceans; they do have compounds with comparable tensioactive properties. These are usually formed from a fatty acid with 22 carbon atoms and a dipeptide containing mainly taurine, as in the combined bile salts of vertebrates. Along with lipase, esterases and lecithinases have also been reported but their location, specificity and their precise role are poorly understood.

In shellfishes secretion of enzymes and absorption are carried out within the same organ, the digestive gland. Absorption is carried out by the epithelial cells of the tubule with the exclusion of embryonic cells, which have no microvilli. M cells as well as R cells contribute most to this function, as they have well-developed microvilli.

Regulation of digestion: The activities of the digestive system are regulated by hormones and neural reflexes. Four important hormones and their effects upon target cells are as follows.

Gastrin: It is produced by the enteroendocrine cells of the stomach mucosa. It stimulates gastric juice (especially HCl) secretion by gastric glands. Its function includes stimulation of smooth muscle contraction in stomach, small intestine, and large intestine, which increases gastric and intestinal motility and relaxation of pyloric sphincter, which promotes gastric emptying into the small intestine.

Secretin: It is produced by enteroendocrine cells of the duodenal mucosa. Its effects include stimulation of bicarbonate secretion by pancreas, which neutralizes acidity of chyme, stimulation of bile production by liver, inhibition of gastric juice secretions and gastric motility, which, in turn, slows digestion in the stomach and retards gastric emptying.

Cholecystokinin (CCK): It is produced by enteroendocrine cells of the mucosa. Its effects include stimulation of bile release by gall bladder, and stimulation of pancreatic juice secretion.

Gastric inhibitory peptide (GIP): It is produced by enteroendocrine cells of the mucosa and causes inhibition of gastric juice secretion and gastric motility, which, in turn, slows digestion in stomach and retards gastric emptying.

The second regulatory agent of the digestive system is nervous system. Stimuli that influence digestive activities may originate in head, stomach, or small intestine. Based on these sites, there are three phases of digestive regulation.

Cephalic phase comprises those stimuli that originate from head, sight, smell, taste, or thoughts of food, as well as from emotional state. In response, the following reflexes are initiated.

Neural responses: Stimuli that arouse digestion are relayed to hypothalamus, which, in turn, initiates nerve impulses in parasympathetic vagus nerve. These impulses innervate nerve networks of the GI tract (enteric nervous system), which promotes contraction of smooth muscle (which causes peristalsis) and secretion of gastric juice. Stimuli that repress digestion (emotions of fear or anxiety, for example), innervate sympathetic fibres that suppress muscle contraction and secretion.

General effects: The stomach prepares for digestion of proteins. The gastric phase describes these stimuli that originate from stomach. These stimuli include distention of stomach (which activates stretch receptors), low acidity (high *p*H), and presence of peptides. In response, the following reflexes are initiated.

- *Neural response.* Gastric juice secretion and smooth muscle contraction are promoted.
- *Hormonal response.* Gastrin production is promoted.
- *General effects.* The stomach and small intestine prepare for digestion of chyme, and gastric emptying is promoted.

Intestinal phase describes stimuli originating in small intestine. These include distention of duodenum, high acidity (low *p*H), and presence of chyme (especially fatty acids and carbohydrates). In response, the following reflexes are initiated.

- *Neural response.* Gastric secretion and gastric motility are inhibited (enterogastric reflex). Intestinal secretions, smooth muscle contraction, and bile and pancreatic juices production are promoted.
- *Hormonal response.* Production of secretin, CCK, and GIP is promoted.
- *General effects.* Stomach emptying is retarded to allow adequate time for digestion (especially fats) in the small intestine. Intestinal digestion and motility are promoted.

Excretory physiology

Excretion and osmo-regulation functions in fishes are closely related and performed by gills and kidneys. Although gills are chiefly respiratory organs, they play an important role in excretion of nitrogenous waste and osmo-regulation. Kidneys also play an important role in excretion and maintaining water-salt balance (homeostasis). Considering pattern of nitrogen excretion, synthesis and handling of mainly ammonia, urea and TMAO and participation of liver, gills, kidneys and certain other tissues to do so is important.

Metabolic breakdown of either lipids or carbohydrates yields mainly energy, water and CO_2 as end products. Water is either conserved, excreted or diffused away depending on the salinity of the environment. CO_2 enters into bicarbonate equilibrium system, and most of it is excreted through gills. Protein digestion yields nitrogenous compound in addition to CO_2 and water.

Teleost fishes are primarily ammonotelic, their nitrogenous waste excretion in the form of ammonia is a common feature. Despite its toxicity, ammonia has many advantages over urea and uric acid as the chief excretory product of nitrogen metabolism. Firstly, small molecular size and high lipid solubility permit non-ionized ammonia (NH_3) to diffuse across gills. Secondly, ionized ammonia (NH_4^+) is exchanged for Na^+ at gills for maintenance of relative alkalinity and internal ion balance. Thirdly, conversion of ammonia to urea or uric acid requires energy.

Only a small fraction of total nitrogen excreted by fishes appears in urine. In teleost fishes, the end products resulting from amino-acid catabolism are largely released at gills rather than kidney. For example, carp and gold fish (*Carassius auratus*) excrete 6-10 times as much nitrogen at gills as at kidney. Of the total nitrogen excretion, 90% is in the form of ammonia, and only 10% consists of urea. Branchial excretion consists of some other highly diffusible substances such as urea and amine or amine-oxide derivatives. Less diffusible nitrogenous end products like creatine and creatinine and uric acid are excreted by kidneys.

Elasmobranch fishes as well as coelacanth (*Latemaria*) excrete urea as the primary nitrogenous end product (i.e. are ureotelic).Much of the urea is retained in these marine fishes, giving their body fluids a near iso-osmotic relationship with the environment. The elasmobranch kidney filters urea from blood plasma at glomerulus. Much of the urea is subsequently recovered from filtrate by active tubular resorption, preventing major losses of urea in urine.

Lungfishes to varying degrees possess biochemical machinery to be either ammonotelic or ureotelic. The African lung fish (*Protopterus*) sometimes endures extensive droughts. When aquatic environment become dry, *Protopterus* constructs a cocoon of mucus in the bottom-mud and aestivates there until water returns. *Protopterus* is mostly ammonotelic while aquatic, but shifts to complete ureotelism while aestivating and survives by metabolizing proteins in its muscles. Urea may accumulate in the blood of aestivating *Protopterus* at concentrations of 500mmol/litre after three years of aestivation.

Kidney

The kidneys are paired elongated structures placed above alimentary canal and are close to vertebral column. Generally kidney of the teleost divides into two portions– the head kidney and the trunk kidney. Marine teleostean kidney can be divided into five following types.

- Two kidneys are fused, e.g Clupeidae.
- Middle and posterior portion of kidneys are fused, e.g. Plotosidae, Eels (Anguillidae)
- Only posterior portion of the kidneys are fused, e.g. Belonidae, Mugilidae, Carangidae, Scombridae.
- Only extreme posterior portion of the kidneys are fused, e.g. Sygnathidae (seahorse, pipefishes)
- Two kidneys are completely separate, e.g Lophiidae

Freshwater teleostean fishes possess kidneys of first three types. Generally, trunk kidney is made up of large number of nephrons, each consisting of a renal corpuscle or the malpigean body and the tubule. The intertubular space is full of lymphoid tissue, which is unevenly distributed. The head kidney is generally made up of lymphoid, haematopoetic, interrenal and chromaffin tissues and is devoid of renal corpuscles and tubules. Head kidney is therefore not excretory in function.

Significance of kidney: In freshwater fishes, kidney functions largely as water excretory device. This is accomplished by filtration at renal glomerulus and implies presence of suitable cellular components to ensure filtered ions and excrete dilute urine.

In marine teleost fishes, kidney functions chiefly as an excretory device for magnesium and sulphate ions. In glomerular marine forms associated machinery must be present to conserve water, monovalent ions and other filtered plasma constituents.

Cartilaginous sharks, skates and rays being hyper-osmotic in marine environment have combined principal functions of kidneys of freshwater and marine bony fishes.

Glomerulus and Bowman's capsule together act as ultra-filters wherein blood is filtered under high pressure. The excretory fluid flows through renal tubules and is driven by the net filtration pressure and movement of long cilia of neck segment and cilia of cells of other segments. Na^+ and Cl^- are almost reabsorbed from ultrafiltrate. Glucose is also removed largely from the filtrate. The ingestion rate of water by teleosts and the renal excretion roles are given in Tables 29.3 and 29.4.

Table 29.3. Ingestion rate of water by teleost

Species	Ingestion rate (ml/hr/kg)
Anguilla rostrata	2.77
Anguilla anguilla	3.25
Salmo gairdneri	5.37
Paralichthys flesus (flounder)	10.00
Serranus scriba	5
Fundulus heteroclitus (killi fish)	15.4-23
Gastrosteus aculeatus (stickle back)	40
Oreochromis mossambica	234

Table 29.4. Renal excretion

Species	Urine flow (ml/hr/kg)
Pacific hag fish (*Eptatretus stoutii*)	0.293
River lamprey (*Lamptera fluviatilis*)	6.5
Spiny dog fish (*Squalus acanthias*)	1.15
Rainbow trout- smolt (*Salmo gairdneri*)	3.8
Common carp (*Cyprinus carpio*)	10.8
Gold fish (*Carasius auratus*)	10.7
Anguilla anguilla	3.5

Ammonia production pathways and excretion routes

In fishes, when amino acids are broken down at the primary catabolite site, liver, majority of them pass their amino groups through cytoplasmic transaminases and then through mitochondrial glutamate dehydrogenase. Transaminase enzymes transfer an amino group from amino acid to α-ketoglutarate to create glutamate and a corresponding keto acid. Alanine would be converted to pyruvate by alanine amino transferase (ALAT), and pyruvate (as well as α-ketoglutarate produced by glutamate dehydrogenase, Gdh) could enter Kreb cycle, where CO_2 is produced. Transaminase and Gdh combined action is known as transdeamination (Fig. 29.3). An important consequence of transdeamination is that ammonia is released by Gdh intramitochondrially specifically as NH_4^+. Thus for a majority of amino acids, potential problems of *p*H disruption by NH_3 production are avoided. A second pathway is through purine nucleotide cycle present in liver (Fig 29.4). But its contribution to hepatic amino acid catabolism is believed to be minor in fishes.

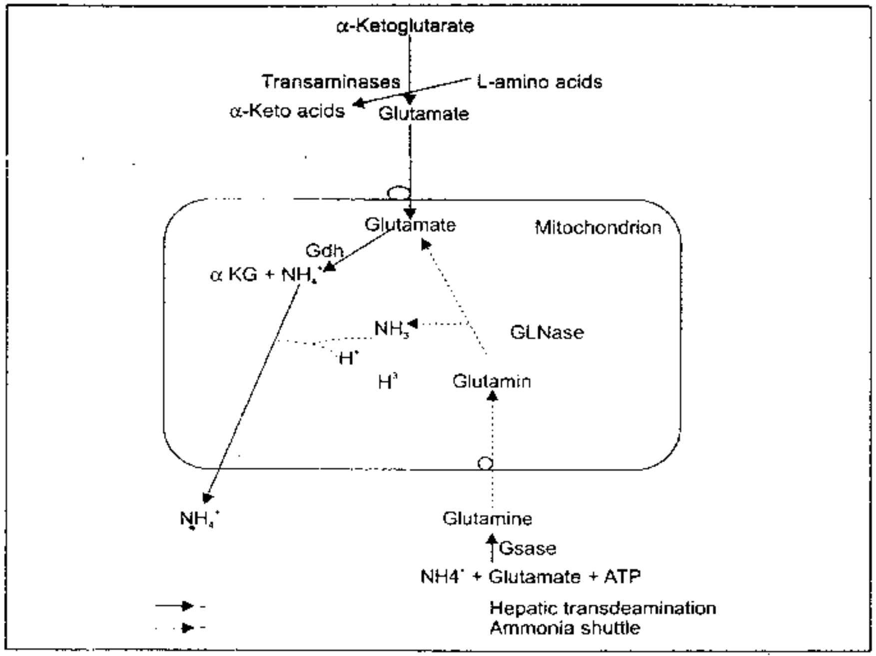


Fig. 29.3. Pathway for ammonia production.

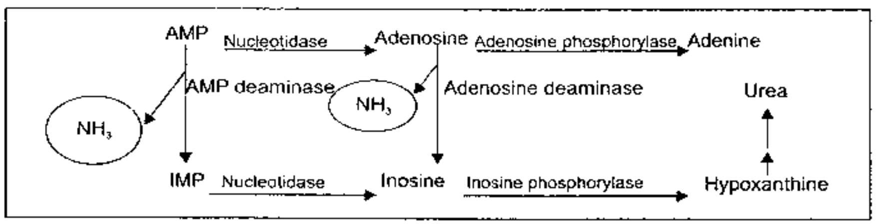


Fig.29.4. Purine nucleotide breakdown.

This pathway directly liberates ammonia as NH_3. This pathway appears to be active in fish- muscle especially post exercise, to scavenge AMP produced by hydrolysis of ATP during muscle contraction. A third important class of ammonia-producing reactions is deamination of glutamine and asparagine by glutaminase and asparaginase, respectively (Fig. 29.5). These reactions directly liberate NH_3 and may be especially important in promoting acid-base balance.

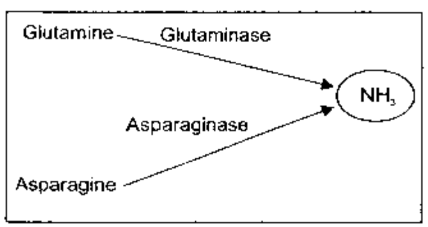


Fig. 29.5. Direct deamination of glutamine and asparagine.

Following are three routes of excretion: Direct diffusion of NH_3 from blood to water; Direct diffusion of NH_4^+; Functional Na^+/NH_4^+ exchange located at the apical membrane of gill cells.

Direct diffusion of NH_3 could occur *via* transcellular or paracellular pathways. It is believed that NH_4^+ diffusion is limited to paracellular pathways. Na^+/NH_4^+ exchange is accomplished by linking NH_3 diffusion with specific Na^+/H^+ exchange protein or a H^+-ATPase/Na^+ channel combination. In one marine fish, gulf-toad, relative contributions of three main pathways were 57% *via* ammonia diffusion, 21% *via* NH_4+ diffusion and 22% *via* basolateral NH_4^+/Na^+ exchange. Ammonia excretion mechanism is somewhat clearer in freshwater fishes and there are evidences that NH_3 diffusion predominates, and that gill boundary layer water chemistry is rather important.

Pathways of urea production and excretion

In fishes, there are several pathways for production of urea. They are Arginine breakdown; Purine breakdown; Denovo synthesis by ornithine–urea cycle (O-UC) (Fig. 29.6).

First two pathways appear to be common in most fishes, a complete O-UC appears to be lacking in most adult fishes. Exceptions are elasmobranches, coelacanth and less than a dozen of teleost fishes. For teleost fishes, which make urea, an adaptive significance of urea synthesis appears to be ammonia detoxification at times when ammonia cannot be freely excreted to environment, e.g. at air exposure, amphibious breathing at high environmental ammonia concentration, etc. The most dramatic example of ammonia detoxification strategy occurs in Lake Magadi tilapia. Water of lake Magadi, Kenya, is of *p*H 10 and is highly buffered. Therefore acidification of gill boundary layer, which is supposed to enable efficient ammonia trapping and excretion, does not occur in this species. To overcome this problem, fish excretes no ammonia but all waste as urea. *De novo* synthesis of urea by O-UC is important for osmoregulation in ureosmotic fishes and for ureotelic fishes, which inhabit environment, where ammonia excretion is precluded. In these species, gills are also the prime excretion site. However rather than being highly and continuously permeable to urea, as it is to ammonia, the fish gill exhibits selective permeability to urea, possibly through action of specific transport proteins. Evidence from the early life history stages of fishes suggest that O-UC may be important in ammonia detoxification during development of all fishes, and that O-UC genes are retained by fishes, which are ammonotelic, as adults for these reasons.

Reduction in branchial ammonia permeability in ureotelic fishes

Dog-fish has very low gill ammonia permeability. When toad-fishes switch from ammonotely to ureotely, their ability to shut off ammonia excretion is nearly absolute. Dog-fish ammonia retention is by gill enzyme scavenging (GSase and Gdh). Indeed, both toad-fish and dog-fish have measurable activities of these enzymes in gills, potentially high enough quantities to trap ammonia. The mechanism of reduction in gill ammonia permeabilities in ureotelic fishes is an important direction of research.

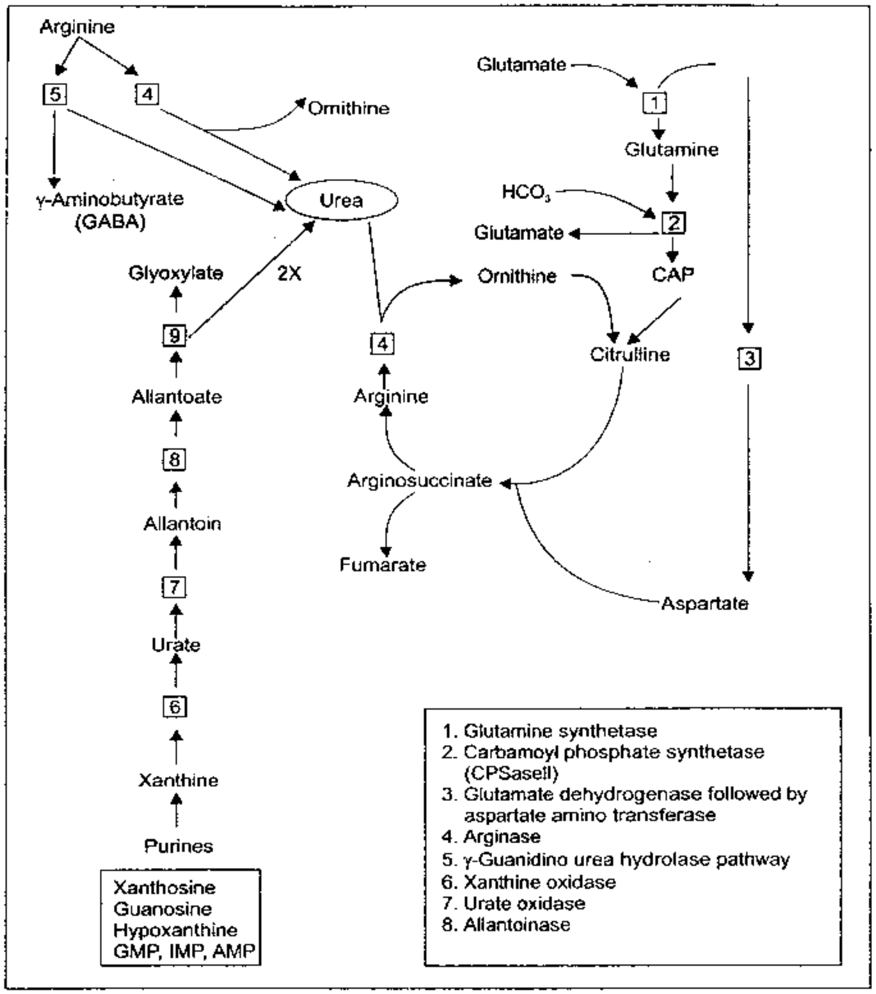


Fig. 29.6. Pathway for urea production (Adapted from *The Physiology of Fishes, Eds. Evans and Claiborne, 1997*).

Excretion in shellfishes

Excretory system of crustaceans: Crustaceans are insects of the sea comprising around 67,000 species including lobsters, cray-fish, shrimp, crabs, water-fleas, copepods, barnacles, pill bugs etc. Crustaceans' excretory system imparts function of expulsion of wastes from animal body. As the energy pathway of cellular respiration proceeds, metabolic waste products of excretion are also released in the animal body; mainly in the form of ammonia. In some of the lower crustaceans excretion is through moulting as storage of waste materials is under exoskeleton. The organ for excretion

is antennary or maxillary gland. Antennary gland is located in the coxa of antenna and maxillary gland is located in the coxa of maxilla.

In marine decapods, antennal glands are not particularly for nitrogen excretion or osmotic regulation but are instrumental in maintaining ionic balance of body fluids. In a number of decapods species, there is evidence of conservation of Ca^{2+}, K^{+} and glucose and elimination of Mg^{2+} and SO_4^-, by excretory glands. These glands also concentrate foreign substances such as dyes.

Non malacostracans → Adult-maxillary gland; → Juvenile-antennary gland

Malacostracans → Adult-antennary gland; → Juvenile-maxillary gland

Ammonia and urea are eliminated through permeable gill epithelium, blocking output of these substances from maxillary and antennal organs. Amino-nitrogen is probably excreted through urine. Other nitrogenous end products such as uric acid are often recorded as being deposited in kidney. Maxillary and antennal glands remove dyes from blood after injection; different parts of the glands sometimes react specifically to particular dyes, and injected dyes may also be removed from circulation by storage in digestive gland or in phagocytic group of cells.

Excretory system of molluscs: Molluscs are shelled organisms with external or internal shell with main classes like Gastropoda, Bivalvia and Cephalopoda. Most of molluscs' excretory organs are nephridia. In gastropods, primary organs of excretion are nephridia, which produce ammonia or uric acid as a waste product. Nephridium also plays an important role in maintaining water balance in freshwater and terrestrial species. Additional organs of excretion, at least in some species, include pericardial glands (Keber's organ) in the body cavity, and digestive glands opening into stomach. There were two kidneys, or nephridia in primitive gastropods, while in advanced forms, one kidney is either small or lost. Most marine gastropods have the same total concentration of solutes as in the surrounding sea-water, and thus a small osmotic differential (i.e. equilibrium) exists between water leaving and entering cell. Little energy is needed, therefore, to prevent cells from losing or gaining too much water.

Like most other molluscs, excretory organs of bivalves are nephridia (also called organ of bojanus). There are two nephridia, each consisting of a long, glandular tube that opens into body cavity just beneath the heart and the bladder. Waste is voided from bladder through a pair of openings near the front of the upper part of the mantle cavity, where it can be easily washed away in the stream of exhalant water. Most cephalopods possess a single pair of large nephridia. Filtered nitrogenous waste is produced in the pericardial cavity of the branchial hearts, each of which is connected to a nephridium by a narrow canal. The canal delivers excreta to a bladder-like renal-sac, and also resorbs excess water from filtrate. Several outgrowths of the lateral vena cava project into the renal-sac, continuously inflating and deflating as branchial hearts beat. This action helps to pump secreted waste into sacs;to be released into the mantle cavity through a pore.

Osmoregulatory physiology

All living organisms including fishes need to maintain critical levels of salts, alkalinity (buffering capacity), and dissolved organic compounds in their internal cell environment. Since fishes live in water, we may conclude that fluid exchange between their bodies and environment is a bit different from what we observe in land-living creatures such as humans. The principle of osmoregulation, however, is same – there is movement from an area with high concentration to an area with low concentration. Besides, balance is to be maintained between internal and external environments. Fishes, which migrate from freshwater to marine water environment, need complex mechanism for maintaining internal environment. Ionic and osmotic challenges of fishes vary with salinity.

Water and small electrolytes like urea and ammonia can move through pores of hydrocarbon chain of lipid bilayer in the plasma membrane. Na^+ K^+ and Cl^- will pass with the help of transporter proteins. These ions move passively or actively. Although kidney is the most important organ for excretion of monovalent cations in terrestrial animals, in fishes extra renal epithelial tissues such as gill-filament, gut, urinary bladder etc are involved for the same. In elasmobranches salt gland and rectal glands help excretion of ions.

Osmoregulation: Osmoregulation refers to regulation of total ion concentration, whereas ion regulation is the regulation of individual ions in blood and tissues. Regardless of the method a fish uses to maintain its osmotic and ionic balance, osomoregulation is usually energy-intensive, affecting growth and swimming performance. According to the strategy used for osmoregulation, fishes can be divided into 5 groups.

Hagfishes (*Myxiniformes*): These are eel-like primitive jawless fishes inhabiting in deep-water marine habitats. They are strictly marine and stenohaline. They are able to tolerate only narrow ranges of salinities. Thus, they deal with the problem of osmoregulation by not dealing with it (osmoconforming), i.e. they maintain an internal salinity identical to water in which they live. They are called osmoconformers.

However, individual ionic concentration may be different which needs an ionic regulation mechanism to maintain balance. Hagfishes maintain higher sodium concentration and lower concentrations of divalent ions like magnesium, calcium, and sulphate. Hagfish kidneys actively secrete divalent ions through urine and slime; where slime seems to have a role in retarding sodium loss.

Marine elasmobranches: Like most vertebrates, elasmobranches maintain a salt content approximately one-third as saline as sea-water. However, large amounts of organic salts such as urea and trimethyl amine oxide (TMAO) in the ratio 2:1 bring total osmotic concentration equal to sea-water. They operate *isosmotically*. The coelacanth, a primitive bony fish, uses this same strategy along with the common strategy of bony fishes. Although salinity of elasomobranch tissues is less than sea-water, but total salt concentration is equivalent to sea-water. Elasmobranches gills are quite water permeable. This passive water influx and efflux, however, is minimized because total concentration of salts inside and outside these fishes is equal. Thus,

there is no problem with water gain or loss to fish. Outflow of Na^+ and Cl^- is minimized as elasmobranchs have low permeability to these ions. These fishes still have to manage concentrations of sodium and chloride ions. They accomplish this by excreting sodium and chloride via a *rectal gland*, found only in elasmobranchs. When rectal gland fluid contains more ions, they secrete it outside. Its membrane and glandular wall contain cells with special Na^+-K^+-ATPase activity, which is involved in actively transporting across the glandular wall into the rectal gland lumen. From lumen, it is excreted outside.

Marine teleosts: They maintain a salt content approximately one-third as saline as the sea-water, and operate hyposmotically, i.e. continually losing water and gaining monovalent ions (chloride) across gill membranes (Fig. 29.7). To minimize this loss, these fishes continually take in sea-water to regain water. However, this results in higher intake of salts, which are to be excreted. These salts are excreted, especially chloride, *via* special cells in the gill filaments and opercular skin called chloride cells through active transport mechanism. They also excrete salts through intercellular junctions. Teleostean kidneys excrete divalent cations, Mg^{2+} and SO_4^{2-}. However, their kidneys cannot produce urine that is more salty than blood as do terrestrial vertebrates. Their kidneys may sometimes be aglomerular or parciglomerular with low filtration capacity.

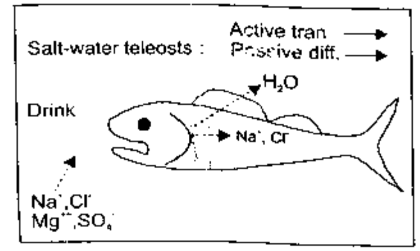


Fig.29.7. Hypo-osmoregulation.

Chloride cells: In marine teleosts, α type of chloride cells are present. The cells contain higher number of mitochondria. They contain Na^+ K^+ ATPase system which actively transports Na^+ out of the cell in exchange of K^+. Thus this enzyme system functions to maintain Na^+ gradient – a high Na^+ in tubules and low Na^+ in cytoplasm. Low Na^+ in the cytoplasm drives Na^+ Cl^- linked carrier system which builds up Cl^- inside the cell. This excess Cl^- is carried out of the cell following an electrochemical gradient through apical pit of chloride cell. Na^+ goes out of the cell, diffuses in the water through shallow intercellular junctions (Fig. 29.8). There are several other ion transport systems in marine teleosts.

Anion channel: NKCC (Na^+:K^+:2Cl^-) co-transporter accumulates Cl^- intracellularly above electrochemical equilibrium so that Cl^- exits passively *via* anion channels in apical surface.

Passive Na^+ secretion: Sea-water fishes have large number of chloride cells. It means Na^+ secretes passively between chloride cells and accessory cells.

Freshwater teleosts and freshwater elasmobranchs. These fishes maintain an internal salinity equal to 1/4-1/3rd of the concentration of sea-water. However, it is higher than that of their environment. Therefore, they tend to gain water and lose chloride and other monovalent ions. They operate *hyperosmotically*. So they gain water by diffusion to the body. This excess water has to be excreted by kidneys (Fig. 29.9). Thus, large, well developed kidneys of these fishes continually excrete excess water

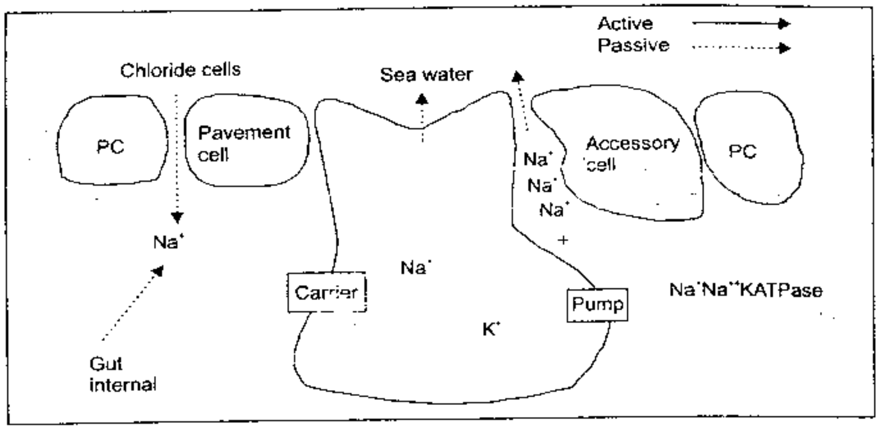


Fig. 29.8. Schematic diagram of major ion movement during osmoregulation in marine teleost gills.

as dilute urine. Hormones secreted by rennin angiotensin aldosterone system control urine secretion. Up to one-third of the body weight of water is excreted per day. Along with urine and gill excretion, some salts are also lost from the body. This diffusion loss can be minimized by increased calcium concentration and with the help of hormone prolactin. These fishes also have α type of chloride cells, however, chloride cells of freshwater fish rather pump chloride out of the body through gills by active transfer mechanism using salt-pump. H^+ ATPase system and Na^+ K^+ ATPase system assist movement of ions into the body. Na^+ exchanges for NH_4^+ conveniently eliminate produced ammonia. Na^+ exchanges for H^+ and Cl^- exchanges for HCO_3^-.Thus active intake of Na^+ and Cl^- through ion exchange pumps is necessary for adequate excretion of NH_4^+, H^+ and HCO_3^-.

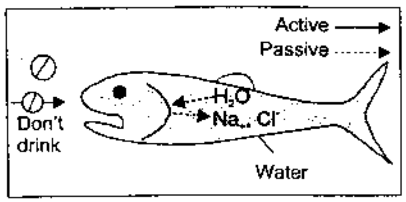


Fig.29.9. Hyper-osmoregulation.

Role of different exchanger systems in osmoregulation: Absorption of Na^+ and Cl^- in freshwater fishes is influenced by several ion-exchange systems. There are two co-transporter systems targeting absorption of Na^+ and K^+ such as Na^+Cl^- cotransporter (NC) and $Na^+ : K^+ : 2\ Cl^-$ cotransporter (NKCC).

HCO_3^- secretion and Cl^- exchange: Apical $Cl^-/\ HCO_3^-$ exchange (AE) has been demonstrated to play a major role in Cl^- absorption. AE secretes huge amount of HCO_3^- and thus is associated with highly alkaline intestine fluid of *p*H 9 or more.

Vacuolar type ATPase and Na^+ transport: V type H^+ATPase is present in the apical membrane of gills, and indirectly drives Na^+ uptake. No direct transmembrane voltage measurement exists for this exchange. V type H^+ATPase serves as the core driving force for Na^+ and Cl^- uptake.

Na^+ channel and uptake: Evidence of Na^+ uptake pathway points to a epithelial Na channel (ENaC) in the apical portion. However there may be alternative cation channels or relatively nonselective channels (such as ECaC), that can take Na^+ inside.

NKCC ($Na^+ : K^+ : 2\ Cl^-$) exchanger and Na uptake: NKCC may perhaps contribute to Na uptake which requires a force of K^+ and sufficient NaCl in the boundary layer to allow Na^+ uptake down its concentration gradient. It is unlikely to operate for NaCl uptake in extremely dilute solution.

Cl^- uptake through exchanger or co-transporter: Na $^+$ channel can't be used for Cl^- due to 60 mV potential operating against anion uptake. Thus, some animal use neutral anion exchanger such as band III proteins. Physiologically anion exchange exists in rainbow trout and tilapia. Extrusion of H^+ across AP membrane *via* H^+ ATPase appears to fuel Cl^- uptake by allowing accumulation of cytosolic HCO_3^- from CO_2 hydration. Killifish lacks high affinity Cl^- uptake mechanism.

PNA^- (peanut lectin agglutinin negative) cells: These are mitochondria-rich cells which secret acid and uptake Na^+ along with V-type ATPase in the apical membrane and an epithellial type Na^+ channel. Electric gradient established by H^+ ATP ase drives Na^+ into the cell and exits *via* Na^+-K^+-ATPase pump. HCO_3^- exits through baso-lateral membrane in exchange for Cl^-.

Euryhaline and diadromous fishes: Euryhaline fishes, sheep head minnow (*Cyprinodon variegatus*), mossambique tilapia, striped bass (*Morone saxatilis*), tolerate wide range of salinity. Diadromous fishes such as Pacific lamprey (*Lampetra tridon*), Pacific salmon, American eel (*Anguilla rostrata*) are euryhaline fishes that move between salt and freshwater at a particular phase of their life-cycle. These fishes operate hyposmotically in sea-water and hyperosmotically in freshwater. When *Anguilla* moves from freshwater to sea-water, it experiences a loss of 4% body weight. Within two days, they will be adapted to sea-water by drinking sea-water. These all processes are carried out with the help of increased gill Na^+ K^+ ATPase activity, which requires energy. Although they are able to osmoregulate even with change in salinity, their growth rate and metabolic efficiency is maximum at certain optimum temperature, e.g. euryhaline sciaenid.

Osmotic and ionic regulation in shellfishes

Osmoregulaton in crustaceans

Osmoconformers: Marine crustaceans usually live in relatively constant salinity of offshore waters. These animals rarely encounter low-salinity waters and most of them cannot control salt concentration and osmotic pressure of their body fluids; they are called osmoconformers because osmotic pressure of their body fluids is very close to that of external medium. However, some live in estuarine waters in which salinity changes continuously as tides ebb and flow and as rainy seasons alternate with dry ones. These animals can control salt concentration of their body fluids to varying degrees, and are called osmoregulators.

Hyper-osmoregulators: Crabs, which can actively transport salts into their body fluids, are able to keep ion concentration and osmotic pressure of their blood higher than that of more dilute external medium, and are called hyperosmoregulators. Thus, they do not suffer from lowered haemolymph salt concentration when they are in estuarine waters. Because osmotic pressure of their blood is higher than that of the medium; blood water concentration is lower and water moves into crabs by osmosis. Crab regulates this osmotic water load by increasing its urinary rate. However, urine it makes is iso-osmotic with the blood because, unlike freshwater crustaceans and vertebrates, it cannot reabsorb salts from its urine. This, in turn, means that crab loses a lot of salt in its urine when it is in dilute waters at the head of an estuary. If the crab needs to keep its blood from becoming diluted, this lost salts are to be replaced by increased inward salt pumping through gills.

When a crab is in a medium that is of the same osmotic pressure as its blood, it is said to be isosmotic with the medium, and it neither gains nor loses water by osmosis. Drinking and urination are minimal in such a medium. Hyperosmoregulating crabs use their gills to actively pump salts into blood as is necessary to osmoregulate. Their gills have patches of special epithelial cells known as ionocytes, which have many mitochondria to make ATP which powers sodium-pump and tight junctions between cells at the apical surface.

Hypo-osmoregulators: Crabs which actively transport ions out of their body fluids are called hypoosmoregulators and their body fluids have a lower ion concentration and osmotic pressure than the medium. This, in turn, means that they lose water to the medium by osmosis and that they must take in water to replace water loss. Such taking in increases salt concentration of the blood and the extra salt must be pumped out of the crab. A few crabs are able to pump salts out of their body fluids with their gills having Na^+ K^+ ATPase activity.

Osmoregulation in molluscs

Molluscan species such as snails, clams and many other sea-shell creatures are isoosmotic. This means that the molluscan species have the same level of osmotic pressure as of the environment. When some groups of molluscans migrate, there is no problem of osmoregulation and they can inhabit, adjust and sustain stability in their new environment. All molluscan species are not able to do this. Mangrove molluscs cannot easily adjust to their new environment .They have a special adaptation technique that lets them survive in the new condition. Once they become adjusted to the new environment, there will be a balance of water when they excrete and throw their wastes out of their body, are called osmoregulators (e.g. freshwater molluscs). In marine molluscs, free metal ions or cations cross cell membrane without energy cost. They maintain ionic balance by storage of ammonia in their body. They provide this ammonia as a nitrogen source to symbiotic algae that lives in their body. Kidney, respiratory system and the mantle play the most important role in molluscan osmoregulation as these tissues contain Na^+ K^+ ATPase system. However in terms of other animals, it varies and they have different bodily components that balance their water concentration. Sometimes to maintain osmotic balance, nutrients and salts are reabsorbed. To regulate

body volume they store more organic compounds such as amino acids and quaternary amine compounds rather than inorganic ions. Freshwater molluscs, however, possess very active Ca^{2+} pumps since they must build calcified shells in a hypotonic environment with associated osmotic and ionic balance problems. Freshwater bivalves have higher urine production than gastropods; as gastropods have more concentrated haemolymph than bivalves.

Reproductive physiology

Reproductive physiology of finfish (RPF) is a vast scientific field, which is directly concerned with a set of physiological processes essential for reproduction – gonad differentiation, puberty, male and female gametogenesis and reproduction seasonality. Environmental cues provide suitable signals for the integration by neuro-endocrine cascade along with the brain-pituitary- gonadal (BPG) axis, which ultimately initiates and then modulates reproductive development. These processes also interact with other important physiological functions – growth, nutrition, osmoregulation and response to stress factor. Several extrinsic and intrinsic factors regulate temperature, photoperiod, water salinity, barometric pressure, habitat, nutritional status and genetic background. Physiology of breeding is also influenced by some social factors like breeding aggregation, territory and simulative process of individuals. In fact, fishes exhibit a huge variety of specific reproductive strategies and tactics with just as many specific adaptations in terms of physiological regulation.

The knowledge of reproductive physiology of fishes is an essential prerequisite for development of aquaculture industry for meeting ever-increasing demand for quality fish- seed by improving protocols for higher efficiency of egg production and enhanced viability of progeny. Moreover with the increasing demand of diversification of species in aquaculture practices and dwindling natural resources owing to over-fishing and anthropogenic activities, there is a pressing need for development of breeding technologies for new species.

Reproductive strategies

Fishes exhibit a great variety in their mode of reproduction. Most of the fishes are iteroparous (reproducing more than once in a life-time), excepting a few, which reproduce only once and die soon after spawning, they are semelparous. Majority of the fishes are oviparous, producing yolk-containing eggs, although viviparity with embryos developing within female reproductive system is also known. Many fishes are known to be gonochoristic–in this, male and female gonads are in separate individuals and genders are distinct throughout the life. Besides, a few fishes show various forms of hermaphroditism such as: protogynous fish (develop first as female and after one or more spawning seasons, may change to male) and protoandrous fish that develop first as males and change later to female. Simultaneous hermaphroditism is also displayed in some species with gonads showing simultaneously testicular and ovarian components.

Ovarian development in fish has been categorized into three types: (*a*) synchronous:

where all oocytes develop and ovulate at the same time; (*b*) group-synchronous: where at least two populations of oocytes can be recognized in the ovary throughout the reproductive season; and (*c*) asynchronous: where oocytes of all stages of development are present without a dominant population.

Spawning pattern generally synchronizes with rhythm of oocyte ovulation. Synchronous ovulators shed full population of eggs in a single lot or over a short period of time. And asynchronous ovulators release eggs in batches, as the process of eggs recruitment through maturation and ovulation occurs in batches during spawning season. Most culture species exhibit external fertilization without parental care and release a large number of benthic (benthophil species) or pelagic (pelagophil species) eggs.

Reproductive behaviour: Various aggressive behaviours such as mouthing, nipping, butting, chasing and fighting have usually been observed in male-fishes during spawning. Courtship activity involves sex recognition, mutual orientation to spawning ground and synchronization of spawning activities in both sexes. Generally, 3 types of chasing movements–hypogyne, subgyne, laterogyne–have been observed in brood fishes. In fishes, courtship may be a temporary association of both ripe sexes or it may be a long-term association between pairs of monogamy. Teleosts exhibit certain mating behaviours such as promiscuity, monogamy and polygamy. The later may be further demarcated into polygyny and polyandry.

Puberty in fish: Puberty designates transition period and underlying physiological process corresponding to acquisition of reproducing capacity. In fish, puberty is generally considered as started with first appearance of spermatocytes in male, and initiation of vitellogenesis in female. Fish species exhibit different ages of puberty, such as late puberty in sturgeons and early puberty in tilapias. BPG axis is supposed to be activated at the onset of puberty and is believed to acquire full physiological capacity at the time. However, details of underlying mechanisms in fishes are still not clearly understood. Recently, it has been demonstrated that *estrogen receptor 1*, *androgen receptor*, *Kisspeptin* gene and *cytochrome*P_{450}*19a2* (the enzyme responsible for estrogen biosynthesis from testosterone) are involved in the onset of puberty in the fish.

Oogenesis in fish: In spite of having different reproductive strategies among fish species, steps leading to formation of eggs share several common features. Main stages during egg development include formation of primordial germ-cells (PGCs), transformation of PGCs into oogonia, and subsequently their transformation into primary oocytes with the onset of meiosis. This is followed by massive growth phase of oocyte during vitellogenesis, whereby oocyte incorporates nutritional reserves required for embryo development. At this phase, oocyte also accumulates maternal RNA and completes differentiation of its cellular and non-cellular envelopes. During this time, oocyte remains in meiotic arrest; at diplotene stage of late prophase. Maturation processes are initiated by decreased or termination of endocytosis, resumption of meiosis, germinal vesicle breakdown (GVBD), formation of a monolayer of cortical alveoli beneath oolemma, and yolk platelet dissolution, followed by hydration particularly, in pelagophil oocytes.

First meiotic division gives rise to two daughter cells; smaller one with the first

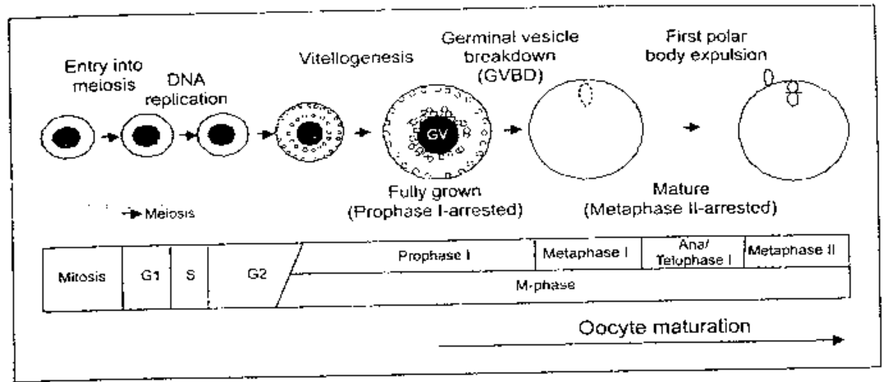


Fig. 29.10. A schematic description of oocyte development in teleost fish during meiosis.

polar body degenerates and the larger one remains as the secondary oocyte, and finally ovulates at the end of maturation process. At this stage, female gamete is known as an ovum. It is haploid as a result of the first meiotic division. The occurrence of the second meiotic division and the formation of the second polar body happens immediately after the entry of the sperm into the ovum through a cavity – micropyle on the outer acellular envelope (chorion or zona radiata or zona pellucida); the second polar body also degenerates soon. During fertilization, the haploid ovum nucleus fuses with the haploid nucleus of the spermatozoon and forms diploid egg or zygote (Fig. 29.10).

Primordial germ cells and formation of oogonia: Germ-cells are unique as they produce haploid reproductive cells or gametes. Shortly after fertilization of egg and during the early stage of embryogenesis, a small number of non-dividing primordial germ cells (PGCs) are produced. PGCs generally contain components known as germplasm that is characterized by the presence of the polar granules or electron dense structural organelles associated with mitochondria, RNA and proteins also identified as *nuage* or *ciments*. PGCs can be easily distinguished from somatic cells by relatively larger size and larger nuclei with a distinct nuclear membrane and one or two prominent nucleoli. Identification of zebrafish ortholog of the *vasa* gene helped in detecting site of germplasm in the mature oocyte and its incorporation into PGCs during embryogenesis. Several other genes were found to be associated with germplasm in zebrafish such as *nanos-1, dazl, dead end, cxcr4b* and *sdf-1a* receptor. The germ- line plays a critical role in female sex determination as loss of the germ line results in masculinization in both medeka and zebra fish. Formation of gametes from primordial germ cells (PGCs) has gained specific attention with the availability of specific molecular markers and their striking potential as a valuable resource for genetic preservation and production of individuals from gametes of germ-line chimeras. Totipotency of PGCs to proliferate into spermatozoa or eggs was applied for developing a surrogate broodstock technology for genetic resource preservation of fish. Recently, complete gonad replacement of the host fish by one xenogeneic PGC from distantly related species was also demonstrated.

Formation of primary oocytes: Transformation process of the PGCs into oogonia involves structural changes within them. Each oogonium multiplies by mitotic divisions forming oogonial nests, where each oogonium is surrounded by a monolayer of somatic granulosa cells that secrete a basement lamina, separating it from ovarian stroma cells. Somatic cells forming a monolayer outside the basement lamina constitute theca that becomes associated with blood vessels. The oocyte with its surrounding granulosa cells, basement lamina and theca somatic layer constitutes ovarian follicle and forms primary oocyte. The transition from the oogonium to a primary oocyte is also characterized by the initiation of the first meiotic division, before leaving oogonial nest.

Primary growth and folliculogenesis: Primary growth encompasses period of oocyte development from meiotic chromatin-nucleolus stage to early cortical alveoli stage, and is intimately linked with the development of the follicle layers surrounding oocyte. Cortical alveoli are synthesized prior to or concurrent with the commencement of lipid and vitellogenin endocytosis.

Transition into secondary growth: Oocyte enlargement takes place due to filling of periphery of oocyte by cortical alveoli, and the stage is known as primary vitellogenesis. As oocyte grows, cortical alveoli increase in number and size, filling oocyte cytoplasm. Cortical alveoli content is released to the egg surface as a part of the cortical reaction at fertilization. This release leads to restructuring of egg-envelop proteins forming chorion. Transcripts associated with cortical alveoli components include serum lectin isoform 2 (*lcal*), rhamnose binding lectin STL3 (*lrham*) and alveolin (*alv*).

Vitellogenesis: The term vitellogenesis generally describes incorporation of vitellogenin proteins by the oocyte and their processing into yolk proteins. However process needs to be extended to include also incorporation of other molecules such as lipids and vitamins. At the end of this process, the oocyte becomes competent to undergo fertilization, and it contains maternal mRNAs, proteins, lipids, carbohydrates, vitamins and hormones that are important for the proper development of the embryo. The vitellogenins (Vtgs) are phospholipoglycoproteins that are found in the blood of females of all oviparous vertebrate females during vitellogenesis and are synthesized mainly in liver, under the regulation of 17-β estradiol (E2), but several other hormones may have role in this process. Vtgs belong to Large Lipid Transfer Protein (LLTP) super family. At least three different types have been reported in teleosts– VtgA, VtgB and VtgC– and all of them are incorporated in the oocyte. The Vtgs reach oocyte by passing from theca capillaries to granulosa layer, arriving at the oocyte surface through the pore canals of the zona radiata. Then Vtgs are sequestered by receptor-mediated endocytosis, involving specific receptors in the endocytotic clathrin-coated pits of vesicles. The coated vesicles move into peripheral ooplasm and fuse with lysosomes forming multivesicular bodies (MVBs). Within MVBs, Vtgs are probably cleaved by lysosomal enzymes such as cathepsin D into smaller yolk proteins.

Egg envelope proteins: In all vertebrate species, egg is surrounded by a vitelline envelope, commonly designated by several names– egg envelope, vitelline membrane, egg capsule or radiate membrane. Egg envelope is formed by following main layers consisting of a cellular plasma membrane (oolemma), acellular zona radiata (zona pellucida or egg shell), and cellular layers consisting of granulosa cells, basement lamina and outermost theca cells. At the onset of the oocyte growth, the oocyte extends microvilli and the synthesis of the zona radiata in the oocyte starts from the base of these microvilli. During ovulation, granulosa, basement lamina and thecal layers are shed and ripe ovum has tough zona radiata as the outermost covering just above the oolemma. In most vertebrates, eggshell is involved in fertilization through sperm binding and sperm guidance. In contrast to mammals, fertilization in fish takes place only through a funnel-like micropyle that is located at the animal pole. When egg is activated by the sperm, micropyle closes and prevents polyspermy. The vitelline envelope also shows antimicrobial and bactericidal functions, protecting egg from bacterial pathogens. After fertilization, the egg envelope, also named as chorion at this stage, protects embryo in the aquatic environment.

Oocyte hydration: This process of oocyte hydration is unique among fish and is thought to provide a water cushion for embryos to survive in the hyperosmotic sea-water. Besides, it helps maintain buoyancy of eggs, thereby increasing their survival and dispersal in the ocean. Thus, pelagophil species produce highly hydrated, floating eggs in sea-water, can account for up to 90-95% of egg weight; and the benthophil species produce minimally hydrated, demersal eggs, showing no buoyancy in sea-water;water content can reach up to 85% of weight.

Osmotic effectors: It was suggested that hydrolysis of yolk proteins could be source of amino acids that increased oocyte osmotic pressure, thereby allowing water influx. Free amino acids (FAAs) also play a crucial role as osmotic effectors during oocyte hydration. In pelagophil species, K^+ ions have also been related to increased oocyte osmolality during maturation, besides increase of Mg^{2+}, Ca^{2+}, Cl^-, total ammonium (NH_4^+) and/or inorganic phosphorus (P_i) in the oocyte.

Role of aquaporins during oocyte hydration: For a long time, it was assumed that water flux into the fish oocyte occurred by simple diffusion through lipid membranes, following osmotic gradient created by accumulation of ions and FAAs. However molecular water channels, aquaporins (AQPs), discovery has prompted detailed investigations into molecular mechanisms involved in oocyte hydration of marine teleosts. *Aqp1b* is translocated transiently into oocyte plasma membrane during oocyte maturation, shortly after germinal vesicle breakdown and before complete hydrolysis of yolk proteins. The results envisaged that accumulation of osmotic effectors and *Aqp1b* intracellular trafficking are two highly regulated mechanisms that allow water uptake into the oocyte.

Ovulation: Ovulation process is defined as the release of a mature oocyte from its follicle into the ovarian cavity or into the abdominal cavity depending on the species. After meiosis resumption, the metaphase II oocyte is released from the follicle as the result of the ovulatory process. During ovulation, oocyte is expelled from the follicle through a localized rupture of follicular layers. Moreover, multiple factors such as the action of specific proteolytic enzymes and/or directed cell death and a mechanical action of the oocyte within the follicle onto the surrounding follicular layers in combination regulate the process.

Mature egg: It is a metaphase II oocyte released from the ovary after the completion of the ovulatory process. At this stage, egg is fully formed and contains all nutritive reserves and molecules needed for embryonic development. After fertilization, maternal factors support early embryonic development until activation of zygotic transcription. The initiation of the zygotic transcription occurs during the mid-blastula transition (MBT), which occurs in zebrafish at cycle 10, and is characterized by increased cell cycle length, loss of cell synchrony, and appearance of motility besides zygotic transcription.

Follicular atresia: Ovarian atresia is a common phenomenon in vertebrate ovaries under natural and experimental conditions during which a number of ovarian follicles recruited into vitellogenesis pool fail to complete maturation and ovulation. However, in teleost fish, a number of factors have been described responsible for increased follicular atresia, such as hypophysectomy, starvation, temperature changes, stress, and inadequate hormone treatments. In captivity, atresia is more frequent in vitellogenic oocytes, although it can rarely occur in previtellogenic oocytes.

Testis structure: In fishes, as in other vertebrates, testis is composed of two main compartments, intertubular (or interstitial) and tubular. Intertubular compartment contains steroidogenic leydig cells, blood/lymphatic vessels, macrophages and mast cells, neural and connective tissue cells. Tubular compartment is delineated by a basement membrane and peritubular myoid cells and possesses germinal epithelium. This epithelium contains only two types of cells, somatic Sertoli cells and germ cells. The germ cells can survive only while remaining close and with continuous interaction with Sertoli cells, thus spermatogenic capacity of testes may be determined by the number of Sertoli cells. The basic functional unit of the spermatogenic epithelium in fish is a spermatogenic cyst formed by a group of Sertoli cells surrounding and nursing one synchronously developing germ cell clone, which originates from a single spermatogonium.

Sertoli cells: These cells are somatic cells and play a crucial role in directing testes differentiation and development. Their main functions are to support germ cell survival, development, and physiological functioning. Moreover, Sertoli cells secrete fluid that generates tubular lumen, and they phagocytize apoptotic germ cells, residual bodies discarded by spermatids during spermiogenesis and residual sperm.

Seasonality and spermatogenic activity: Some tropical species do not display apparent seasonal variations in spermatogenic activity. However, in most species with habitats at higher latitudes, environmental cues regulate seasonal or cyclic events of reproduction. Active spermatogenesis may take place in summer (trout, carp, pike), in spring (tench, bream, whiting, sea bream), or may begin in autumn and finish in spring (killifish, stickleback, roach). Salmonids, pike, or Atlantic cod show distinct seasonality in reproduction.

Spermatogenesis: It is a highly organized, coordinated and conserved process in vertebrates, in which diploid spermatogonia proliferate and differentiate to form mature spermatozoa. Its duration is usually shorter in fishes than in mammals, and is also influenced by water temperature. In principle, the process can be categorized in three

different morpho-functional phases– mitotic or spermatogonial phase with different generations of spermatogonia (i.e. undifferentiated spermatogonia including the stem cells, and differentiated or differentiating spermatogonia); meiotic phase with primary and secondary spermatocytes; and spermiogenic phase with haploid spermatids emerging from meiosis and differentiating without further proliferation into motile, flagellated genome vectors, the spermatozoa.

The basal compartment of the seminiferous tubules of adult animals can be classified in three different types on the basis of their morphology and their presence in different stages of seminiferous epithelium cycle (Fig. 29.11)–type A, intermediate and type B. Functionally, type A spermatogonia are divided in undifferentiated and differentiated spermatogonia. Undifferentiated spermatogonia includes – A single, A_s; A paired, A_{pr}; A aligned, A_{al}; the latter usually clones of 4, 8, or 16 cells –that are continuously present; whereas differentiated spermatogonia (A_1-A_4) that are present at specific stages of epithelial cycle and committed to form mature sperm following a genetically determined schedule. Undifferentiated type A spermatogonia (A_{und}) transform to differentiated type A spermatogonia (A_{diff}), still sharing some morphological characteristics with A_{und} but with a greatly reduced potential for self-renewal. Committed to further maturation with several morphological changes, type A spermatogonia give rise to more rapidly dividing type B spermatogonia, of which there are usually several generations. The number of generations remain species specific and are genetically determined.

After the final mitosis, type B spermatogonia differentiate into primary (preleptotene) spermatocytes, from where sequential developmental stages proceed

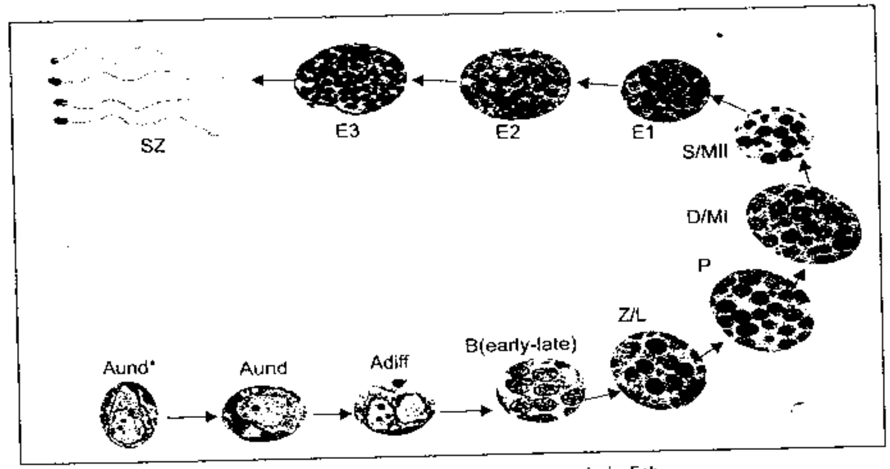


Fig. 29.11. Non-cystic spermatogenesis in fish.
Type A undifferentiated* spermatogonia (Aund*); type A undifferentiated spermatogonia (Aund); type A differentiated spermatogonia (Adiff); spermatogonia type B [B (early–late)]; leptotenic/zygotenic primary spermatocytes (L/Z); pachytenic primary spermatocytes (P); diplotenic spermatocytes/metaphase I (D/MI); secondary spermatocytes/metaphase II (S/MII); early (E1), intermediate (E2) and final spermatids (E3); spermatozoa (SZ).

as: primary spermatocytes (1st meiotic division) → secondary spermatocytes (2nd meiotic division) → spermatids (differentiation without proliferation) → spermatozoa (Fig. 29.11).

In spermiogenesis, spermatids undergo a series of morphological changes, nuclear condensation, elimination of organelles and cytoplasm, flagellum formation, and rearrangement of cellular organelles along the spermatozoon cytoplasm, and finally differentiate into spermatozoa. Three types of spermatids have been characterized with respect to nuclear condensation–E1 (early spermatids), E2 (intermediate spermatids) and E3 (final spermatids).

In teleost fish, spermatozoa generally have no acrosome (anacrosomal sperms) and the impenetrable chorion is pierced by a micropyle that gives access to membrane of the oocyte. Spermatozoa often show a spherical nucleus with homogenous, highly condensed chromatin, a nuclear fossa, a midpiece of variable size with or without a cytoplasmic channel, and one or two long flagella. Moreover, fish spermatozoa can be classified into aquasperm and introsperm, according to external or internal mode of fertilization. At the end of spermiogenesis, when intercellular bridges collapse to make individualized spermatozoa, subsequent dynamic remodelling cyst-forming Sertoli cells make opening in the cyst wall to liberate spermatozoa in tubular lumen during spermiation. Sertoli cells produce fluid in which spermatozoa remain suspended, however, in some species, like catfishes, seminal vesicles also produce fluid which may contain pheromones. There is a paucity of data dealing with timing of spermatogenetic events in fishes. Duration of meiosis plus spermiogenesis varies from 7 to 21 days in 4 tropical species to 1 to 3 months in species living in temperate and cold zones.

Endocrine regulation of reproduction

Pituitary gonadotropins, follicle-stimulating hormone (FSH = gonadotropic hormone I or GtH I) and luteinizing hormone (LH = gonadotropic hormone II or GtH II) play central role in regulating gametogenesis and production of gonadal hormones required for the development of sexual behaviour and secondary sex characters in all vertebrates. Like gonadotropins in tetrapods, fish FSH and LH secreted from proximal pars distalis (PPD) of the pituitary gland are heterodimeric glycoproteins, each consisting of a common α and hormone specific β subunit that are non-covalently linked. Generally in fish, gonadotropin binds to its receptors in the ovarian (theca and granulosa) and testicular (Leydig cells) somatic cells that initiate signal transduction cascade resulting in the formation of maturation-inducing steroids (MIS), 17α,20β,-dihydroxy-4-pregnen-3-one (DHP) or 17α,20β,21-trihydroxy-4-pregnen-3-one (20β-S), which in turn cause final maturation, ovulation and spermiation by inducing generation of maturation promoting factor (MPF), a complex of dimeric protein of two monomers, cyclin B and cdc 2 kinase. MPF affects oocyte germinal vesicle breakdown (GVBD), a clear sign of final maturation.

Hypothalamic regulation of gonadotropin release: Various brain hormones and neurotransmitters are implicated in the relation of GtH release from pituitary: gonadotropin releasing hormone (GnRH), secreted from the nucleus preopticus (NPO) of hypothalamus of several teleosts, its various forms, neuropeptide Y (NPY), γ-aminobutyric acid (GABA), taurine, glutamate, aspartate, dopamine (DA), norepinephrine, bombesin (BBS), cholecystokinin (CCK), galanin (GAL), activin/inhibin, nicotine and serotonin. In addition, cholinergic nerves may also participate in this regulation. The GnRH, NPY, BBS, CCK and GAL are directly delivered to gonadotrophs by hypothalamic neurons whereas 5HT and activin/inhibin are probably from paracrine sources within pituitary.

GnRH: Neurodecapeptide GnRH is the central regulator of the reproductive hormonal cascade regulating synthesis and release of GtH secretion from pituitary gland. GnRH exerts its regulatory role through recognition and binding by specific membrane associated receptors belonging to members of rhodopsin-like G-protein coupled receptor (GPCR) family. GtH II secretion is also under the control of inhibitory hypothalamic factors in fishes. In majority of the fishes, dopamine (DA) directly inhibits GnRH-induced GtH-II response on gonadotrops, and in some, DA reduces basal GTH-II secretion directly at pituitary level. DA acts through D_2 receptors to decrease GnRH release from nerve terminals in the pituitary and via D_1 receptors to reduce GnRH release from preoptic anterior hypothalamic slices. Dopamine inhibition is paramount in cyprinids although less pronounced in loach, salmonids and tilapia, and in catfish (*Hetropneustes fossilis*) it is relatively minor.

Regulation of oogenesis: Hormonal mechanisms controlling oogonial proliferation and oocyte recruitment are not clearly understood for any vertebrate. However, it is well established that GtHs, either directly, or indirectly via stimulation of ovarian mediators, increase oogonial proliferation. Two sex steroids have been implicated in controlling oogonial proliferation and transition of oogonia into meiosis–estradiol-17β (E2) is involved in early oogenesis, acts directly on oogonial proliferation; and 17α,20β,-dihydroxy-4-pregnen-3-one (DHP), which in addition to promoting oogonial proliferation initiates first meiotic division, leading to the development of the first stage in primary growth, i.e., chromatin nucleolar oocytes. Interestingly, initiation in oocyte growth prior to cortical alveoli stage has been found GtH-independent as both FSH β and LH β transcripts and proteins were detected in primary and secondary oocytes. Synthesis of cortical alveoli has been found associated with enhancement of plasma and pituitary FSH, plasma E2, and expression of transcripts encoding ovarian steroidogenic acute regulatory protein (StAR), which serves to move cholesterol across inner mitochondrial membrane, the rate limiting step in steroidogenesis. Subsequently, accumulation of lipid droplets was found to be associated with increased plasma IGF-levels and components of the FSH-ovary axis, including plasma FSH, E2, and ovarian mRNAs for GtH receptors, StAR, IGF-I and IGF-II. The TGF super family factor, GSDF is expressed in granulosa cells and may play a role in granulosa cell proliferation, as is reported in mammals.

In vitellogenic fishes, thecal cells supply androgen substrate to ovarian granulosa cells that express P_{450} aromatase and produce E2 (Fig.29.12). E2 promotes hepatic Vtg synthesis, and FSH has been demonstrated experimentally to increase Vtg uptake by rainbow trout ovarian follicles in *in vitro*. Simultaneously, growth hormone (GH) potentiates effects of E2 in stimulating Vtg synthesis as demonstrated in eel primary hepatocyte cultures. Besides, IGF-I signaling system is important in regulating steroidogenic activity of ovarian follicles during vitellogenesis. In addition to affecting steroidogenic machinery, IGF-I exhibits mitogenic effects on granulosa cells at the onset of vitellogenesis. Epidermal growth factor (EGF), produced in oocytes stimulated expression of both activin bA and bB, and suppressed basal and human chorionic gonadotropin-induced expression of follistatin (a protein which binds and neutralizes activins) in cultured follicle cells. Since EGF receptor has been found to express in follicle cells, EGF appears to act in a paracrine fashion to regulate function of follicle cells.

Major endocrine events associated with termination of vitellogenesis and resumption of meiosis (oocyte maturation), show acute increase in plasma LH levels, increased expression of LH receptor and an LH-driven switch in ovarian follicle steroidogenic pathway from production of predominantly E2 during vitellogenesis to production of maturation-inducing steroids (MIS) (Fig. 29.12). These compounds are species-specific derivatives of progesterone which bind to oocyte membrane-specific receptors to activate maturation promoting factor (MPF), which is a dimmer protein of cyclin and cdc2 kinase in the ooplasm that finally triggers dissolution of germinal vesicle and reinitiates meiosis. MIS of salmonids and many other species is 17α,20β,-dihydroxy-4-pregnen-3-one (DHP) or 17α,20β,21-trihydroxy-4-pregnen-3-one (20β-S), and is found in some, but not all perciforms and some other species. In a few species, both steroids appear to participate in regulating oocyte maturation.

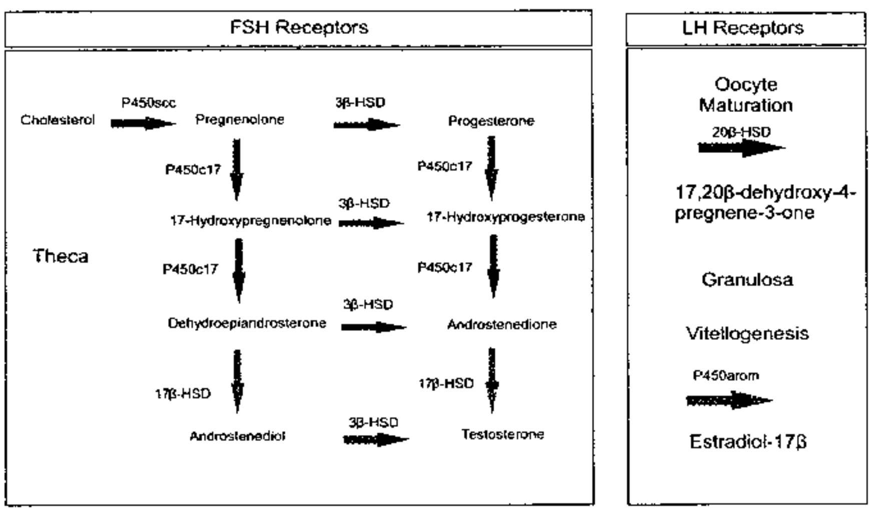


Fig. 29.12. Two cell models depicting steroidogenesis pathway involved in oocyte growth and maturation in fish. Enzymes: P450scc, P450 side-chain cleavage; P450c17, 17-hydroxylase/ C17-C20-lyase; 3β-HSD, 3β-hydroxysteroid dehydrogenase; 17β-HSD, 17β-hydroxysteroid dehydrogenase; 20β-HSD, 20β-hydroxysteroid dehydrogenase; P450arom, P450 aromatase.

The ability to synthesize MIS by follicle cells must also be accompanied by acquisition of sensitivity of the oocyte to respond to MIS. This process is known as maturational competence, and includes an increase in the MIS receptors on the oocyte cell membrane and also in communication among granulosa cells, and between granulosa cells and oocyte through gap junctions. The role of gap junctions during this process is,however, not clearly known. IGF-I, and in some cases IGF-II, stimulate acquisition of maturational competence and/or induce oocyte maturation, depending on the species. In some cases, this has been linked to increased MIS production, while in others effects appear to be independent of alterations in steroid output.

Substantial evidence is available to show that maturational competence is induced by GTHs, however a number of hormones and growth factors may be involved in this process, but their precise roles have yet to be determined. Arachidonic acid and its metabolites including prostaglandins (PGs), have been shown to be involved in ovulation in some species; MIS also takes part to stimulate both oocyte maturation and ovulation *in vitro*. Involvement of other factors in ovulation in fish includes: proteases and protease inhibitors, progestins, other eicosanoids, catecholamines, and vasoactive peptides.

Regulation of spermatogenesis: ***Pituitary hormones and growth factors:*** Gonadotropins, GtH I (FSH like) and GtH II (LH like) are the most important pituitary hormones regulating testicular physiology. The data on receptor pharmacology and localization suggest that leydig cell steroidogenesis is directly regulated by LH and FSH, while Sertoli cell functions are structural, nutritional and regulation (paracrine) support for germ cell development, and are predominantly regulated by FSH, although high LH concentrations, such as during spawning season, might cross-activate FSHR (Fig.29.13).

Sex-steroids: The steroids such as progestagens, androgens, and estrogens are mainly produced in gonads; in males, 17β-estradiol (E2) remains low and shows a transition elevation at the beginning of the reproductive cycle. Down regulation of the anti-Müllerian hormone (AMH) gene in estrogen treated trout indicates involvement of

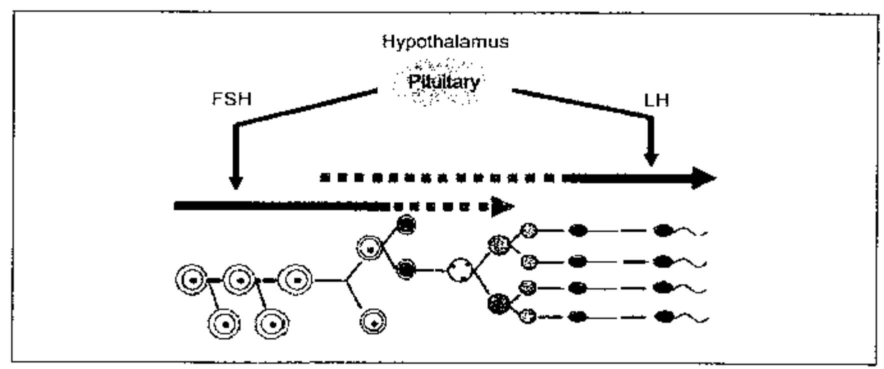


Fig. 29.13. A schematic presentation on the role of FSH and LH in spermatogenesis. FSH, mainly regulating processes during the mitotic phase, and LH, mainly regulating processes during the spermiogenic phase.

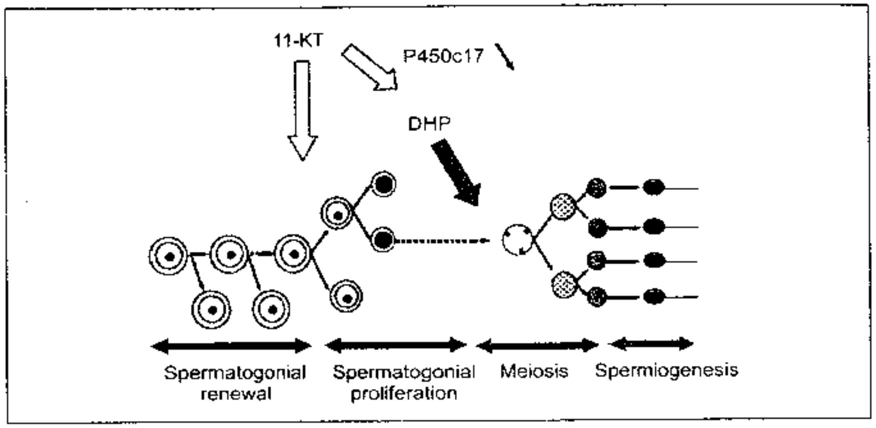


Fig. 29.14. A schematic summary of the role of 11-ketotestosterone (11-KT) and DHP (17α,20β,-dihydroxy-4-pregnen-3-one) in regulating fish spermatogenesis. 11-KT can inhibit the expression of P450c17, facilitating DHP production via an increased availability of substrate for DHP synthesis. Modified from *Schulz et al.* (2010).

estrogens in stimulation of spermatogonial stem cell renewal in males. Androgens such as testosterone (T) and 11-ketotestosterone, (11-KT) are effective in supporting either whole process of spermatogenesis, or at least some steps such as spermatogonial multiplication and spermatocyte formation or maturation (Fig. 29.14). They may also participate in initiation of puberty.

Progestins such as DHP or 17α,20β,21-trihydroxy-4-pregnen-3-one (20β-S) advance and induce spermiation in Salmonidae and Cyprinidae. Besides, the involvement of DHP in meiosis was recently reported in male eel.

Growth factors and other hormones: A few growth factors have been identified that are produced by Sertoli cells and that regulate germ cell proliferation behaviour such as, the TGFβ family members activin, gonadal soma derived factor (GSDF), AMH and its receptor or an orthologue of platelet-derived endothelial cell growth factor (PD-ECGF). The growth hormone can modulate directly and/or through locally produced IGF-I, process of testicular steroidogenesis and/or germ cell proliferation.

In general, it appears that regulatory input to spermatogenesis via gonadotropins and sex steroids can be modulated or fine-tuned by other pituitary hormones and local signaling in testes. LH secretion induces increase in the production of testicular steroids such as 11-KT and DHP or 20β-S. Recently, it has been proposed that 11-deoxycorticosterone participates in control of milt fluidity as well. In some teleosts, it has been suggested that DHP regulates sperm maturation mediated through increased seminal plasma *p*H, which in turn increases cAMP content in sperm, thereby allowing acquisition of sperm motility. However, progestins may have a direct action on sperm motility since 20β-S binds to sperm plasma membrane and stimulates sperm hyper-motility in Atlantic croaker and sea trout (*Salmo trutta*

trutta). Thus, estrogenic, androgenic and progestagenic sex steroids are important regulators for progression of spermatogenesis from spermatogonial stem cell renewal to sperm maturation.

Pheromones in fish reproduction: They are externally secreted semiochemicals, which alter behaviour and/or physiology of the recipient, either through ingestion, absorption, gustatory or olfactory pathways. Sex attraction and synchronization of reproductive processes, breeding migration and parent-offspring recognition are shaped by pheromones. It has been demonstrated that mitral cells located in medial tracts of olfactory pathway convey pheromonal responses to high centres of brain, while lateral olfactory bundles are responsible for transducing feedback stimuli in fishes.

A female pheromone is apparent at pair formation, copulation and spawning. Pheromone released along with the ovarian fluid is sufficient to evoke courtship behaviour in males. Circulating levels of androgen are essential to render male differentially sensitive to pheromone released by gravid female. Mature female fishes release primer pheromone in urine, which immediately elevates gonadotropin and testosterone levels in plasma, and under prolonged exposure milt volume as well as sperm motility increases in male fishes. Some females release chemical copulins during ovulation which are releaser pheromones that induce immediate response without altering plasma concentration of gonadotropins. Maturation inducing hormones, estrogen, prostaglandins-F and steroid glucuronides are major components reported in pheromones of female fishes.

Odoriferous secretions of cutaneous anal gland, seminal vesicle, gill gland, sperm-duct gland, urino-genital fluid of male fishes serve as the source of pheromones to attract female fishes during breeding season, which ultimately induces ovulation and spawning in fishes. Testosterone, steroid glucuronides and Prostaglands-F are major components found in male fish pheromones.

Thermal ecophysiology

Effect of temperature has been studying on the aquatic organisms for more than a century due to its multifaceted implications in the ecosystem. Research in thermal ecology has increased manifold in the recent years considering present scenario of global warming and climate change. Temperature is one of the most pervasive environmental factors virtually affecting all biochemical and physiological activities of poikilothermic animal's growth, development, reproductive capacity, mortality and distribution. Indirect effects alter productivity, structure and composition of aquatic ecosystems. Temperature changes do, however, exhibit positive effects too. Up to a certain limit, high temperature favours aquaculture by reducing time in production of marketable size animals, thereby allowing more generations per year; by enhancing growth rates and food-conversion efficiencies.

When internal or external environment of an animal deviates from normal, cascades of compensated mechanisms get activated for restoration of normal function. This phenomenon is regarded as the General Adaptation Syndrome (stress responses). However, these compensatory mechanisms face limitations; beyond which breakdown

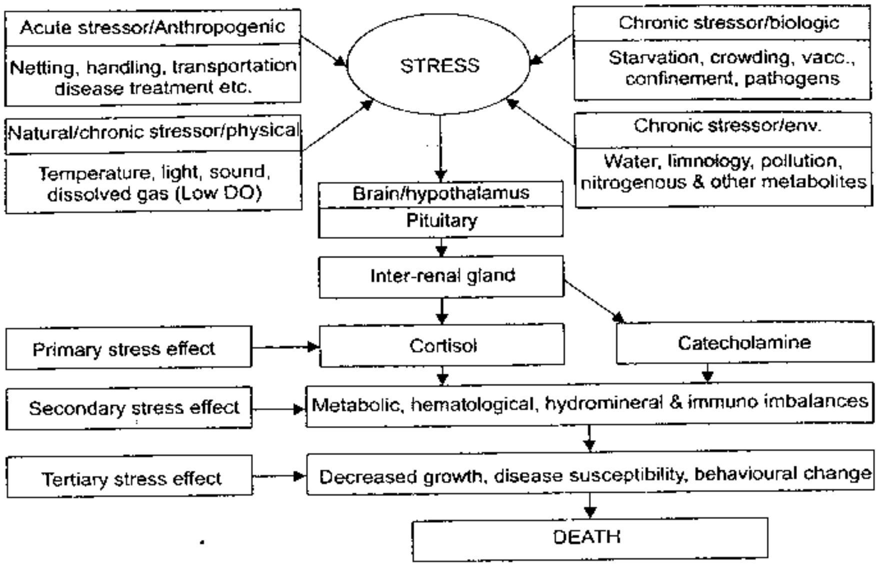


Fig. 29.15. Stress responses in fishes.

begins, leading to a stage of disturbed function, disease, and ultimately death of the animal (Fig. 29.15).

Adaptation to temperature can be well understood by viewing complementary roles played by macro and micro molecules of the cell. Qualitative and quantitative modifications in the micromolecular constituents of the cell create an appropriate milieu for macromolecular (mainly genes and proteins) structure and function needed for adaptation to changed environment.

Temperature sensitivity and thermoregulation: Fishes maintain their body temperature within 1-2°C of the environment, and lose metabolic heat across gills. Body temperature of an aquatic organism is maintained equivalent to surroundings owing to thermal homogeneity of aquatic environment resulting from high specific heat and thermal water conductivity. *Ampullae of lorenzini* are special sensing organs that help shark to detect temperature variations in water through bundle of sensory cells having numerous nerve fibres filled with glycoprotein-based gel, which releases to surface through a pore. Heat transferred by gills, which are effective heat exchangers, accounts for only 10-30% of the total heat exchanged between fish and its ecosystem, since most of the heat is transferred directly by conduction through body wall. All freshwater fishes are obligatory ectotherms 4-5 times less energetically costly mode per unit mass than to a similar sized endothermic animal. This energy consumed by minimization of energy costs in body temperature is used directly towards growth and reproduction. The reason could be that many ectotherms are highly fecund, their reproductive size grows rapidly and more than 99.9% of the species on the earth are

Table 29.5. Thermal tolerance limits* of Indian fishes with respect to different acclimation temperatures

$T_{acclimation}$ (°C)	Species and life stage	CT_{Max}	LT_{Max}	CT_{Min}	LT_{Min}
25	*Labeo rohita* early fingerling	40.20	40.40	12.90	8.20
25	*Cyprinus carpio* early fingerling	39.70	39.80	8.40	11.50
25	*Anabas testudiens*	40.15	–	12.43	–
25	*Macrobrachium rosenbergii* adult	40.73	–	14.90	–
26	*Labeo rohita* fry	42.33	–	12.00	–
26	*Channa punctatus* adult	42.72	–	10.38	–
26	*Gonoproktopterus curmuca* adult	41.10	–	20.54	–
26	*Danio aequipinnatus* adult	38.00	–	15.00	–
26	*Etroplus suratensis* adult	42.60	–	17.00	–
26	*Horabragrus brachysoma* adult	41.01	–	15.14	–
26	*Labeo calbasu* adult	40.10	–	17.82	–
26	*Mastacembalus armatus* adult	39.00	–	12.14	–
26	*Ompok malabaricus* adult	40.03	–	13.08	–
26	*Parluciosoma daniconius* adult	39.00	–	11.06	–
26	*Puntius filamentosus* adult	38.53	–	14.00	–
26	*Labeo rohita* advanced fingerling	40.63	41.16	13.73	13.31
26	*Catla catla* advanced fingerling	40.45	41.03	13.92	13.60
26	*Cirrhinus mrigala* advanced fingerling	42.25	42.51	12.12	11.90
26	*Pterophyllum scalare* juveniles	39.67	40.67	16.47	14.18
28	*Pterophyllum scalare* juveniles	39.30	40.72	17.00	14.58
30	*Labeo rohita* advanced fingerling	41.52	–	14.01	–
30	*Labeo rohita* early fingerling	41.60	41.90	14.20	13.50
30	*Catla catla* advanced fingerling	41.16	–	14.23	–
30	*Cirrhinus mrigala* advanced fingerling	42.46	–	13.35	–
30	*Cyprinus carpio* early fingerling	40.60	40.90	8.60	8.40
30	*Pangasius pangasius* advanced fingerling	42.68	42.95	12.37	11.75
30	*Macrobrachium rosenbergii* adult	41.06	–	15.40	–
30	*Pterophyllum scalare* juveniles	40.03	42.71	17.67	15.58
30	*Anabas testudiens*	41.40	–	13.06	–
31	*Labeo rohita* advanced fingerling	41.91	42.30	14.20	13.71
31	*Catla catla* advanced fingerling	41.39	41.70	14.40	13.95
31	*Cirrhinus mrigala* advanced fingerling	42.55	42.93	13.70	13.30
31	*Labeo rohita* fry	44.81	–	12.46	–
32	*Pterophyllum scalare* juveniles	40.98	43.25	19.58	16.58
33	*Labeo rohita* advanced fingerling	42.65	43.06	15.00	14.43
33	*Catla catla* advanced fingerling	42.63	42.96	15.20	14.81
33	*Cirrhinus mrigala* advanced fingerling	42.76	43.11	13.81	13.41
33	*Labeo rohita* fry	45.35	–	13.80	–
34	*L. rohita* advanced fingerling	42.87	–	15.19	–
34	*Catla catla* advanced fingerling	42.85	–	15.37	–
34	*Cirrhinus mrigala* advanced fingerling	42.84	–	13.99	–
34	*Cyprinus carpio* early fingerling	42.58	–	10.02	–
34	*Pangasius pangasius* advanced fingerling	43.67	44.35	14.48	12.5
34	*Pterophyllum scalare* juveniles	42.71	44.00	20.55	15.93
35	*Labeo rohita* early fingerling	42.20	42.70	15.00	14.40
35	*Cyprinus carpio* early fingerling	42.90	42.90	10.20	10.10
35	*Anabas testudiens*	41.88		13.94	–
35	*Macrobrachium rosenbergii*	41.96	–	16.98	–
36	*Labeo rohita* advanced fingerling	42.86	43.31	15.58	14.90
36	*Catla catla* advanced fingerling	42.73	43.06	15.63	14.98
36	*Cirrhinus mrigala* advanced fingerling	43.07	43.68	13.95	13.56
36	*Labeo rohita* fry	45.60	–	14.43	–
38	*L. rohita* advanced fingerling	43.30	–	15.95	–
38	*C. catla* advanced fingerling	43.18	–	15.97	–
38	*Cirrhinus mrigala* advanced fingerling	43.23	–	14.32	–
38	*Cyprinus carpio* early fingerling	43.86	–	10.74	–
38	*Pangasius pangasius* advanced fingerlings	44.05	44.53	17.22	14.35

— Data not available; * Critical temperature methodology (CTM).

strictly ectothermic. Endothermic fishes (27 species), including shark, are able to maintain muscle temperature up to 19°C above by a novel thermogenic organ called brain heater, which is actually a modification of muscle (fibre type called heat cells, is an extraordinary oxidative cell that is specialized for generating heat) in the brain and eye, and can raise 13°C above ambient temperature. Hence these groups of fishes can live in a thermal environment at a low energetic cost.

Thermal tolerance: All species have a certain thermal limit in response to varying acclimation temperatures. Environmental temperature directly influences body temperature in ectotherms; while endotherms in contrast, physiologically maintain relatively constant internal temperature, regardless of environmental temperature. According to Vant Hoff's law (Q_{10}), every 10°C raise in environmental temperature doubles metabolic rate of ectotherms. Fishes can tolerate a certain temperature range, beyond which it creates thermal stress producing significant disturbance in normal functions for survival. It has been established that increasing acclimation temperatures significantly increase critical thermal maximum (CTMax), critical thermal minimum (CTMin), lethal thermal maximum (LTMax) and lethal thermal minimum (LTMin) (Table 29.5). All species have a certain thermal tolerance limit in response to varying acclimation temperatures.

Thermal tolerance polygon: Zone of thermal tolerance bounded by upper and lower critical temperatures for a wide range of acclimation temperatures is known as thermal tolerance polygon, which determines tolerance capacity of a fish species. Thermal tolerance polygon of *L. rohita* with three preset acclimation temperatures viz., CTM methodology is 273.5°C². Interestingly, thermal-tolerance polygon in *C. carpio* (311.6°C²) is higher than that in *L. rohita* by virtue of its being cold tolerant (Fig. 29.16). This shows that *C. carpio* is more tolerant than *L. rohita*, which must be the reason for *C. carpio* showing cosmopolitan distribution and culture potential in comparison to *L. rohita*. The complete thermal-tolerance zone of Indian major carps are as follows: *L. rohita* (744.8°C²), *C. catla* (728.8°C²) and *C. mrigala* (801.8°C²) Fig. 29.16. Hence area of thermal-tolerance polygon is dependent on acclimation temperatures.

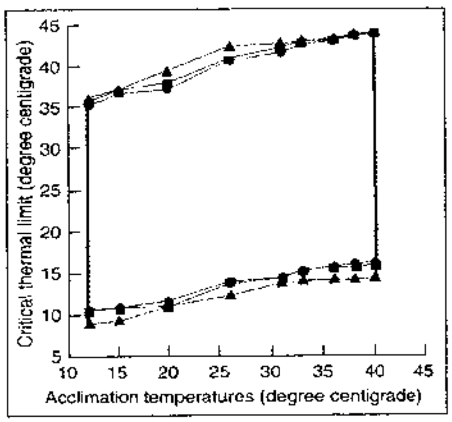


Fig. 29.16. Thermal tolerance polygon of Indian major carps with respect to different acclimation temperature. Thermal tolerance polygon (°C²) of *C. catla* (—■—), *L. rohita* (—●—) and *C. mrigala* (—▲—) over 12–40°C range of acclimation temperatures using CTM values.

Metabolic elasticity and thermal adaptation: The thermal range tolerated by an organism can be extended by adaptive modifications in the physiology of the animal in response to rise or fall in the temperature. The animal must strike a balance between

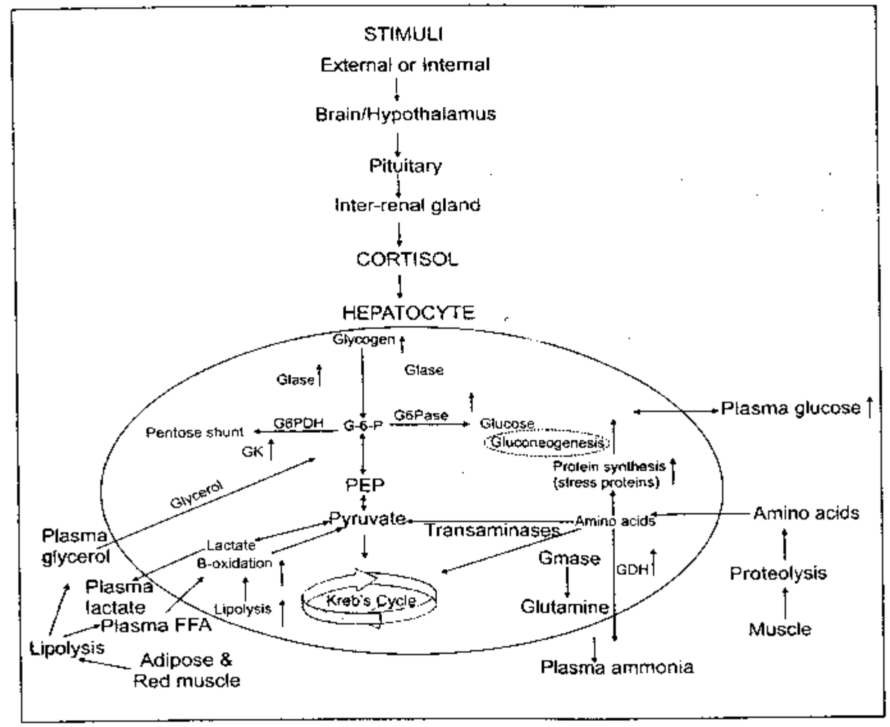


Fig. 29.17. Physio-biochemical process during thermal stress.

its various processes on exposure to temperature changes. These adaptive responses are demonstrated by increased enzyme concentrations during colder conditions through direct modification of enzymes or by changed compartmentalization within the cell or by altered activity due to allosteric modulation by activators or inhibitors. In a complex multi-enzyme system, just as branch points compete for a single substrate so also any change in temperature may affect ability of various metabolic pathways to compete for the substrate (Fig. 29.17). Effect of temperature on the enzyme-substrate interaction has led to most prevalent means of reducing temperature sensitivity of these reactions, also referred to as the inherent properties of enzymatic proteins.

Enzyme variants and temperature adaptation: All teleosts have developed their specific adaptive mechanisms, both behavioural and physiological to cope with temperature fluctuations. Such adaptative responses may occur instantaneously after a period of acclimation, for days or months, or over a period of evolutionary time-scale. The biochemical adaptations in fishes can be measured in changes in activities of their metabolic enzymes, changes in lipids composition of cellular membranes, quantitative changes in total or specific proteins in different organs and expression of different isozymes that permit continued functions at altered temperatures. The outcome of these adaptative processes is to maintain a constant metabolic function at altered environmental temperatures.

Enzymes associated with pathways of energy production and those involved in glycolysis, gluconeogenesis, hexose monophosphate, citric acid cycle, electron transport, digestion and protein synthesis exhibit compensatory acclimations. Organisms produce alternative forms of enzymes that catalyze same reaction, termed as isozymes or allozymes. These isomeric forms of enzymes have subtle differences in their temperature sensitivities. Hence maintenance of catalytic efficiency during thermal conditions may be due to change in the suite of isoenzymes present.

Enzyme activity and adaptation: High temperatures cause higher free amino acid

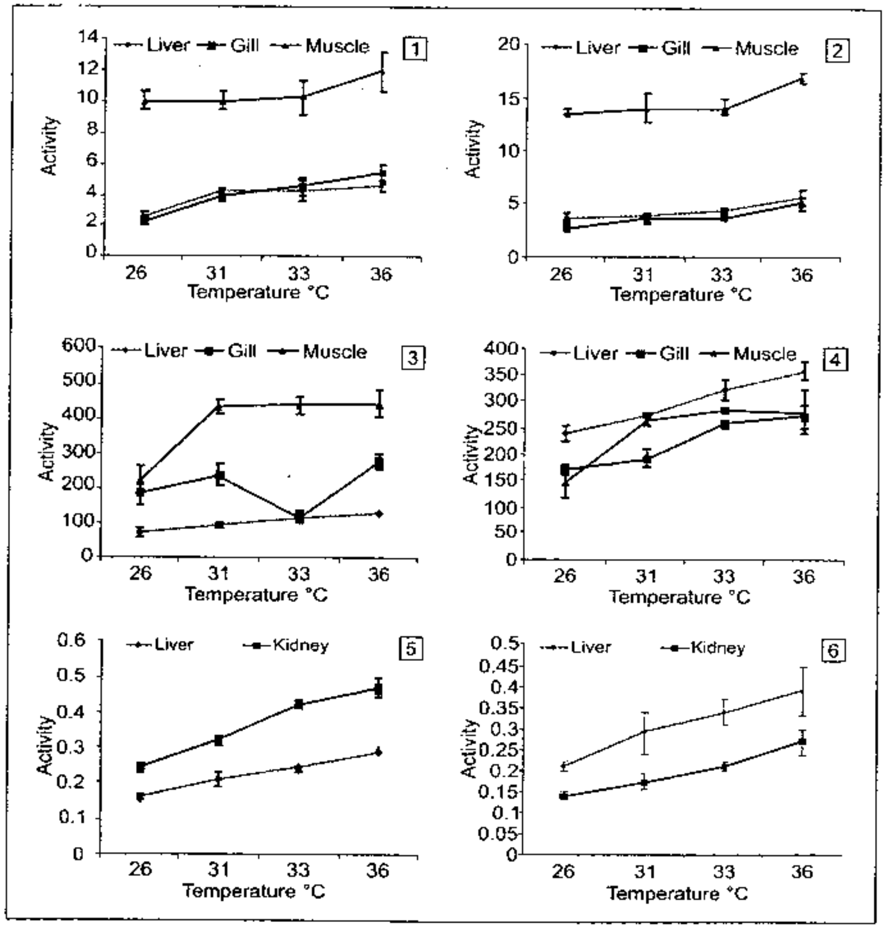


Fig. 29.18. Effect of acclimation temperatures on enzyme activity of *L. rohita* acclimated to 26, 31, 33 and 36°C. AST (1), ALT (2), LDH (3), MDH (4), G6Pase (5) and F 1,6-BiPase.

mobilization. Thermal stress imposes higher enzyme activities of ALT (Alanine Amino Transferase) and AST (Aspartate Amino Transferase) in *L. rohita* (Fig. 29.18). ALT and AST enzyme activities increase with increasing acclimation temperature, which in turn produce glucose to cope with stress, as is evident with increased gluconeogenesis process. Similarly, LDH activity also increases at higher temperatures (36°C) due to higher production of lactate, which is preferred substrate for gluconeogenesis in fish. The capacity of lactate mobilization in liver is more due to higher metabolic condition in stressed fish. Absolute value of LDH activity in muscle is higher during thermal stress due to muscle glycolysis. Malate dehydrogenase (MDH) is an enzyme of TCA cycle, and its activity increases at higher acclimation temperature to use the product (oxaloacetate) due to higher activity of AST for production of more energy (ATPs), which is utilized for other physiological activities. Similarly, MDH activity increases in fishes when acclimated at higher temperatures, which strengthen above hypothesis. Glucose-6-phosphatase (G-6Pase) is an enzyme, which catalyzes conversion of glucose-6-phosphate to glucose. Glucose-6-phosphatase activity increases at higher acclimation temperatures, which indicates higher glycogen mobilization for blood glucose production; similarly fructose 1-6 bi-phosphatase (a gluconeogenic enzyme) activity also increases at higher acclimation temperatures, which also indicates that higher temperature increases gluconeogenic activity in *L. rohita*.

Activities of a number of enzymes involved in the metabolism (malate and lactate dehydrogenases, aspartate and alanine aminotransferases, alkaline and acid phosphatases and acetylcholinesterase) generally increase with rising temperature in *Puntius filamentosus*, *Parluciosoma daniconius* and *Etroplus suratensis*. However, activities of acetylcholinesterase in brain and liver and alkaline and acid phosphatase

Table 29.6. Rate of oxygen consumption (mg O_2/ kg/ hr) of different species acclimated to various temperatures

Species	Tacclimation (°C)	Oxygen consumption (with acclimation)	Oxygen consumption (without acclimation)
Macrobrachium rosenbergii	25	2.11	2.18
	30	2.95	3.17
	35	3.36	4.13
Catla catla	26	81.00	81.16
	31	98.66	113.33
	33	127.00	134.50
	36	140.83	175.66
Labeo rohita	26	72.33	75.66
	31	91.66	106.00
	33	119.66	122.00
	36	122.83	164.55
Cirrhinus mrigala	26	70.33	69.83
	31	91.55	101.33
	33	102.50	118.33
	36	116.83	150.33
Pangasius pangasius	30	111.49	100.20
	34	231.72	258.29
	38	236.25	265.01

in liver decrease with increased temperature. These enzymes are known to respond to any stress that the organism faces, and marginal increase in their activities at higher temperature reflects ability of fish to avoid these stressors.

Thermal effects on oxygen consumption: Acclimation temperatures also have strong effects on oxygen consumption, which is often used as an index of metabolism in freshwater fishes. Rate of oxygen consumption increases with rising temperature and shows variations among species like *L. rohita* and *C. carpio* at three acclimation temperatures (Table 29.6). The observations show higher rates of oxygen consumption and Q_{10} value in *L. rohita*, in comparison to *C. carpio*. This is an indication of species-variations for energy utilization during thermal acclimation.

Molecular chaperones (HSPs) and thermal adaptation: Long-term exposure to an environmental condition, not previously encountered, leads to acclimation wherein cellular machinery remodels itself to cope up with future adverse environmental conditions. House-keeping functions of the cell are carried out by molecular chaperones, i.e. proteins coded by a large group of genes wherein heat-shock genes are only a subset of this group. Molecular chaperones prevent inappropriate aggregation of other proteins, and are also involved in transport, folding, unfolding, assembly and disassembly of multi-structured units and degradation of misfolded and aggregated proteins. Under normal cellular conditions, these tasks are important but an accelerated need for these molecular chaperones under stressful conditions could potentially damage cellular and molecular structures in the cells. HSPs can play an important role in a natural population exposed to variable environments, including occasional stress exposure and environmental condition that appears benign. HSPs can be induced by an individual stressor or by synergistic interactions of various stress types leading to further up-regulation. When exposure is to a combination of 'low-level stress types', HSP expression may be significantly affected, influencing resistance and fitness of natural populations. Therefore, the need to assess ecological role of HSPs becomes imperative.

Ecological importance of inducible HSPs depends on the balance between benefits and costs. Cost of HSP expression involves fertility/ fecundity, energy, development and survival; thought to arise by obstruction of normal cell functions in response to stress, extensive use of energy and toxic effects of high HSP concentrations. Sub-lethal thermal stress may lead to increased amount of HSP induction and cross protection against subsequent lethal stressors. There can be a positive correlation between ability to induce stress proteins and survival. Heat-shock protein plays a key role to protect organisms from unfavourable conditions and maintain their homeostasis. Cross protection is a phenomenon wherein an animal once exposed to sub-lethal temperature is better equipped to endure future thermal shocks. Ectothermic vertebrates and eucaryotic cells become thermally tolerant (heat hardened) after exposure to heat shock. Cellular thermal tolerance and induction of heat shock proteins are correlated. Thermotolerance is an endogeneous mechanism for cells to withstand subsequent greater thermal injury. It can be achieved by induction of HSPs in response to mild heat stress. The beneficial effects of thermotolerance to hyperthermia could protect

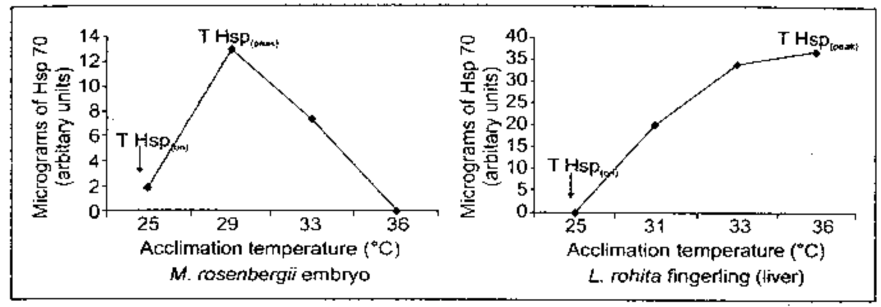


Fig. 29.19. Expression of HSP70 in *M. rosenbergii* and *L. rohita* after heat shock.

against other forms of exogeneous stimuli. Thermal dependence of HSP induction process is found to vary among different thermally adapted species. The different aspects of thermal dependence on HSP induction includes *(i)* the temperature at which HSP synthesis first begins ('threshold induction temperature –T_{on}); *(ii)* the temperature at which maximal synthesis of HSP occurs (T_{peak}); and *(iii)* the upper thermal limits of HSP synthesis (T_{off}) (Fig. 29.19).

Various environmental, pathological and physiological stimuli lead to induction of HSPs, which act as a biomarker for monitoring stress in fish. Diverse forms of heat-shock proteins exists, which are classified into different families on the basis of their molecular weights, viz. HSP90, HSP70, HSP60 and ubiquitin (low molecular weight HSPs) have reviewed the HSP families and their molecular functions in detail.

- HSP 90 is known to interact with specific target proteins, and plays an essential role in steroid-receptor fidelity thereby supporting various components of cytoskeleton, enzymes and steroid-hormone receptor.
- HSP 70 is considered to be the major HSP family consisting of solely inducible, constitutive and inducible and solely constitutive proteins (heat-shock cognates).
- HSP 60 family is present in bacteria, plant chloroplast and mitochondria of animal cell. It is found involved in many autoimmune diseases and allows multivalent protein binding.
- Ubiquitin group is low molecular weight protein, varying from 15to 30 kDa. These have diverse species-specific functions unlike other HSPs. It functions by tagging proteins to be degraded by proteosome.

HSP 70: HSP70-protein family is the most abundant and widely studied group of stress proteins, comprising constitutive as well as inducible isoforms; it is highly conserved across phyla from bacteria to mammals and is the most commonly induced stress protein in response to sub-optimal physiological conditions. Although heat-shock protein studies in Indian fishes are still in their incipient stages, there are reports available on the induction of HSP 70 to heat stress in *L. rohita* and *M. rosenbergii* (Fig. 29.20); also in response to stressors like temperature and chlorine etc. This strongly suggests role of HSPs in the physiological process of adaptation in Indian fishes. The expression of heat-shock proteins in fish varies with season (less during winter than in

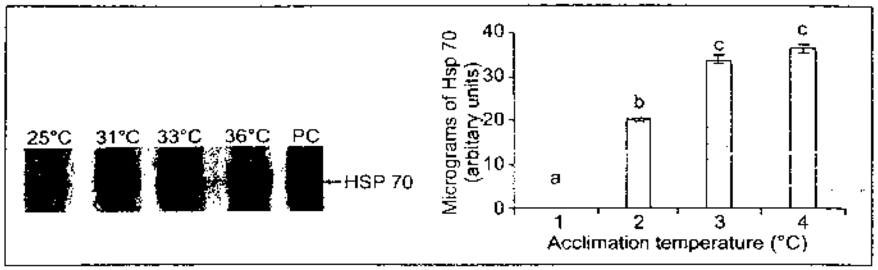


Fig. 29.20. Western blot with histogram (b) showing the protein profiles of *L. rohita* acclimated at four different temperatures (25, 31, 33, 36°C and Positive control).

summer). Hence, this can be attributed to acclimatization or adaptive mechanism of animals to changing environment.

Acclimation to higher temperatures results in higher basal levels of HSP 70. This is already evident by the fact that in natural conditions, levels of heat-shock proteins vary during acclimatization to seasonal temperatures (less during winter than in summer). Maximum accumulation of HSP 70 has been reported during summer acclimatization in the gill tissue of the mussel, *Mytilus trossulus*, digestive gland and gills of *M. galloprovincialis* and HSP 90 in the brain of the eurythermal goby *Gillichthys mirabilis*.

Thermal adaptation and lipid modification: Temperature-induced lipid restructuring causes complex changes in lipids composition. The ability of poikilotherms to acclimate to a range of environmental temperatures may be attributed to restructuring of cellular membrane. Physical properties of the membrane conducive to physiological functions are maintained at different temperatures. The high degree of unsaturation of phosphatidylethanolamine (PE) is in natural membrane. Coordinated changes in the activities of various classes of lipid biosynthetic enzymes have lead to lipid adjustments in carp liver in response to cold conditions

Alterations in phospholipid composition and structure have been the best characterized responses to temperature change in cell membranes of poikilotherms. Poikilothermic animals have evolved mechanisms to counteract direct effects of temperature on membrane viscosity, since they experience body temperature changes. These mechanisms are collectively termed as homeoviscous adaptations. At low temperatures, most animals substitute polyunsaturated fatty acids (PUFA) into membrane phosphatides. With respect to 'saturated fatty acids', PUFA has low-melting point and thus it opposes rigidifying effects of cold temperature.

Temperature variation and behaviour: Direct influence of water temperature on animal behaviour has already been established. Most of the fishes are ectotherms; hence they nevertheless thermoregulate behaviourally. This is well observed by their selection of appropriate water temperature and their ability to avoid the ones that are harmful. Thermoregulatory behaviour of fishes includes locomotion, upper and lower avoidance temperatures, preferred temperature, maximum and minimum critical thermal tolerance, upper and lower lethal temperature, change in feeding habit, nutrient utilization and growth, upper and lower limiting temperature for growth, migration,

sexual recognition, species-specific optimum temperature for reproduction, mate preferences and female-female interactions, etc. In most teleost species, body-tissue temperature is generally considered to equilibrate rapidly with any change in water temperature. This change in body tissue temperature leads to complicated changes in the rates of metabolic processes, enzymes and other components of the tissue. Another behavioural change observed is that the swimming speed is severely reduced in cold-water. This involves effects of low temperature on the biochemical and physiological processes involved in muscle contraction.

Thermal effects on reproduction: Endocrine system of vertebrates forms main link between reproductive organs and environmental regulations. Fluctuating regulators such as temperature mediate through central nervous system, triggering neurosecretions, which in turn regulate activities of pituitary gland. As one of many target organs, gonads are influenced accordingly leading to regulation of reproductive cycles by trophic hormones of pituitary.

Many experiments on fishes have involved observations of gonadal development to interpret effects of certain environmental regulators on the reproductive cycle. One of the most important factors concerned is temperature that initiates pituitary activity in fishes belonging to temperate and subtemperate regions. Temperature is found to be a dominant entity for *Fundulus heteroclitus, Phoxinus laevis* and *Apeltes quadracus*. In *Salvelinus fontinalis*, influence of environmental regulator varies with the stage of gonad maturation. The most responsive period to a regulator can in fact differ between males and females of the same species, and the gametogenic process may be independent of the environmental regulators at certain stage of maturity. In tropical waters, carps can mature in three months of age (90 to 140 mm F.L), in contrast to five years (355 to 430 mm F.L) required by carp to reach maturity in Northern Europe or North America.

Ovarian development: In the tropics, early maturation and spawning in carp, *Cyprinus carpio*, has been observed. It is well known that water temperature does have an effect on the carp reproduction as well as in aquaculture practices. The fishes mature early in the tropical countries as compared to temperate countries due to the comparatively higher water temperature. Temperature also has a prominent effect on the gonadal maturity of both male and female fishes. In most temperate-zone teleosts, timing of reproduction appears to be modulated by seasonal changes in day light and water temperature, which act to entrain endogenous reproductive rhythms. Higher temperature (32°C) augments gonado-somatic index (GSI) as well as reproductive hormones (testosterone and 17-β-estradiol) in advanced fingerling of *C. carpio*.

Hypoxia: A number of physiological and metabolic consequences pertaining to global warming exist and one such important occurrence includes hypoxia in water-bodies to restrict whole animal tolerance to thermal extremity. Evidence of scientific documents attest that large inputs of freshwater into sea by melting ice-caps, settle at the top of the ocean water, since that is not as dense as saline water and prevents oxygen exchange. The rainwater takes along with it nutrients from earth's soil into waters causing algal bloom and an increased demand for oxygen. Hypoxia does cause an imbalance in the reproductive performance of fishes, decreasing level of neurotransmitter-serotonin by inhibiting enzymes responsible for serotonin synthesis pathway. Oxygen limitation acts as a hormone disrupter in carps and interferes with their capacity to reproduce, subsequently posing threat to sustainability of fish population.

A group of chemicals (pesticides, methyl paraben etc.) known as 'endocrine disrupters' at low concentration disturb hormonal balance and change sex status of aquatic animals. Recently, it has been proved that hypoxia/ oxygen starvation in water also acts as an endocrine disrupter. It interferes with the functions of the endocrine glands, which secrete sex hormones like testosterone and estrogen. This interference causes a decline in the fertilization capabilities of fishes. Hypoxia also acts as a teratogen causing malformation during embryonic development and alters expression of gene controlling sex differentiation and development. This reproduction impairment may lead to population decline and extinction of species in the long-run.

Embryonic development: It is a complex process, which involves simultaneous occurrence of cellular differentiation and proliferation at different rates. Temperature directly influences developmental rate; hence it is observed that development is faster at increasing temperature within acceptable thermal limits. It has been found that 31°C is an ideal temperature for incubation of *L. rohita* eggs for faster embryonic development; better hatching percentage and least time duration (Fig.29.21). Teratogenicity in the embryo was observed at 36°C. Similarly, in the case of *M. rosenbergii*, a direct linear relationship between developmental rates of embryo with incubation temperature exists only up to 31°C.

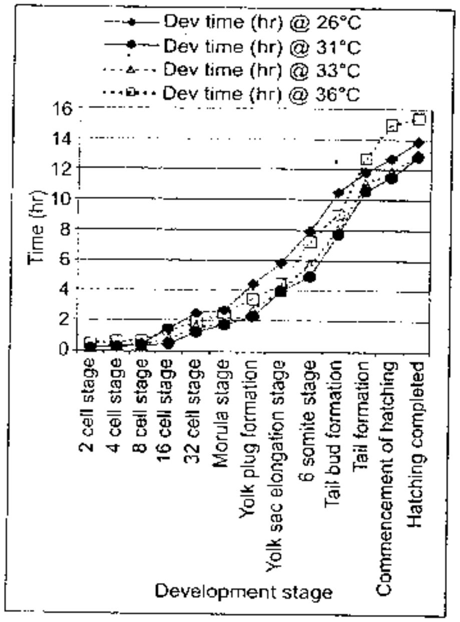


Fig. 29.21. Time (hours) required for embryonic development of *L. rohita* eggs at different incubation temperatures (26, 31, 33 and 36°C).

A temperature-sensitive phase in ovarian development may occur during transition from vitellogenic growth to oocyte maturation, and the degree of timing of sensitivity to environmental temperature is dependent on female endogenous reproductive rhythms. Moreover combined effect of temperature and pollutants in the water-bodies causes reduction in oxygen levels; consequently resulting in sex change leading to social hierarchy and ecological disaster.

Thermal effects on histo-architecture of cellular organelles: Environmental temperature is the most significant stressor, affecting homeostasis of cellular organelles.

Gills are among the most delicate structures of the teleost body. Their vulnerability is vital because of their proximity to external environment and direct exchange of ions across the membrane. Conduction of heat between environment and fish is mediated through gills;regarded as effective heat-exchangers. Gills are vital organs partially responsible for osmoregulation, acid-base balance and excretion of nitrogenous compounds in fishes and shellfishes. Hence, it is essential to know effects of thermal extremes (maximum and minimum) on the histo-architecture of vital organs in aquatic organisms. Therefore, gills are considered the most appropriate organ for indicating thermal pollution, and consequently all pollution studies of fish and shellfish have invariably indicated gill as an organ of paramount importance to assess magnitude of damage.

Higher water temperature affects ability of fishes to maintain osmotic balance by altering lipids of gill cells, resulting in leakage of cells and reducing efficiency of salt excretion and balance. Temperature has a key role in determining mitochondrial morphology and metabolic activity. Mitochondrial cristae are dense at 30°C in comparison to cells acclimated at 25°C, and tissue damage is pronounced at 35°C of acclimation.

Thermal effects on immunophysiology: In a healthy state, fishes defend against potential invaders with a complex system of innate and adaptive immune mechanisms. The strength of innate defense mechanisms against biotic and abiotic stressors is impressive, despite its limited pathogen recognition machinery. Stressors can affect fishes by directly killing them or by indirectly exacerbating diseased state by lowering their resistance thereby allowing invasion of environmental pathogens. Exposure to individual stressors may affect immune system in a variety of ways either by altering macrophage function or circulating levels of immune cells. Ambient water temperature plays a crucial role in the development of both specific and non-specific immunity in fishes. Temperature increases up to a certain limit favour fish growth by increasing metabolic activities. However, elevated water temperature (within the physiological range of fish) alters fish immune function.

Temperature and disease manifestation: There is a complex relationship that exists between pathogens, their hosts and disease occurrence. The prevalence or severity of a disease can be influenced by alterations made to the environment by human activities. Increase in temperature adversely affects health of fish and other aquatic life causing a variety of physiological responses in fishes, some of which apparently lower disease resistance. Microbes are generally constant and ubiquitous component of the environment. Weakening of patient caused by another factor allows these microbes to cause disease, as the infection proceeds unrestrained, at least for a while. Hence thermal stress poses as a predisposing factor for alteration in host-parasite relationship.

The stress-mediated diseases in warm and cold-water fish culture are vibriosis (*Vibrio anguilarum*), myxobacterial gill diseases (*Myxobacteria* sp.), bacterial hemorrhagic septicemia (*Aeromonas hydrophila*) and such protozoan parasites as costia (*Costia necatrix*), etc. Fish seed, when reared at optimum temperature throughout the year, grows faster than ambient temperatures. Parasitic infections are common when eggs are incubated at higher temperature. Similarily brood fishes are prone to disease infestation when maintained at elevated temperature).

Temperature and multiple stressors: A sub-lethal dose of pollutants and increasing temperature within tolerance range affect organ-specific biochemical pathways. Exposure to chlorine at higher temperature affects protein metabolism, gluconeogenic pathway and subsequently glycolytic pathway, leading to an energy-limited condition. This shows that persistent sub-lethal chlorine exposure elicits temperature-induced stress response in early fingerlings of *C. carpio*. Combination of temperature shock and sub-lethal levels of chlorine fails to elicit acquired thermotolerance in *L. rohita* spawn after a recovery of 48 hr, whereas exposure to the same temperature shock alone imparts development of cross protection to its full potential. This suggests that beneficial effects of temperature can prove deleterious when combined with other environmental pollutants. Even pesticide augments stress responses and immunosuppression with increasing temperature in *L. rohita* fingerlings.

Thermal tolerance limit of fishes assumes an ecological significance in assessing fish distribution, migration and their impact on ecosystems. *Cyprinus carpio* is more tolerant than *L. rohita*, which must be the reason for *C. carpio* showing cosmopolitan distribution and culture potential in comparison to *L. rohita*. Hence, thermal tolerance is species-specific. Temperature gradient in a closed or open environment influences species-specific distribution of fishes. The biochemical adaptations in fishes can be measured in terms of changes in activities of their metabolic enzymes, changes in the lipid composition of cellular membranes, quantitative changes in the total or specific protein (HSP) in different organs and the expression of different isozymes that permit continued functions at altered temperatures may be attributed to the restructuring of the cellular membrane and various organelles. Rates of oxygen consumption increase with rising acclimation temperatures within the tolerance limits and show variation among species.

The various methodologies that could be employed to brighten the future of fisheries include studying the basic effect of temperature on living system at all levels of biological organization from basic molecular processes to ecosystem. Such analysis will not only give insight into major patterns of evolutionary adaptation but will also indicate how changes in temperature due to global warming will cast an impact on the distribution and physiological performance of the organisms. The actual impact of global warming should be evaluated by studying the synergistic or antagonistic effect of temperature with multiple stressors of the ecosystem on aquatic animals. Development of different models based on climate changes representing different aquaculture systems is essential for decision making and culture practices.

30. Biotechnology in Fisheries and Aquaculture

Aquatic biotechnology has been broadly defined as any technique that uses living aquatic organisms or parts of these organisms to make or modify products, to improve plants or animals or to develop microorganisms for specific uses. Of late, it has assumed crucial importance in the context of the imperative need to upgrade the quality of cultivated species for enhancing aquaculture productivity and conservation and management of genetic diversity in natural fish stocks. Although China and India are perhaps the traditional cradles of art of aquaculture, fish culture remained largely empirical and artisanal in these countries till the recent past. Aquaculture research based on application of genetic and biotechnological principles in the eighties remained focussed on the temperate and subtropical species of fish. But modern biotechnological tools have been applied these days in India also to boost up the fish production through aquaculture as well as conservation of the vast aquatic resources of the country for sustainable utilization. Some areas of biotechnology those have direct bearing on fisheries especially in Indian context and the premier research organizations involved in the fish genetic research in India are mentioned below. Basic information on finfish and shellfish genome in comparison to that of human beings is given in Table 30.1.

Table 30.1. Fish genome – basic information in comparison to human genome

Category	Fish	Human
Diploid chromosomal number (2n)	24 (*Mugil curema*) 48 (*Mugil cephalus*) 32 (*Channa punctatus*) 40 (*Channa striatus*) 78 (*Channa gachua*) 48-50 (several carp, mullet and perch species) 100 (*Tor* spp., *Gonoproktopterus* spp., *Barbus barbus*) 104 (*C. capio, C. auratus*) 88 (*Penaeus monodon*) 20 (*Crassostrea madrasensis*)	46 (Others: 8-*Drosophila*; 24-rice; 42-bread wheat)
Total DNA	99% in nucleus and 1% in mitochondria	99% in nucleus and 1% in mitochondria
Genome size (C value) [The amount of DNA in the haploid genome. It is measured in picograms/cell in eukaryotes (1 pg = 10^{-12} g). In prokaryotes, genomes are smaller and are sometimes measured	0.4 pg (*Fugu rubripes* – a puffer fish; smallest fish genome) to 142 pg (*Polypterus aethiopias*) 1.04 pg (Perciformes - average) 1.6-7.0 pg (Carps) Genome size (C value) varies considerably in fish. Differences in C value due to differences in the amount	3.5 pg

(Continued)

(Table 30.1 concluded)

Category	Fish	Human
in Daltons. For viral genomes, mitochondria or chloroplasts, the size is generally given in kilo base pairs]	of non-coding repetitive DNA sequences; no correlation between the genome size (C-value) and genetics complexity.	
Total number of DNA base pairs (haploid) (using an estimate 1 pg = 0.98 x 10^6 kbp)	3.92 x 10^8 base pairs (*Fugu rubripes*) (~400 mbp= 0.4 x 10^9 bases) 1.4 x 10^{11} base pairs (*Polypterus aethiopias*) 2 x 10^9 base pairs (= 2,000 mbp) (*Penaeus monodon*)	~ 3.43 x 10^9 base pairs (3,400 mb)
Number of functional genes	~30,000 (*Fugu rubripes*, zebra fish and Medaka) 13,000 (*Drosophila melanogaster*)	~ 25,000
Mean size of cDNA (functional gene)	3.5 kbp	3.5 kbp
Size of mitochondrial DNA	16-18 kilo bases (kbp)	16.5 kbp
Sex chromosomes	XX-XY (more prevalent) ZZ-ZW (in many catfishes and Poecilids) Multiple sex chromosomes (*Chiondraco harmatus*- Antarctic fish) Polyfactorial/polygenic Indistinguishable (in several species)	XX-XY

1 kbp=1,000 (=10^3) base pairs; 1 mega base (mbp)=10^6 base pairs; 1,000 mbp = 1Gbp= 10^9 base pairs; 1 kbp= 1.02 × 10^{-6} pg = 618,000 daltons; 1 pg of double stranded DNA = 0.98 × 10^6 kbp or 6.02 × 10^{11} daltons

Molecular markers for documentation of genetic variation in natural and farmed fish populations

The primary objective of the genetic characterization is to assess the distribution and pattern of genetic variability, at intra- as well inter-specific levels in the populations, through use of identified genetic markers. The first priority for such research is the identification of appropriate genetic markers. Expertise has been developed for various classes of molecular markers, namely proteins (allozymes) and DNA markers. The approach has also led to a far greater understanding not only of fish stocks but also of the movements, nature of breeding populations and dispersal of a variety of marine invertebrates such as corals, starfish, sea urchins and molluscs; migratory fishes like tunas and billfishes; marine mammals like seals, whales and turtles. Such information will be of considerable importance in the design of aquatic sanctuaries/marine protected areas (MPA), and in projects involving restocking or reseeding species. Loss in genetic variation (inbreeding) at hatchery level or due to reduction in the size of a particular natural population can also determined using genetic markers.

Molecular markers are polymorphic DNA or protein sequences that can be used to identify a chromosomal region. These markers blended with the PCR technology, electrophoresis and sequencing have become the central tool in many areas of fisheries research. There are two types of markers based on their origin: (*i*) soluble proteins – the gene products (isozymes/allozymes) and (*ii*) DNA markers [nuclear DNA markers such as – microsatellites, Random amplified polymorphic DNA (RAPD), Random fragment length polymorphism (RFLP), and sequence data of Internal transcribed spacers (ITS); and mt-DNA sequence information]-- which are used for genetic stock identification and for resolving taxonomic ambiguity in fishes.

Isozymes are the analogous but separable forms of enzymes encoded by one or more loci. The isozyme products of 2 different alleles at the same locus are known as allozymes. Allozymes are heritable and can be detected electrophoretically by their difference in amino acid composition. This technique has been used for more than 30 years to analyze population-level genetic variation in many fish species. Primary linkage maps have also been prepared based on protein markers in several fishes. In allozyme method, tissue extracts are allowed to run on starch gels or polyacrylamide or cellulose acetate gels. Protein variants are detected on the basis of their net charge and size separated through electrophoresis using a variety of buffer systems varying in *p*H and ionic strength. The gel is stained to visualize the bands by enzyme-specific or general protein stains. The resultant bands are scored and interpreted as protein allele frequencies at Mendelian inherited loci. Usually for population genetic analysis (to score differences at intra-specific level), polymorphic loci are preferred, while for resolving taxonomic ambiguity or to score interspecific or intergeneric differences, less polymorphic/fixed markers are preferred. The data thus generated will be analyzed using comprehensive statistical packages for allozyme variability and identifying the stocks/resolving taxonomic ambiguity. A related technique, iso-electric focusing (IEF) is also popular. In this, the proteins are separated based on the differences in their 'iso-electric point', i.e. the *p*H at which their net surfaces charge is zero. The technique has been used in species identification as well as population level studies. Allozyme studies have achieved more widespread use than IEF in fisheries research.

Though protein electrophoresis has proved the wealth of genetic data related to fisheries, it has some drawbacks. The resolution of protein on electrophoresis is not always enough for detecting differences between populations or individuals. Secondly, due to the redundancy of the DNA code, all changes in DNA sequence in a gene may not result in a change in the overall charge of the corresponding protein. As a result, many genetic variants escape from being detected by protein electrophoresis. In addition, strict requirement of fresh, frozen tissue samples and that too in good amounts often poses problems. Temporal and spatial expression of the genes does not allow many loci to be analyzed at a time. Being the coding loci, it is debatable whether the protein polymorphisms are selectively neutral or adaptive. However, random use of these markers for population genetic analysis indicates that they are neutral markers and therefore are not under selective pressure in the evolution.

The DNA markers are based on polymorphism, detected at DNA level. Polymorphic DNA markers serve as landmarks or anchor loci for identification and analysis of new loci or genes in genome. Nuclear DNA markers include minisatellites, microsatellites, RAPD, Amplified fragment length polymorphism (AFLP), single nucleotide polymorphism (SNP) and ITS, while sequence data of genes in the 16-18 kilo base pair containing circular, maternally inherited mitochondrial DNA (mtDNA) offer the possibility of using this genome as a marker for population and evolutionary genetic studies. Polymorphism information content (PIC) is the most important characteristic of a marker and it is calculated from the allelic frequencies in the population. A PIC value greater than 0.5 is considered highly informative; that between 0.25 and 0.5 indicates a reasonably informative marker; whereas a value less than 0.25 indicates only slightly informative. There are two main categories of DNA markers: Type I and Type II markers. Type I markers are the coding gene loci conserved across the species. They are often monomorphic or slightly polymorphic, mostly with just 2 alleles. Type II markers are derived mostly from non-coding sequences and are highly polymorphic (PIC >0.6). Micro- and minisatellites are the examples of Type II markers.

The National Bureau of Fish Genetic Resources (NBFGR), Lucknow; Central Marine Fisheries Research Institute (CMFRI), Kochi; Central Institute of Freshwater Aquaculture (CIFA), Bhubaneshwar and the National Institute of Oceanography (NIO), Goa, are the leading institutions in India carrying out research in this field. In fishes, at intra-specific level the variation is assessed within and between the populations. Such studies provide precise information stock structure of the prioritized endangered and commercial fish species. This is vital for planning propagation-assisted rehabilitation of endangered fishes and for genetic improvement of cultivable species. Investigation, using allozymes and microsatellite DNA, on *Labeo rohita* and *Catla catla* clearly established existence of sub-structuring of natural population in Indus and Ganga River systems. The anadromous fish hilsa (*Tenualosa ilisha*) population in Ganga (above and below Farakka Barrage) and Brahmaputra river system did not exhibit significant genetic heterogeneity. Distinct stocks of natural populations of many endemic and commercially important freshwater fishes such as *Horabagrus brachysoma*, *Gonoproktopterus curmuca*, *Etroplus suratensis*, *Puntius denisonii*, *Chitala chitala*, *Labeo dyocheilus*, *L. calbasu*, *L. dero* and *Tor putitora* have been identified from different river systems, using polymorphic microsatellite DNA markers. Similarly, the stocks of endangered monotypic marine fish (*Lactarius lactarius*), sea-horse (*Hippocampus kuda* and *H. trimaculatus*) and Bombay duck (*Harpadon nehereus*) from east and west coasts of India were found to be distinct. This indicates that each stock of these species should be treated as the separate unit for conservation and management. But, genetic homogeneity has also been reported in stocks of finfishes, namely *Labeo dussumieri*, *Cirrhinus mrigala*, *Mugil cephalus*, *Priacanthus hamrur*; penaeid species pearl oyster (*Pinctada fucata*); and populations of Indian mackerel (*Rastrelliger kanagurta*) and oil sardine (*Sardinella longiceps*) from West coast of India. Molecular genetic markers have also been used to resolve taxonomic ambiguity. The separate identity of the two species of marine catfish (*Arius maculatus* and *A. subrostratus*) and mahseers (*Tor malabaricus* and *T. khudree*) was confirmed. Species-specific diagnostic markers (nuclear and mtDNA) were also developed to detect hybridization and genetic introgression in hatchery and wild populations of Indian major carps. Restriction endonuclease (RE) banding and fluorescent *in-situ* hybridization (FISH) techniques are the chromosome-banding methods that are used for identification of species/stocks and sex chromosomes in fishes.

DNA barcoding

DNA sequence analysis of a uniform target gene to enable species identification has been referred to as DNA barcoding, by analogy with the UPC barcodes used to identify manufactured goods. The Universal Product Code system developed by the industrial sector to brand retail items employs 10 options at each of 11 positions to create 100 billion alternates. Just like UPC barcodes, the DNA sequences within each species are unique. A run of 15 nucleotides, with four options at each position, creates the possibility of 1 billion codes, a hundred-fold excess over the estimated number of animal species. Of course, specific nucleotides are fixed at some positions by selection. However, this constraint can be overcome by focusing on protein-coding genes, where every third position is generally free to vary because of the degeneracy of the genetic code. As a result, by examining a stretch of 45 nucleotides in these genes, one has the prospect of close to 1 billion alternates. Since Linnaeus, biologists have used distinguishing features in taxonomic keys to apply binomial species names, such as *Homo sapiens*. Then, as a master key opens all the rooms in a building, the binomial species name accesses all knowledge about a species. From insects to birds, evidence now shows that short DNA sequences from a uniform locality on genomes can also be a distinguishing feature. As a Linnaean binomial is an abbreviated label for the morphology of a species, the short sequence is an abbreviated label for the genome of the species. The barcode of life thus provides an additional master key to knowledge about a species. Compiling a public library of sequences linked to named specimens, plus faster and low-priced sequencing, will make this new barcode key increasingly practical and useful. An appropriate target gene for DNA barcoding is conserved enough to be amplified with broad-range primers and divergent enough to allow species discrimination. A remarkably short DNA sequence should contain more than enough information to distinguish 10 or even 100 million species.

In practice, there is no need to constrain analysis to such short stretches of DNA, because sequence information is easily obtained for DNA fragments 10 times as large. This ability to inspect longer sequence arrays is desirable because the likelihood of detecting diagnostic differences between species rises with the number of nucleotide positions examined. Moreover, since the incidence of diagnostic characters depends on species age and rates of evolution, there is no simple prescription as to the number of nucleotides that must be examined to ensure species recognition. However, given a modest rate (2% per million years) of sequence change, one expects to discover 12 diagnostic differences in a 600 bp comparison between species with a million year history of reproductive isolation. It is certain that most species possess much longer histories of evolutionary independence than this. In fact, it is true that even the most closely allied species, those belonging to a single genus, usually have longer histories of reproductive isolation than this. As a result, it follows that the sequence analysis of a 600 bp segment of the genome will permit the reliable diagnosis of most species.

Why do we need a molecular taxonomy tool?: An increasingly accepted view is that traditional taxonomic practices are insufficient on their own to cope with the growing need for accurate and accessible taxonomic information. Although approximately 1.7 million species have been described and named under the Linnaean system, the total number of species on earth remains unknown and estimates vary widely, ranging from 10 million to more than 100 million (*http://www.barcodinglife.com//*). Even using conservative estimates, it is recognized that the number of species remaining to be discovered far outstrips the current resources of descriptive taxonomists and systematists.

The task of recognizing new species has certain urgency; the diversity of our biosphere so large that the methodical cataloguing of new species by traditional methods is being outpaced by losses from human impacts. In the face of such mounting losses to biodiversity, the need to catalogue and describe life is greater than ever, and there is a growing realization that it will be critical to seek technological assistance for a species' initial recognition and its subsequent identification. Additionally, barcoding clearly has enormous potential to relieve taxonomists of routine identifications, providing more time to focus on new taxonomic hypotheses and to concentrate on rare, poorly characterized, and new species. Embracing the molecular biology tool to identify species can turn taxonomists into a high tech community. The ability to quickly to put a name to an unknown specimen benefits not only conservationists, but is also a tremendous tool for a ecologists as well. The use of barcoding will readily allow the identification of small plant fragments or sterile material, eggs and larvae of marine species and forensic materials which previously would have been extraordinarily difficult or impossible to identify.

Ten reasons for identifying species by DNA barcodes: ***Works with fragments:*** Barcoding can identify a species from bits and pieces. When established, barcoding will quickly identify undesirable animal or plant material in processed foodstuffs and detect commercial products derived from regulated species. Barcoding will help reconstruct food cycles by identifying fragments in stomachs and assist plant science by identifying roots sampled from soil layers.

Works for all stages of life: Barcoding can identify a species in its many forms, from eggs and seed, through larvae and seedlings, to adults and flowers.

Unmasks look-alikes: Barcoding can distinguish among species that look alike, uncovering dangerous organisms masquerading as harmless ones and enabling a more accurate view of biodiversity.

Reduces ambiguity: Written as a sequence of four discrete nucleotides – CATG – along a uniform locality on genomes, a barcode of life provides a digital identifying

feature, supplementing the more analog gradations of words, shapes and colours. A library of digital barcodes will provide an unambiguous reference that will facilitate identifying species invading and retreating across the globe and through centuries.

Makes expertize go further: The bewildering diversity of about 2 million species already known confines even an expert to morphological identification of only a small part of the plant and animal kingdoms. Foreseeing millions more species to go, scientists can equip themselves with barcoding to speed identification of known organisms and facilitate rapid recognition of new species.

Democratizes access: A standardized library of barcodes will empower many more people to call by name the species around them. It will make possible identification of species whether abundant or rare, native or invasive, engendering appreciation of biodiversity locally and globally.

Opens the way for an electronic handheld field guide, the life barcoder: Barcoding links biological identification to advancing frontiers in DNA sequencing, miniaturization in electronics, and computerized information storage. Integrating those links will lead to portable desktop devices and ultimately to hand-held barcoders.

Sprouts new leaves on the tree of life: Since Darwin, biologists seeking a natural system of classification have drawn genealogical trees to represent evolutionary history. Barcoding the similarities and differences among the nearly 2 million species already named will provide a wealth of genetic detail, helping to draw the tree of life on Earth. Barcoding newly discovered species will help show where they belong among known species, sprouting new leaves on the tree of life.

Demonstrates value of collections: Compiling the library of barcodes begins with the multimillions of specimens in museums, herbaria, zoos and gardens, and other biological repositories. The spotlight that barcoding shines on these institutions and their collections will strengthen their ongoing efforts to preserve Earth's biodiversity.

Speeds writing the encyclopedia of life: Compiling a library of barcodes linked to vouchered specimens and their binomial names will enhance public access to biological knowledge, helping to create an on-line encyclopedia of life on Earth, with a web-page for every species of plant and animal.

Mitochondrial DNA

Although there has never been a broadly based effort to implement a micro-genomic identification system for animals, enough work has been done to indicate key design elements. It is clear that the mitochondrial (mt) genome of animals represents a better target for analysis than the nuclear genome because of its lack of introns, its limited exposure to recombination and its haploid mode of inheritance. As well, there are robust primers that enable the recovery of specific segments of the mitochondrial genome from a broad range of animals. The mitochondrial genome includes just 13 protein-coding genes that might serve as the core of a DNA-based identification system. The length of each gene varies little across the animal kingdom, but there is more than a 10-fold difference among genes. This length variation acts to exclude most genes from consideration, as a minimum length of 900 bp is required to make best use of existing technologies. Current sequencers may only routinely recover 700 bp, but internal PCR primers must be used to generate the DNA for sequencing to avoid complications which would arise from shifts in gene order if external primers were used. In fact, only four mitochondrial genes have a minimum length in excess of this 900 bp threshold – cytochrome c oxidase subunit I (COI), cytochrome b (cyt B), NADH dehydrogenase subunit 4 (ND4) and NADH dehydrogenase subunit 5 (ND5).

Differential rates of evolution of genes in mitochondrial genome

Aside from varying in size, the protein-coding genes in the mitochondrial (mt) genome vary in their rates of molecular evolution. Among the four genes that meet the 900 bp size threshold, COI and Cyt b evolve much more slowly than ND4 or ND5. This rate variation has one important practical implication–it is impossible to design universal primers for ND4 and ND5, effectively ruling out their use as the basis for a comprehensive DNA-identification system. By contrast, because the other two genes evolve more slowly, it has been possible to design primers for them with broad taxonomic utility. Aside from determining the ease with which the DNA needed for sequencing can be recovered, rates of molecular evolution influence the information content of the resultant sequences. Obviously a gene that showed no sequence changes across life would be useless in a taxonomic context. Conversely a gene with extremely high rates of evolution might distinguish closely allied taxa, but could fail to discriminate more distantly related forms because of secondary convergences. In the case of protein-coding genes, information content can be obtained by inspection of both nucleotide sequences and amino acid arrays in the gene products. Because amino acid composition is so conserved, analyses at this level are most useful for identifying higher taxonomic categories (phyla, classes, orders), while studies at the nucleotide level are useful in making species-level identifications.

Cytochrome c oxidase subunit I (COI)

Selection of an appropriate gene is a critical strategic and practical decision, with significant consequences for the overall success of barcoding. A number of genes may be likely to meet one or more goals (discrimination and identification of species, discovery of new and cryptic species, scoring genetic divergence at intra-specific level, reconstruction of evolutionary relationships among species and higher taxa). Past phylogenetic work has often focused on mitochondrial genes encoding ribosomal (12S, 16S) DNA, but their utility in taxonomic analyses is constrained by the prevalence of insertions and deletions (indels) that complicate sequence alignments. The 13 protein-coding genes in the animal mt genome are a better target because indels are rare since most lead to a shift in the reading frame. There is no compelling *a priori* reason to focus on generating partial sequences of a specific gene, but the mitochondrial cytochrome c oxidase subunit I gene (COI) does have two important advantages. The universal primers for this gene are very robust, enabling recovery of its 5' end from the representatives of most, if not all, animal phyla. As well, COI likely possesses a greater range in phylogenetic signal than any other mitochondrial gene. In common

with other protein-coding genes, its third position nucleotides show a high incidence of base substitutions. However, changes in its amino acid sequence occur more slowly than those in any other mitochondrial gene. The selection of COI as a target gene for DNA barcoding is supported by published and ongoing work, which demonstrates that barcoding via COI, will meet the goals for a wide diversity of animal taxa.

Proof of principle for DNA barcoding has been provided by comparison of COI partial sequences among closely related species and across diverse phyla in the animal kingdom. An important outcome of DNA barcoding will be to identify the groups in which alternate targets are needed and to define what those targets should be. Cnidarians (sea anemones, corals, and some jellyfish) for example, have little mitochondrial sequence diversity, perhaps due to a supplemental mitochondrial DNA repair system, and a nuclear gene target will likely be needed. Recently diverged species and species that have arisen through hybridization may not be resolved by COI sequencing. DNA barcoding has the potential to be a practical method for identification of the estimated 10 million species of eukaryotic life on earth. As a uniform method for species identification, DNA barcoding will have broad scientific applications. It will be of great utility in conservation biology, including biodiversity surveys. It could also be applied where traditional methods are unrevealing, for instance identification of eggs and immature forms, and analysis of stomach contents or excreta to determine food webs. In addition to enabling species identification, DNA barcoding will aid phylogenetic analysis and help reveal the evolutionary history of life on earth.

Protocol

This protocol addresses DNA barcoding of animal species. Alternate targets or protocols will likely be needed for DNA barcoding of other eukaryotes. Plants have too little mitochondrial sequence diversity; probably due to hybridization and introgression [Potential targets include matK, a chloroplast gene, and ITS (internal transcribed spacer), a nuclear gene]. The mitochondrial DNA of fungi contains introns, which can complicate DNA amplification (this could be circumvented by applying RT-PCR). For protists and planktonic organisms, the utility of COI sequencing has not been explored in depth. The essential points are (*a*) specimen preservation in 95% ethanol (not formalin) to facilitate DNA isolation, (*b*) amplification and sequencing of uniform target gene(s), and (*c*) data basing of DNA sequences linked to specimens including ancillary data.

Specimen preservation: Tissue samples include fin-clips of fishes, appendages of crustaceans, and small pieces of muscle tissue, leaf etc. To allow DNA isolation, 95% ethanol should be used–from formalin-preserved specimens, it is difficult to extract DNA. The ethanol should generally be poured off and replaced with new 95% ethanol within a few days of collection to optimize DNA preservation. Though DNA has been successfully extracted from formalin-preserved tissue, including relatively ancient samples, its quantity and quality appear to be very poor and alternative techniques may be important in examining previously archived specimens.

Specimen labeling: The usefulness of DNA barcoding depends on linking the sequence to a specimen and its associated data (collector, taxonomic confirmation, date, collection site and its geo-reference coordinates, etc.).

DNA isolation: In addition to standard methods, there are commercial kits that have high success in recovering DNA.

Gene target(s): The target sequence is the 5' segment of COI.

Primers for COI: In order to obtain barcode sequences from such a broad spectrum of animal taxa, researchers require an arsenal of primer sets. Some primers will amplify COI across a wide range of organisms, while others may be designed to target-specific taxonomic groups. A brief summary of the primers used to barcode animal life is given below. Broad range primers are available that will amplify an approximately 700bp segment from diverse invertebrates (including Annelida, Arthropoda, Coelenterata, Echinodermata, Echiura, Mollusca, Nemertina, Platyhelminthes, Pogonophora, Sipuncula, and Tardigrada). The widely-used primer set LCO1490 and HCO2198 amplify a 658 bp fragment of the COI gene in a wide range of invertebrate taxa (*Source:* Folmer *et al.* 1994). These primers will also amplify COI-5' from some chordates.

Primer name	*Sequence (5' – 3')*
LCO1490	5' - GGTCAACAAATCATAAAGATATTGG - 3'
HCO2198	5' - TAAACTTCAGGGTGACCAAAAAATCA - 3'

Additional primers, with broad application for chordates and GC-rich species, are also available, e.g. Palumbi, S.R., A. Martin, S. Romano, W.V. Mc millan, L. Stice. G. Gra-bowski. 1991. *The Simple Fool's Guide to PCR*. University of Hawai, Honolulu, USA. www.palumbi.stanford.edu/publications.html

Primer name	*Sequence (5' - 3')*
COIa	H 5' - AGTATAAGCGTCTGGGTAGTC - 3'
COIf	L 5' - CCTGCAGGAGGAGGAGAYCC - 3'

Ward and his co-workers in 2005 barcoded 207 Australian marine finfish for a 655 bp region of the cox I using the following set of primers and concluded cox I sequencing or barcoding can be used to identify fish species.

Primer name	*Sequence (5' - 3')*
FishF1	TCAACCAACCACAAAGACATTGGCAC
FishF2	TCGACTAATCATAAAGATATCGGCAC
FishR1	TAGACTTCTGGGTGGCCAAAGAATCA
FishR2	ACTTCAGGGTGACCGAAGAATCAGAA

PCR steps for COI amplification

Steps	Temperature	Time	Cycles
Initial step denaturation	95°C	2 min	1
Denaturation	94°C	30 sec	35 cycles
Annealing	54° C	30 sec	
Extension	72°C	1 min	
Elongated extension	72°C	10 min	1
Soak	4°C	-	-

Databasing results: Barcode sequences are generally submitted to a Barcode of Life database (BOLD) under the auspices of the Hebert laboratory that integrates sequence data with taxonomic and specimen information or National Centre for Biotechnology Information (NCBI) GenBank. The BOLD is an informatics workbench aiding the acquisition, storage, analysis and publication of DNA barcode records. By assembling molecular, morphological and distributional data, it bridges a traditional bioinformatics chasm. BOLD is freely available to any researcher with interest in DNA barcoding. By providing specialized services, it aids the assembly of records that meet the standards needed to gain BARCODE designation in the global sequence databases. Because of its web-based delivery and flexible data security model, it is also well positioned to support projects that involve broad research alliances.

Barcoding elective: Other genes– If COI is not sufficient for species discrimination, other rapidly evolving gene(s) may need to be analyzed as potential barcoding targets. Possible supplementary sequences include the complete COI gene, other mitochondrial genes (e.g. 16S rRNA, cytochrome b), and/or ITS2 (internal transcribed spacer2), which is a nuclear gene located between rRNA genes. Recombination Activation Gene (RAG2) is another potential nuclear region in vertebrates that is considered for phylogenetic studies. Small subunit nuclear ribosomal RNA (SSU rRNA) also referred to as 18S rRNA, is a slowly evolving gene useful for deeper phylogenetic analysis. In addition to the analysis of COI-5', it will be ideal to determine SSU rRNA sequences from specimens. SSU rRNA is the basis for the Tree of Life and other comprehensive examinations of evolution of life. The following primers will amplify SSU rRNA (approximately 1,800 bp) from most eukaryotes:

Primer name	*Sequence (5' - 3')*
18SrRNA forward	AACCTGGTTGATCCTGCCAGT
18SrRNA reverse	TGATCCTTCTGCAGGTTCACCTAC

DNA barcoding of Indian fishes

India is blessed with huge inland water resources with 29,000 km of rivers, 0.3 million ha of estuaries, 0.9 million ha of backwaters and lagoons, 3.15 million ha of reservoirs, 0.2 million ha of floodplain wetlands and 0.72 million ha of upland lakes. It has been estimated that about 0.8 million tonnes of inland fish is contributed by different types of inland open-water systems. The 14 major rivers, 44 medium rivers and innumerable small rivers of the country provide one of the richest fish faunistic resources (765 species of finfishes) of the world. The mega-biodiversity hotspots of the country – the Western Ghats, northeastern region along with the Himalayas – also harbour rich, highly diverse and endemic aquatic resources. The bounty of marine biodiversity, which is exploited from 2.02 million km^2 of the Exclusive economic zone (EEZ) constitutes one of the largest heritage resources of India. There are nearly 1,570 species of finfishes known from our seas. However, taxonomic ambiguity exists in several groups of Indian finfishes and many are insufficiently identified. Indian seas also have many unexplored habitats like the mesopelegic zone and deep waters that may harbour many species of finfishes yet to be documented. Although much of the finfish research at present depends on species diagnoses based on morphological characters and meristic counts, taxonomic expertize has been collapsing in recent years. The limitations inherent in morphology-based identification system and dwindling pool of taxonomists signal the need for new approach to document diversity of Indian marine finfishes DNA-based approaches to taxon identification which exploit diversity among DNA sequences, can be used to identity marine fishes and resolve taxonomic ambiguity including discovery of new or cryptic species.

The National Bureau of Fish Genetic Resources (NBFGR) has been identified as the lead centre in South Asia to generate DNA barcodes of marine and freshwater finfish species of the region in collaboration with the global International Consortium for the Barcode of Life (cBOL) — FishBOL (www.fishbol.org). The NBFGR has initiated a mega programme on DNA Barcoding of Indian marine and freshwater finfishes and shellfishes and approximately 3,500 samples have been collected covering 660 marine and freshwater fish species from the mainland and island ecosystems. The DNA barcodes (DNA sequence profile of 655 bp fragment of cytochrome c oxidase I) of more than 450 species has been completed in India. This could be of great utility in sustainable exploitation, management and conservation of Indian marine and freshwater fish species.

Forensic identification of meat of endangered aquatic species

Whale shark (*Rhincodon typus*) is the largest shark in the ocean, reaching lengths of 20 m and a weight of 20 tonnes. This icon species in spite of its mammoth size is quite harmless and is often referred to as charismatic mega fauna and a gentle giant. Whale sharks are regarded as highly migratory and have a broad distribution in tropical and warm temperate seas, usually between latitudes 30°N and 35°S in both deep and shallow coastal waters and the lagoons of coral atolls and reefs. With very few defences, it has become susceptible to exploitation and has a global conservation status of 'vulnerable to extinction' as listed by World Conservation Union in the Red list of threatened species. To enable trade in whale shark products to be adequately regulated, *Rhincodon typus* was nominated in Appendix II of Convention on International Trade in Endangered Species (CITES) in April 2000. To conserve the species in Indian waters, it is enlisted as one of the protected species and its fishing prohibited under Schedule I of the Indian Wildlife Protection Act, 1972, according to the Order No.1-2/2001 WL1 dated 28.05.2001, Government of India. Although current Indian legislation prohibits the practice of fishing of whale shark, illegal capture using hook and lines and trawlers with necessary modifications for *at-sea processing* is still reported from India. Flesh suspected as that of whale shark was seized from fishermen by the Forest Range Officer (Government of Kerala), Kannur, Kerala. A case was filed and the Judicial First Class Magistrate, Thalassery, Kannur, Kerala approached the NBFGR Kochi Unit (Case No. R.P.330/08, dated 29 Sept. 2008) to analyze the meat sample for confirmation of the species using DNA markers. Based on DNA sequencing of COI (660bp), 16SrRNA (595bp), cyt B (601bp) and RAG2 (981bp) genes and comparing with the sequences earlier generated by the NBFGR (NCBI Genbank accession numbers FJ375724, FJ375725, FJ375726; DNA sample from a stranded whale shark along North Kerala on 30 October 2006), the seized meat sample was confirmed as that of endangered whale shark and the result was communicated to the Court. This was the first case in India in which scientific evidence was sought to identify the meat of a fish enlisted in the Wildlife Protection Act, 1972 and the DNA markers reiterated their ability to reliably identify product/meat sample of a species, thus helping in curtailing illegal trade of the endangered organisms.

In another case, identity of cooked fish (pomfret - *Pampus chinensis*) from a restaurant in Mumbai was also confirmed at the NBFGR through DNA barcodinig.

Genotoxic studies

An increasing number or genotoxic chemicals that damage DNA, like pesticides, heavy metals etc. are being released into the aquatic environment, threatening not only our rich aquatic biodiversity but also human health. The tests like micronuclei test, chromosome aberration test, sister chromatid exchange (SCE) assay and Comet Assay are employed to study genotoxic effect in fishes. The latter one is a very sensitive technique for quantification of DNA damage due to genotoxicants. Such studies are important to determine safe level of genotoxicants in water-bodies and in planning remedial measure for conservation of aquatic biodiversity.

Sperm cryopreservation protocols and gene-banking programmes

Cryopreservation is the *ex-situ* storage of fish spermatozoa, eggs and embryos without loss of viability in ultra low temperatures such as –196°C in liquid nitrogen. It is of considerable value in aquaculture and conservation. The basic technique of cryopreservation involves (*i*) collection of fish gametes from quality brood fish, (*ii*) testing the milt (sperm suspension) samples for spermatozoa motility and numbers (minimum 70% motile sperms), (*iii*) diluting milt samples in specific diluent (extender) in which a cryoprotectant (like dimethyl sulfoxide-DMSO; propylene glycol; ethylene glycol; glycerol; methanol) is added and filling French straws (0.5 ml) with diluted milt and sealing, (*iv*) equilibrating the samples at 10°C, (*v*) exposing the straws for few minutes over liquid nitrogen vapour in a thermocol chamber; and (*vi*) freezing rapidly and storing in liquid nitrogen. After thawing, the milt can be activated for use in fertilizing the eggs. The sperm-cryopreservation protocol has been effective in production of seeds of a number of finfishes in late season when natural milt is not available. In artificial propagation, sperm-cryopreservation protocol can be an asset where milt-related problems exist. This can be due to inadequate milt production or asynchronization in maturity of two sexes or broodstock. The technique can also help in maintaining high genetic variability; in introduction of improved varieties of cultured species; and reduce the problems pertaining to maintenance of broodstock in *in-situ* condition and their transportation. This *ex-situ* conservation tool has very strong application to support *in-situ* conservation strategies like propagation-assisted rehabilitation of endangered fish species. Sperm-cryopreservation protocol for storing finfish sperms for very long periods has been reported for more than 200 species across the world. Fertilization rates by cryopreserved milt and normal (fresh) milt were not found to differ statistically. In India, the NBFGR is the primary organization in carrying out fish-sperm cryopreservation for long-term gene banking. The fish-sperm cryopreservation needs development of species-specific protocols. Such protocols are developed through experimental standardization of various parameters, after the captive breeding protocol is developed. This becomes a bottleneck due to low domestication of most of the species, especially from marine environment and protracted breeding season. Nevertheless, in all such cases, time available in a year for conducting experiment is small and determined by breeding cycle of the species. In view of the constraint, it is essential that candidate species for sperm cryopreservation be prioritized. Species-specific sperm cryopreservation protocols have been developed for 26 species namely, *Catla catla, Labeo rohita, Cirrhinus mrigala, Labeo dyocheilus, Oncorhynchus mykiss, Salmo trutta fario, Cyprinus carpio, Tenualosa ilisha, Tor khudree, Tor putitora, Heteropneustes fossilis, Clarias batrachus, Chitala chitala, Labeo dussumieri, L. dero, L. calbasu, Barbodes carnaticus, Horabagrus brachysoma, Horabagrus nigricollaris, Pangasius pangasius, Etroplus suratensis, Schizothorax richardsonii, Garra surendranathanii, Ompok malabaricus, Puntius sarana subnasutus* and *Hypselobarbus curmuca*. The continuous improvement in protocols has provided hatching success ranging from 65 to 100% of the control value for different species. The strategy and technique used for fish-sperm cryopreservation is simple and does not need any electrically operated equipment. This provides easy adaptability and customization in difficult remote locations and successful application has been proved in species of various taxonomic groups. However, fish gamete cryopreservation research still faces an important challenge in the form of long-term storage of finfish and shellfish eggs and embryos (except the minute fertilized eggs of abalones and pearl oysters). Due to large size, large amount of yolk and tough chorion preventing penetration of cryoprotectants, egg and embryo cryopreservation of teleosts and crustacea have not met with success so far. Attempts to cryopreserve embryos of *C. carpio, L. rohita* and nauplii of *P. monodon* did not succeed below –40°C. Crustacean spermatozoan cryopreservation is also not very successful. In the attempts to cryobank male gametes of *Penaeus semisulcatus* and *P. indicus*, reduction in motility of frozen-thawed spermatozoa was reported, leading to low fertilization percentages.

In conjunction with sperm-cryopreservation method, androgenesis (method of reproduction where only the paternal genome is contributed to the offspring) may prove useful in conservation programme in fishes, especially when egg and embryo cryopreservation is difficult and females of a species are not available. Development of other tools for retrieval of genome like cloning also needs active consideration. Thrust is also being given to tissue banking, as it is a fast mode to store the material for long term. This can be used to retrieve the genetic information and for genetic manipulation in future with technological advancement. In view of the fact that milt accessions can be made only for prioritized and selected fish species, as it requires species-specific protocols, building tissue repository has been given priority.

Genetic engineering and transgenic fish

An organism that has a foreign or modified gene integrated in its genome is called transgenic or genetically modified organism (GMO) or living modified organism (LMO). Genetic engineering process offers scope to identify and construct the genes that have desirable traits, clone the genes in suitable vectors and transferring the gene construct into the fertilized egg before cleavage. Selective breeding is the first step towards genetically improving the beneficial traits in fishes. But the process is generally slow and also not predictable in every case. Genetic engineering is really the only commercially feasible way of bridging large gaps between an organism's natural characteristics and what the aquaculturist wants. For example, much of the Himalayan region is too cold for aquaculture of Indian major carps. Artificial selection might eventually produce a cold-tolerant strain but only after many generations of careful breeding, which would be beyond the scope of an aquaculture business. Modifying the Indian major carps to produce the antifreeze protein from winter flounder could extend their range instantly. Also, through this process, transfer of new traits to the genome of another individual, which are not present in that (fish) is possible. The main reasons for genetic manipulation of species used in aquaculture are directly connected to improved output:input ratios. These are: (*a*) to enhance growth and or efficiency of food conversion, (*b*) to increase tolerance to/of environmental variables such as temperature and salinity, (*c*) to produce new colour variants of ornamental species, (*d*) to enhance commercially significant flesh characteristics, (*e*) to control reproductive activity and or sexual phenotype, (*f*) to increase resistance of species to pathogens or parasites, (*g*) to modify behaviour, e.g. aggression, (*h*) to control fertility and or viability, and (*i*) to produce novel medicinal substances with fewer animal welfare problems when mammals are used. While all these targets are desirable in aquaculture, work has been focussed primarily upon points *a*, *e* and *h*.

Production of GMOs is a multistage process, which can be summarized as follows: (*i*) identification of genes of interest–it can be chromosomal DNA or DNA copy of a mRNA or cDNA; (*ii*) isolation of these specific genes; (*iii*) amplifying the gene to produce many copies; (*iv*) associating the gene with an appropriate promoter and poly-A sequence and insertion into plasmids; (*v*) multiplying the plasmid in bacteria and recovering the cloned construct for injection; (*vi*) transference of the construct into the recipient tissue, usually fertilized eggs; (*vii*) integration of gene into recipient genome; (*viii*) expression of gene in recipient genome; and (*ix*) inheritance of gene through further generations.

Choice of target genes: Fishes are known to slow down somatic growth after sexual maturation and invest about 20% of their body energy for production of gametes and breeding activities. Hence growth hormone (GH) gene is an ideal choice for gene transfer to cause significant increase in growth rate in prioritized species. The GH has been used in many finfish species and as the gene sequence is highly conserved; the product is readily utilized across species boundaries. Cold-water temperatures are often a major problem in aquaculture in temperate climates when an unusually cold winter can severely damage both production and brood fish stocks of fish. Some marine teleosts like winter flounder (*Pleuronectes americanus, Pseudopleuronectes amenis*) have high levels of serum anti-freeze proteins (AFP) or glycoproteins (AFGP), which reduce the freezing temperature by preventing ice-crystal growth. The AFP gene has been successfully introduced into the genome of Atlantic salmon that integrated into the germ line and passed on to F_3 offspring where it was expressed in the liver. Genetic manipulation has also been undertaken to increase the resistance of fish to pathogens. This is currently being addressed by the use of DNA vaccines (encoding part of the pathogen genome) and antimicrobial agents such as lysozyme. An example is the injection of Atlantic salmon with a DNA sequence encoding infectious hematopoeitic necrovirus (IHNV) glycoprotein under the control of cytomegalovirus promoter (pCMV). Eight weeks after the challenge with the virus, significant degree of resistance had been achieved. The fish were still resistant and were shown to have generated antibodies three months later. Similar studies were undertaken for other fish diseases, e.g. hemorrhagic septicemia virus (VHS) and work of this kind appears to have great potential values for fish farms. Similar attempts can be made with the help of lysozyme genes and RNA interference (RNAi)/antisense RNA in penaeids and finfishes to fight against various viral diseases. RNAi describes the phenomenon by which double-stranded RNAs (dsRNAs) elicit degradation of a target mRNA containing homologous sequence. Thus, the phenomenon is essentially a new incarnation of the well-established antisense principle–the inactivating agent interacts with the target through the complementary interaction and results in inability of the latter to produce corresponding protein. The hit rate and efficacy of RNAi is much better than those of other anti-sense techniques. This has opened up tremendous opportunities to develop a novel generation of oligonucleotide-based drugs and in the best case scenario, development of the new drug would require simply knowledge of the sequence of the gene causing the corresponding disease.

Problems of poor-water quality affect most developed countries in the world, the contaminants stemming largely from industrial waste and sewage. The effects of these pollutants have already been noticed, particularly in fish, which often show reproductive dysfunction, with males displaying feminization. The biochemical responses of organisms to organic and metal compounds in the water can be measured and used as a biomarker for the level of pollution. Most commonly, cytochrome P4501A is used, as it is responsive to a number of organic chemicals including aromatic hydrocarbons and dioxins. The induction of this gene by these contaminants is measured by change in protein expression or mRNA levels. Alternatively, metallothioneins are utilized, which are induced specifically by metals. The green flourescent protein (GFP) gene is a novel one isolated from a jellyfish (*Aequorea victoria*) and is most commonly used as a reporter gene. Light is produced when calcium binds to this protein. The GFP with 238 amino acids absorbs blue light at 395 nm and emits green light at 509 nm and this fluorescence is stable. The gene encoding GFP is fused to a number of promoters, which will respond to water pollutants. The promoters from inducible genes include (*i*) those encoding heat-shock proteins or metallothioneins which are induced by general stress, heavy metals or chemical toxins, (*ii*) those that contain estrogen response

elements being induced by estrogens or xeno-estrogens, and (*iii*) tumour-marker genes, which are induced by carcinogens. The availability of the GFP as a reporter gene has enabled the use of transgenic organisms as qualitative biosensors for water contamination, providing rapid and visible results while eliminating the need for enzymatic or specific protein assays.

The increasing world demand for ornamental fish has opened the market for new varieties with novel shapes or colours, which can be supplied through the use of transgenics. Clearly, this approach extends the possibilities considerably and is more satisfactory than the injection of dyes or selective breeding, which are the two methods currently used to widen the availability of phenotypes. The GFP is a valuable tool in the colour transgenics. It has many advantages: (*i*) it does not require substrate over it to be irradiated by blue light, so not limited by availability of the substrate; (*ii*) the gene expression can be monitored in living cells/animals; (*iii*) the substance is not toxic to living cells or animals and; (*iv*) since this protein is persistent even in formaldehyde-fixed tissues, it can be examined later also. The viability of genes encoding additional flourescent proteins, such as red (RFP), blue (BFP), yellow/golden (YFP) and cyan (CFP), has enabled the production of green, red, blue, yellow or cyan fish in an almost endless variety of combinations. Production of novel coloured fish requires fusion of flourescent colour-encoding genes to appropriate tissue-specific promoters and the expression has been directed to the skin or skeletal muscles. In addition, two-colour fishes were produced, showing green colouration in the skin and red in the skeletal muscles. Such an approach, combined with selective breeding between fish carrying these different transgenics, could produce a wide array of multi-coloured fish in future generations. Fluorescent protein genes can be introduced into commonly available and less expensive fish species for value-addition.

Isolation and amplification of genes of interest: Usually the gene of interest will already be available as an element of a library of short sections of the total genome of the donor strain or species and the gene is multiplied to the level of several million copies needed for the generation of the construct using the technique of the polymerase chain reaction (PCR).

Cloning the gene of interest: When many copies of the target gene have been generated, the gene is placed in a construct. Once the gene of interest has been ligated enzymatically into the construct, this whole complex is ligated into bacterial plasmid, which act as production vectors and enable the gene to be replicated many times within the bacterial cells. The bacteria are then plated out. It is possible to know from reporter genes whether the bacterial cells have taken up the vector. This usually involves some colour change in the colonies containing inserted DNA. The many times amplified DNA construct is then enzymatically cut out of the plasmids (after these have been removed from the bacterial cells) and it is ready to be used for insertion into eggs of the host species. Selection of suitable vectors is a very important step in cloning because, isolation of many replicate copies of DNA sequence is mostly dependent on the kind of vectors that are used to carry the DNA inserts into cells where it can be replicated. The common cloning vehicles are the plasmids, which are extra chromosomal elements.

The plasmid vectors that are suitable for cloning need to have certain qualities like small size to enhance their stability, relaxed control which means should be able to replicate independent of the host chromosome to provide more replicates of inserted DNA sequence and non-conjugative transmission. The incorporation of DNA fragments into plasmid vectors allows foreign DNA to be replicated in cloned cells for later isolation and identification. The successful use of plasmids as vectors in recombinant DNA research has led to the use of temperate phages as vectors since many phages had already demonstrated their ability to act as transducting agents between donor and recipient bacteria.

The gene construct: A gene construct is a piece of DNA, which functions as the vehicle or vector carrying the target gene into the recipient organism (Fig. 30.1). It has a promoter region, which controls the activity of the target gene, a region where the target DNA is inserted, usually some type of reporter gene to enable one to ascertain whether target has combined successfully with the construct and a termination sequence with polyadenylation signal. The sources of these several DNA sequences may be different species although promoter and target genes would ideally be derived from the same species.

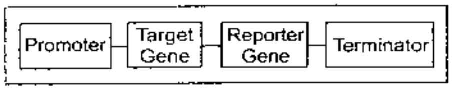


Fig. 30.1. DNA sequence of typical gene construct for making transgenic organisms.

The number of different constructs is greater than the number of target genes used in aquaculture and a substantial research effort has been made in this area. From the early 1990s research focussed on developing all fish constructs in preference to using mammalian promoters. The use of all-fish constructs has great effects on expression of transgenes; an all salmon gene construct that accelerated the growth of transgenic salmonids by over 11-fold. In tilapia, using carp beta actin instead of rat beta actin promoter led to a ten-fold increase in production of hormone in transgenic animals. In India, all-fish gene constructs have been developed for rohu and singhi, catla and calbasu.

Strategies for the gene transfer: The strategy for the gene transfer and subsequent handling differs in different groups of animals. Fish offers some advantages in conducting transgenic experiments in comparison to mammalian models and farm animals. A single fish can produce hundreds of eggs, which can be fertilized easily *in vitro* and the embryonic development takes place outside. The mammals, on the other hand, need super-ovulation; embryo splitting to increase the number of embryos and require a host for implantation of the embryo and its development. After gene transfer, the fish embryos do not require the complex manipulation as needed in the case of the animals.

There are several methods of transferring the gene into the animal embryo, which include: (*i*) microinjection – with the help of a micro manipulator, (*ii*) electroporation, (*iii*) use of retroviral vector, (*iv*) lipofection (uptake of nucleic acid or nucleic acid protein complex encapsulated with synthetic lipid vesicles – liposomes – that is permitted into the de-chorionated cells following the fusion of the vesicles with the plasma membrane), (*v*) use of embryonic stem cells (ESC), and (*vi*) ballistic methods using microprojectiles (e.g. in generating transgenic *Artemia* and also in seaweed species).

Transgenic fish have largely been produced through microinjection into fertilized eggs or early embryos. However, this method is not very efficient for mass production of transgenic fish, as every fish zygote has to be injected individually at a particular stage (one-celled stage) of the embryo development, which in many cases lasts for only few minutes. This method may be useful for experimental production. The use of embryonic stem cells as a method for inducing transgenesis has been advocated. These cells (blastomeres) are undifferentiated and remain totipotent or pluripotent, so they can be manipulated *in vitro* and subsequently re-introduced into early embryos where they can contribute to the germ line of the host. In this way, genes could be stably introduced or deleted. The use of disarmed retroviruses as vectors can be risky, as some of these viruses are reported to induce cancer formation. It is therefore suggested that the use of retroviruses for gene transfer and even the use of viral promoters should be avoided for producing transgenic food fishes. Sperm cells have been also tried as vectors, not only in fish but also in other animals. This method is easy particularly for mass transfer of exogenous genes. However, it may not be an alternative for successful gene transfer in fishes to produce transgenic fish, but liposome-mediated gene introduction to the sperm cells that in turn can be used for fertilization appears to be promising. In electroporation, the cell membrane is subjected to high voltage electric field using an instrument, gene pulser, resulting in its temporary breakdown and the formation of pores that are large enough to allow macromolecules to enter or leave the cells. This method was used to produce transgenic fish by introducing the genes in sperm cells or fertilized eggs.

The microinjection method is suitable for relatively small numbers of organisms being manipulated, whereas electroporation, sperm/liposome mediation and bombardment methods are more suitable for mass treatments. However, the problem of mosaic expression of the transgenes is common, and this gives rise to varying proportions of transgenic genotypes in the progeny.

Integration sites: The injected DNA (*i*) may be degraded by the nucleases enzyme present in the host cell before integration or (*ii*) persists but not integrated to the host genome or (*iii*) integrated after partial degradation or (*iv*) integrated intact before cleavage or after several rounds of cell-division. If its get integrated to the host genome, it may occur before the first cleavage division or after one or several rounds of cell division. Even it gets integrated it may or may not expressed itself and may or may not perpetuate through germ line transmission.

Expression and inheritance of gene: The uptake and integration of a transgene does not guarantee that the gene will express itself in the new genetic environment. Clearly, in commercial aquaculture only those transgenics expressing the target gene at a sufficiently high level will be of interest. A fish that expresses the target gene at an acceptable level may not be able to transmit the gene to the progeny. This is because many transgenics are mosaic individuals and unless the gonads are included in the tissues possessing the transgene, the transgenic animals will not breed true. Therefore, appropriate breeding tests must be carried out to study the inheritance pattern.

Benefits arising from the use of GMOs: Evidence of real benefit in terms of economically significant characters comes mainly from work on growth hormone (GH). The overall conclusion from the studies of several workers is that fish GH transgenics enjoy growth rates markedly superior compared to those in non-transgenics. The economic gains to be made from use of such GMOs are obvious and transgenics must therefore be considered as a route for providing superior strains along with selective breeding. There are also a number of other target phenotypes for which transgenics offer considerable potential. These include salinity tolerance, cold tolerance [incorporating anti freeze peptides/glycoproteins (AFP/AFGP) genes], sterility, feeding behaviour, predator avoidance, nutritional physiology and energetics, control of sexual phenotype, disease resistance to specific pathogens and behavioural modifications. Another use closely related to aquaculture, is that of using fish as a bio-reactor/bio-factory system for valuable gene products, which can be extracted similar to that achieved with mammals. Such products might include drugs, vitamins etc., and work is underway to produce factor VII (one of the human blood clotting factors), in tilapia.

Risk factors of GMOs: Potentially useful transgenic fish strains have been developed in different parts of the world, but their widespread use in aquaculture currently has not yet occurred because of social issues and the concerns associated with the potential effects that GM fish might have on natural ecosystems. The most important areas of risks, which need to be considered in the use of transgenics are human health and biodiversity.

Human health: About 98% of the dietary DNA from fish including GMOs is degraded by digestive enzymes relatively quickly but use of viruses (disarmed or otherwise) as vectors, might increase the risk factor significantly, as these organisms are adapted to integrating into host genomes and some represent risk factors for cancer induction. Experiments proved capacity of retroviral vectors in inducing leukemia in transgenic mice and there were reports of leukemia induction in a child undergoing gene therapy using a retrovirus. Another risk from the production of the transgene (autotransgenics) will lie in the use of novel proteins or other molecules produced by the transgenic organisms. Either in the native form or following modifications in the human body, such molecules could be inimical to human health (e.g. through allergies). It would seem sensible to avoid the use of such substances except where strictly necessary and under rigorous control. Other potential risks may lie in incorporation of transgenic DNA into the genomes of resident gut microflora or a change in the pathogen spectrum of the transgenic fish leading to it hosting a new pathogen, which happens to be also a human pathogen.

Biodiversity and ecological concerns: The primary ecological concerns regarding utilization of transgenic fish are the loss of genetic diversity and loss of biodiversity and reduction in species richness. Aquaculture has a problem in that the unintended escapes of genetically distinct farmed fish are unpredictable and often large in numbers and it is clear that escapes of these magnitudes pose considerable problems to the

ecosystem. It is difficult to predict the long-term impact of these modified fishes (if established in nature) on the aquatic diversity. If the GMOs are fertile and if escaped, they can breed with the wild stocks of the same species, leading to the spread of transgene in natural populations, despite low juvenile viability.

Physical containment: The first line of defence against the escape of genetic modified fish and their viable gametes into natural aquatic habitats is to establish physical structure (cage or similar structure with facilities for screening in-flow and out-flow water ways) and proper management procedures. But, this is not 100% foolproof as containments are subjected to disruption caused by human errors, lack of maintenance and poaching. The facilities required for transgenic marine fishes, which are to be cultured in cages in open sea/sea pens, pose a greater problem for containment.

Biological containment: Ecological threat from a sterile-farmed fish would be less. The techniques to produce sterile transgenics include triploidisation, antisense transgenics, hormonally induced sterility, production of androgenetic and gynogenetic progenies and sterile hybrids.

Disadvantages of transgenics: The disadvantages due to transgenics are discussed here.

Dependence on external agencies for seed fish: If special broodstocks are required to produce fry of a widely grown transgenic fish, a dependency is created which can lead into problems.

Intellectual property right issues: Since genes may now be patented and therefore, enjoy commercial value, disputes connected with the intellectual property rights (IPR) of gene constructs and transgenic strains can arise because of the increasingly protective attitudes taken by owners of IPR.

Transgenic fish research in India: The research on fish transgenics in India is relatively recent. The first Indian transgenic zebra fish was generated in 1991 using borrowed constructs from foreign sources. To construct transformation vectors for the indigenous fishes, growth-hormone genes of rohu and catfish, *Heteropneustes fossilis* were isolated, cloned, sequenced and confirmed in prokaryotic and eukaryotic systems. A vector was made with grass carp ß-actin promoter. The sperm-electroporation technique was used for gene transfer that resulted in 25% hatchling survival and 37% presumptive transgenics. Southern analysis confirmed genomic integration in 15% of the tested individuals. Transgenic rohu and singhi grew faster than the respective controls and converted the food at a significantly higher efficiency. The Central Institute of Fisheries Education (CIFE), Mumbai; Central Institute of Freshwater Aquaculture (CIFA), Bhubaneshwar; Centre for Cellular and Molecular Biology (CCMB), Hyderabad; and Madurai Kamaraj University, Madurai, are the organizations involved in fish transgenic research in India. Auto-transgenic *Catla catla*, *Labeo rohita* and *Clarias batrachus* were produced using the growth-hormone gene constructs (both cDNA and genomic DNA) fully developed from these species, thus giving a swadeshi touch to the entire experiment. Also, steps have been initiated to isolate and characterize anoxia and salt-tolerance genes from *Clarias batrachus*, mangrove plants like *Avicennia* sp., sea grasses and marine microbes.

Ex-vivo or *in-vitro* culture of fish cells and their applications

Cell culture has become one of the major tools used in the life sciences today. Tissue culture is a general term for removal of cells, tissues, or organs from an animal or plant and their subsequent placement into an artificial environment conducive to growth. This environment usually consists of a suitable glass or plastic culture vessel containing a liquid or semi-solid medium that supplies the nutrients essential for survival and growth. The culture of whole organs or intact organ fragments with the intent of studying their continued function or development is called organ culture. When the cells are removed from the organ fragments prior to or during cultivation, thus disrupting their normal relationships with neighbouring cells, it is called cell culture.

Although animal cell culture was first successfully undertaken by Ross Harrison in 1907, it was not until the late 1940's to early 1950's that several developments occurred that made cell culture widely available as a tool for scientists. First, there was the development of antibiotics that made it easier to avoid many of the contamination problems that plagued earlier cell culture attempts. Second was the development of the techniques, such as the use of trypsin to remove cells from culture vessels, necessary to obtain continuously growing cell lines (such as HeLa cells). Third, using these cell lines, scientists were able to develop standardized, chemically defined culture media that made it far easier to grow cells. These three areas combined to allow many more scientists to use cell, tissue and organ culture in their research. During the sixties and seventies, commercialization of this technology had further impact on cell culture that continues to this day. The overall result of these and other continuing technological developments has been a widespread increase in the number of laboratories and industries using cell culture today.

Fish cell culture

There are several ways with which monolayer cultures of fish cells may be initiated. This is a quick method that employs multiple explants of tissues of either freshwater or marine fish as the simplest way to produce monolayer cultures. However, the resulting primary monolayers develop more slowly and are less homogeneous than primary monolayer cultures prepared from trypsinization procedures.

The physiology and the blood plasma constituents of teleost fishes are very much like those of terrestrial vertebrates; therefore the methodology for culture of cells and tissues is also similar. Fish cell culture differs somewhat from mammalian cell culture in having a greater temperature range for incubation. Cells from cold-water species such as salmonids can grow at temperatures as low as 4°C their optimum is near 20°C but prolonged incubation at much above 25°C is apt to be somewhat inhibitory or even lethal. Cells from warm-water species can be grown at higher temperature; goldfish cells, for example, can be incubated at 37°C but incubation at 15°C or lower markedly inhibits mitosis. Also, osmolality must be adjusted upward for fishes of marine origin.

All things considered, ovaries (oogonia and primary oocytes undergoing mitotic division) are the best source of tissue for introductory exercises in fish-cell and tissue culture. If sufficient ovarian tissue cannot be obtained from a specimen, any organs like kidneys, spleen, swim bladder, heart and liver may also be tried after following precautions are suggested to prevent or minimize gross contamination. Conventional physiological solutions and culture media intended for mammalian or avian work are wholly appropriate without modification for use with freshwater teleost cells and tissues. The same solutions and media may be used with cells and tissues of marine teleost, but most workers have found it advantageous to adjust osmolality to isotonicity of marine teleost.

Most of the established cell lines available are derived from cold or cool water fish of European origin. Very few cell lines have been developed from the tissue of tropical fish species. Over the last two decades, intense interest has been generated in India, to develop fish-cell lines. The Indian scenario is changing fast towards developing cell lines and short-term cultures from species of aquaculture and commercial importance. Successful primary cultures from a variety of tissues including fin, heart, kidney ovary tissue etc of Indian major carp, stinging catfish (*Heteropneustes fossilis*), African catfish (*Clarias gariepinus*) and rohu (*Labeo rohita*) have also been developed. In India cell lines from the different tissue like fin, kidney, spleen, ovary embryo, eye muscle, brain, etc of various fish, namely mrigal (*Cirrhinus mrigala*), Asian seabass (*Lates calcarifer*), Golden mahseer (*Tor putitora*), catla (*Catla catla*), grouper (*Epinephalus merra*), three spot damsel (*Dascyllus trimaculatus*), cobia (*Rachycentron canadum*), rabbit fish (*Siganus canaliculatus*), rohu and *Puntius denisonii*, have mainly been reported from fishery research institutes and colleges, namely National Bureau of Fish Genetic Resources (NBFGR), Lucknow and Kochi, Central Marine Fisheries Research Institute, Kochi, C. Abdul Hakeem College, Vellore, Tamil Nadu; Fisheries College and Research Institute, Tuticorin etc.

Development of cell culture: *Primary culture:* When cells are surgically removed from an organism and placed into a suitable culture environment, they will attach, divide and grow. This is called a primary culture. There are two basic methods for doing this. First, for explant cultures, small pieces of tissue are attached to a glass or treated plastic culture vessel and bathed in culture medium. After a few days, individual cells will move from the tissue explant out onto the culture vessel surface or substrate where they will begin to divide and grow. The second, more widely used method speeds up this process by adding digesting (proteolytic) enzymes, such as trypsin or collagenase, to the tissue fragments to dissolve the cement holding the cells together. This creates a suspension of single cells that are then placed into culture vessels containing culture medium and allowed to grow and divide. This method is called enzymatic dissociation.

Subculturing: When the cells in the primary culture vessel have grown and filled up all of the available culture substrate (called monolayer), they must be subcultured to give them room for continued growth. This is usually done by removing them as gently as possible from the substrate with enzymes. These are similar to the enzymes used in obtaining the primary culture and are used to break the protein bonds attaching the cells to the substrate. Some cell lines can be harvested by gently scraping the cells off the bottom of the culture vessel. Once released, the cell suspension can then be subdivided and placed into new culture vessels. Once a surplus of cells is available, they can be treated with suitable cryoprotective agents, such as dimethylsulfoxide (DMSO) or glycerol, carefully frozen and then stored at cryogenic temperatures (below –130°C) until they are needed.

Cell culture systems: Once in culture, cells exhibit a wide range of behaviours, characteristics and shapes. Some of the more common ones are described here. Two basic culture systems are used for growing cells. These are based primarily upon the ability of the cells to either grow attached to a glass or treated plastic substrate (monolayer culture systems) or floating free in the culture medium (suspension culture systems).

Monolayer cultures: Monolayer cultures are usually grown in tissue culture-treated dishes, T-flasks, roller bottles, or multiple well plates, the choice being based on the number of cells needed, the nature of the culture environment, cost and personal preference.

Suspension cultures: Suspension cultures are usually grown either:

1. In magnetically rotated spinner flasks or shaken Erlenmeyer flasks where the cells are kept actively suspended in the medium;
2. In stationary culture vessels such as T-flasks and bottles where, although the cells are not kept agitated, they are unable to attach firmly to the substrate.

Many cell lines, especially those derived from normal tissues, are considered to be anchorage-dependent, that is, they can only grow when attached to a suitable substrate. Some cell lines that are no longer considered normal (frequently designated as transformed cells) are frequently able to grow either attached to a substrate or floating free in suspension; they are anchorage-independent. In addition, some normal cells, such as those found in the blood, do not normally attach to substrates and always grow in suspension.

Hybridomas: Using cell-fusion techniques, it is also possible to obtain hybrid cells by fusing cells from two different parents. These may exhibit characteristics of either parent or both parents. These hybrid cells (called hybridomas) are formed by fusing two different but related cells. The first is a spleen-derived lymphocyte that is capable of producing the desired antibody. The second is a rapidly dividing myeloma cell (a type of cancer cell) that has the machinery for making antibodies but is not programmed to produce any antibody. The resulting hybridomas can produce large quantities of the desired antibody. These antibodies, called monoclonal antibodies owing to their purity, have many important clinical, diagnostic, and industrial applications with a yearly value of well over a billion dollars.

Embryonic stem cells: Embryonic stem (ES) cells are undifferentiated cell lines derived from early developing embryos of animals, retaining their full developmental potential and their capability to differentiate. When introduced into host embryo, ES cells can participate in normal development and contribute to several tissues of the host including cells of the germ line. These characteristics make embryonic stem cell ideal experimental systems for *in-vitro* studies of embryo cell development and differentiation and a vector for the efficient transfer of foreign DNA into the germ line of an organism.

Embryonic stem cells are stem cells derived from the inner cell mass of an early-stage embryo known as a blastocyst. Embryos reach the blastocyst stage 4-5 days post-fertilization, at which time they consist of 50-150 cells. The ES cells are pluripotent. This means they are able to differentiate into all derivatives of the three primary germ layers: ectoderm, endoderm and mesoderm. These include each of the more than 220 cell types in the adult body. Pluripotency distinguishes ES cells from multipotent progenitor cells found in the adult; these only form a limited number of cell types. When given no stimuli for differentiation (i.e. when grown *in vitro*), ES cells maintain pluripotency through multiple cell-divisions. The presence of pluripotent adult stem cells remains a subject of scientific debate.

When introduced into host embryos, ES cells can participate in normal development and contribute to several host tissues including cells of the germline. Transgenic fish with enhanced resistance to pathogens will be beneficial to aquaculture. The attempts to develop stem cell lines from fish are successful. Embryonic fish stem lines have been established from zebra fish, medaka, sea bream (*Sparus aurata*) and sea perch (*Lateolabrax japonicus*). An important aspect of piscine stem cells is that they are sometimes useful for xenotransplantation in mammals. The islet tissue called Brockmann bodies in certain teleost fish like *Tilapia* has been shown to restore normoglycemia upon transplantation into diabetic nude mice. Similarly, reversal of diabetes has been achieved after transplantation of piscine islets to nude mice. These reports indicate potential of piscine cells for clinical applications.

Types of cells: Cultured cells are usually described based on their morphology (shape and appearance) or their functional characteristics. There are five basic morphologies, namely *Epithelial-like:* cells that are attached to a substrate and appear flattened and polygonal in shape; *Lymphoblast-like:* cells that do not attach normally to a substrate but remain in suspension with a spherical shape; *Fibroblast-like:* cells that are attached to a substrate and appear elongated and bipolar, frequently forming swirls in heavy cultures; *Endothelial cells:* these are very flat, have a central nucleus, are about 1-2 μm thick and some 10-20 μm in diameter; *Other types:* macrophages, neuronal cells, melanocytes, etc. It is important to remember that the culture conditions play an important role in determining shape and that many cell cultures are capable of exhibiting multiple morphologies.

Finite and continuous cells: The characteristics of cultured cells result from both their origin (liver, heart, etc.) and how well they adapt to the culture conditions. Some cell lines will eventually stop dividing and show signs of aging. These lines are called finite. Other lines are or become immortal; these can continue to divide indefinitely and are called continuous cell lines. When a normal finite cell line becomes immortal, it has undergone a fundamental irreversible change or transformation. This can occur spontaneously or be brought about intentionally using drugs, radiation or viruses. Transformed cells are usually easier and faster growing, may often have extra or abnormal chromosomes and frequently can be grown in suspension. Cells that have the normal number of chromosomes are called diploid cells; those that have other than the normal number are aneuploid.

Growth requirements of cell culture *in vitro:* Usually, it means an environment that, at the very least, allows cells to increase in number by undergoing cell division (mitosis). To provide this environment, it is important to provide the cells with the appropriate temperature, a good substrate for attachment and the proper culture medium. Temperature is usually set at the same point as the body temperature of the host from which the cells were obtained. Anchorage-dependent cells also require a good substrate for attachment and growth. Glass and specially treated plastics (to make the normally hydrophobic plastic surface hydrophilic or wettable) are the most commonly used substrates. However, attachment factors, such as collagen, gelatin, fibronectin and laminin, can be used as substrate coatings to improve growth and function of normal cells derived from brain, blood vessels, kidney, liver, skin, etc.

The culture medium besides meeting the basic nutritional requirement of the cells, also have any necessary growth factors, regulate the *p*H and osmolality, and provide essential gases (O_2 and CO_2). Usually a CO_2-bicarbonate based buffer or an organic buffer, such as HEPES, is used to help keep the medium *p*H in a range of 7.0-7.4 depending on the type of cell being cultured. When using a CO_2-bicarbonate buffer, it is necessary to regulate the amount of CO_2 dissolved in the medium. This is usually done using an incubator with CO_2 controls set to provide an atmosphere with between 2% and 10% CO_2 (for Earle's salts-based buffers). However, some media use a CO_2-bicarbonate buffer (for Hanks' salts-based buffers) that requires no additional CO_2, but it must be used in a sealed vessel (not dishes or plates).

Finally, the osmolality (osmotic pressure) of the culture medium is important since it helps regulate the flow of substances in and out of the cell. It is controlled by the addition or subtraction of salt in the culture medium. Evaporation of culture media from open-culture vessels (dishes, etc.) will rapidly increase the osmolality resulting in stressed, damaged or dead cells. For open (not sealed)-culture systems, incubators with high humidity levels to reduce evaporation are essential.

Problems in cell culture: *Effects of over-subculturing:* The ability of continuous cell lines to exist almost indefinitely opens the possibility that cell lines are used beyond safe passage numbers. Long-term subculturing places selective pressure on cell-line traits leading to, for example, faster growing cells that eventually over-run slower proliferators in the population. In addition, cell lines maintained in culture over a long period of time may experience mutations that alter the original functional characteristics of the cell lines identified at earlier passage levels. A straightforward method for determining the passage number of adherent cell lines does not exist.

Cross-contamination and misidentification: The problem of intra-species and inter-species cross-contamination among cell lines has been recognized for half a century. One of the earliest reports suggesting a high frequency of HeLa cell cross-contamination was made by Stanley Gartler in 1966 at a cell culture conference. For those scientists working on cell lines derived themselves or received from a colleague, basic authentication tests such as STR profiling, isoenzyme analysis, and contamination

tests are readily available and should be routinely used. Transferring cell lines to colleagues should be avoided, or when it does occur, accompanied with comprehensive documentation verifying the integrity of the material or tests need to be repeated.

Microbial contamination of cell cultures: Cell-line contaminations are one of the main problems in cell banks of the world and in monetary term, it attributes to loss of millions of dollars annually. The causative agents are different chemicals, invertebrates, bacteria, fungi, parasites, viral species and even other cell lines. The bacterial and fungal (including molds and yeast) contamination of cell lines (except mycoplasmas) can be readily detected, as these organisms cause increased turbidity, shift in media *p*H (change in medium colour) and cell destruction. Some reports have indicated that putative pathogens such as nanobacteria also will not be detected by this method. Although utilization of various antibiotics to prevent cell-line contamination is advantageous, usual usage of antibiotics in culture leads to development of resistant organisms with slow growing property, which is very difficult to detect by direct visual observation. In the case of mycoplasmas their cell-line contamination is always undetected for many passages. They can proliferate within the cell, tolerate antibiotics and their growth always does not have any obvious microbial evidence like turbidity and *p*H changes or cytopathic effect. Mycoplasma contamination also affects function, growth, metabolism, morphology, attachment, membranes, chromosomal aberrations and so many other properties of cell lines. Their contamination also spreads quickly to the other cell lines.

Sources of microbial culture contamination: The sources of microbial culture contamination are different and may be grouped under four subjects, namely (*i*) contaminated tissue or cells which are used as the primary starting material; (*ii*) labwares or apparatus, including storage bottles and pipettes, and improper shipment of disposable sterile apparatus; (*iii*) culture media and their components, which are used for cell growth; and (*iv*) airborne modes which can occur anytime the culture vessel is opened or contact is made with culture fluid through a defective culture vessel, stopper or poor technique

International resource centres for cell-culture materials: There are legions of continuous cell lines now available for *in-vitro* research, diagnosis and development of novel products. Catalogues of these are readily accessible from national and international resource centres and examples are given in Table 30.2. These centres should be the first point of call when obtaining cell lines to ensure the best chance of obtaining authentic and contaminant-free cultures.

Applications of cell culture: Cell culture has become one of the major tools used in cell and molecular biology. Some of the important areas where cell culture is currently playing a major role are briefly described here:

Toxicity testing: Cultured cells are widely used alone or in conjunction with animal tests to study the effects of new drugs, cosmetics and chemicals on survival and growth in a wide variety of cell types. Especially important are liver- and kidney-derived cell cultures.

Cancer research: Since both normal cells and cancer cells can be grown in culture,

Table 30.2 International Resource Centres for cell-culture materials

Centre	Location	Number of cell lines
American Type Culture Collection (ATCC)	PO Box 154G, Mannasas, Virginia 20108, USA *http://www.atcc.org/*	Consisting of over 3,400 cell lines from more than 80 different species (19 fish cell lines)
Coriell Institute for Medical Research	401 Haddon Avenue, Cambden, NJ 08103,USA *http://locus.umdnj.edu/nigms/*	4
Deutsche Sammlung von Mikro-organismen und Zelikulturen (DSMZ)	Mascheroder Weg 1b,D38124, Braunschweig, Germany *http://www.dsmz.de*	629
European Collection of Cell Cultures (ECACC)	CAMR, Salisbury, SP40JG, *UKhttp://www.camr.org.uk*	More than 1,100 different cell lines originating from over 45 different species (23 fish cell line)
Interlab Cell Line Collection (ICLC)	CBA, L.go R Benzi 10,16132 Genova, Italy *http://www.biotech.ist.unige.it/interlab/intro.html*	254
National Centre for Cell Science (NCCS)	Pune University Campus, Ganeshkhind, Pune, Maharashtra, India	At present, the total number of culture strains is 1,127, of which about 300 are available for distribution

the basic differences between them can be closely studied. In addition, it is possible, by the use of chemicals, viruses and radiation, to convert normal-cultured cells to cancer-causing cells. Thus, the mechanisms that cause the change can be studied. Cultured cancer cells also serve as a test system to determine suitable drugs and methods for selectively destroying types of cancer.

Virology: One of the earliest and major uses of cell culture is the replication of viruses in cell cultures (in place of animals) for use in vaccine production. Cell cultures are also widely used in the clinical detection and isolation of viruses, as well as basic research into how they grow and infect organisms.

Cell-based manufacturing: Cultured cells can be used to produce many important products, like viral vaccines, genetically engineered protein of medicinal and commercial value and replacement of tissues and organs.

Genetic counseling: Amniocentesis, a diagnostic technique that enables doctors to remove and culture fetal cells from pregnant women, has given doctors an important tool for the early diagnosis of fetal disorders. These cells can then be examined for abnormalities in their chromosomes and genes using karyotyping, chromosome painting and other molecular techniques.

Genetic engineering: The ability to transfect or reprogram cultured cells with new genetic material (DNA and genes) has provided a major tool for molecular biologists wishing to study the cellular effects of the expression of these genes (new proteins).

Gene therapy: The ability to genetically engineer cells has also led to their use for gene therapy. Cells can be removed from a patient lacking a functional gene and the missing or damaged gene can then be replaced. The cells can be grown for a while in culture and then replaced into the patient. An alternative approach is to place the missing gene into a viral vector and then infect the patient with the virus in the hope that the missing gene will then be expressed in the patient's cells.

Future of biotechnology research with respect to aquaculture development and fisheries management is promising notwithstanding some technical problems, which stand in the way of its commercialization. Fundamental research using molecular markers will lead to a better understanding of the genetic structures of the wild populations. This can lead to improved management of specific fisheries and selective breeding programmes, but will also lead to a greater ability to catalogue and better manage fish diversity. The development of effective protocols for cryopreservation of both male and female gametes will further enhance the development of aquaculture industry by making it more sustainable. It also facilitates the process of dissemination of genetically improved varieties of fish and the exchange of germplasm in an easy and effective manner in addition to its leading role in conservation of endangered species. Establishment of fish genebanks has already been initiated in our country in some fishery institutes such as the NBFGR. The transgenic research needs further improvement. Continuous efforts are necessary to isolate and identify novel useful genes; and suitable promoters of fish origin to regulate the expression of the transgene in a tissue-specific manner at an appropriate level. DNA microarray technique in particular is likely to become a powerful tool for this purpose. Gene transfer techniques should be improved and methods to be developed to improve and control the number of copies of a gene to be incorporated and its location of integration in the chromosomes. The physiological, nutritional and environmental factors that will maximize the performance of transgenic individuals should be determined. Biosafety issues of transgenic fishes also need very careful attention.

Annual world landings of aquatic resources have increased more than four-fold during the last fifty years. The larger share of this production came from the capture fishery sector, which has been over-exploited, leading to decline of fish diversity. On the other hand, aquaculture provides greater scope for increasing fish production. Thus, biotechnology as a growing discipline will have an important role to play in the future for increasing aquaculture productivity and would help in reducing the fishing pressure on natural resources. Transgenic fish produced through gene transfer techniques have demonstrated superior performance. In Indian context, sex-reversed or sterile transgenic aquatic organisms with secure physical containment would be a boon and appear to be an assuring approach in enhancing the fish production and food security of the nation.

31. Nutrition of Finfishes and Shellfishes

In India, composite carp culture is the main activity of freshwater aquaculture in which three indigenous carps and equal number of compatible exotic carps are used as candidate species. These are catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrihinus mrigala*), silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*). They are normally grown in non-drainable earthen ponds in varying cultural practices, ranging from extensive, semi-intesive to more or less intensive levels. Scientific interventions have been intensified to standardize cultural practices of several diversified freshwater fish species like *Clarias batrachus, Anabas testudineus, Heteropneustes fossilis, Sperata seenghala, S. aor, Wallago attu* and *Channa* spp. and prawns (*Macrobrachium rosenbergii* and *M. malcolmsonii*). In addition to the above three exotic carps, snow trouts (*Schizothoraichthus niger, S. esocinus, S. micropogon, S. planifrons* and *Schizothorax richardsonii*), golden (*Tor putitora*) and Deccan mahseers (*T. khudree*) and exotic varieties of brown (*Salmo trutta fario*) and rainbow trouts (*Oncorhynchus mykiss*) are important commercial coldwater fish species that are cultured in the Himalayan region and in the Western Ghats.

Marine shrimp farming is a major activity in brackishwater sector of this country, mostly using *Penaeus monodon, Fenneropenaeus indicus, F. merguiensis, F. penicillatus, Penaeus semisulcatus* and *Metapenaeus* spp. Besides, several other finfishes such as *Mugil cephalus, Liza parsia, L. macrolepis, L. tade, Chanos chanos, Lates calcarifer* and *Etroplus suratensis* have high potentials for brackishwater farming.

Feeding of artificial diet balanced in all nutrients has assumed foremost importance in aquaculture industry. Artificial feeding is an essential practice in an aquaculture operation accounting for over 60% in total input cost.

Consequent to researches done in India and abroad, a strong database has been developed about nutrition of the great majority of these cultivable fish and shellfish species, and several feed formulations have been successfully undertaken. With optimum pond management as well as feeding of formulated balanced diets, it has been possible to increase aquaculture production as high as 15-17 tonnes/ha/year for carps (8-10 months) and 4-6 tonnes/ha/crop (4-5 months) in semi-intensive prawn and shrimp farming in India.

Nutritional requirements

There are about 40 essential dietary nutrients required by fish, prawn and terrestrial animals.

Protein and amino acids: Proteins are the major organic material in fish tissue constituting about 65-75% of the total on dry weight basis and are needed for replacement of worn-out tissues as also several proteinaceous products like intestinal

epithelial cells, enzymes and hormones which are required for proper body function. Proteins are also required for synthesis of new tissues and hence growth. Since protein acts both as structural component as well as an energy source, its requirement for fish is 2-3 times higher than that of mammals.

The dietary protein requirement has a linear relationship with the specific growth rate, and the requirement data are obtained from dose-response curves in fish. The optimal protein requirement in fish is affected by nutritional qualities of dietary protein and the level of energy from non-protein sources. Besides, size, water temperature, dissolved oxygen, *p*H, and feeding rate are also some of the factors that affect protein requirement of fish (Table 31.1)

Table 31.1. Dietary protein requirements of some finfish and shellfish species for their optimum growth

Species	Protein source	Protein requirement (% dry weight of food)
Cyprinus carpio (spawn, fry and fingerlings)	Casein	45
C. carpio fingerlings	Fish meal	54
C. carpio juvenile	Casein	31-38
Labeo rohita fry	Casein	45
L. rohita fry	Fish meal and groundnut oilcake	40
L. rohita fingerlings	Casein and groundnut oilcake	30
Catla catla fry	Casein gelatin	47
C. catla fingerlings	Casein gelatin	40
Cirrhinus mrigala fry and fingerlings	Fish meal and groundnut oilcake	40
Tor khudree fingerlings		40
T. putitora		45
Puntius gonionotus	Casein-gelatin	32
Ctenopharyngodon idella	Leaf protein concentrate	36
C. idella fry	Casein	42
Macrobrachium rosenbergii	Fish meal and groundnut oilcake, soybean meal	35
Channa striatus fry	Fish meal and groundnut oilcake	55
Anabas testidineus	Carcass waste and groundnut oilcake	40
Clarias batrachus fingerlings	Casein gelatin	40
Chanos chanos fry and juvenile	Casein	39-40
Tilapia aures fingerlings	Fish/soybean meal	36
Oreochromis niloticus fry	Casein/albumin	34-56
Oreochromis mossambicus fingerlings	Fish meal	35
Lates calcarifer juvenile	Fish meal	42
L. calcarifer grow-out		40-45
Salmo trutta fario fry		48-53
Oncorhynchus sp.		35-55
Penaeus mondon		40
Fenneropenaeus (P.) indicus		43
P. merguiensis		42-52

The gross protein requirement decreases with increase in age and size of fish. However, generally 25-30% protein is optimum for practical diets for herbivorous and omnivorous fishes for pond feedings.

The information on protein requirement is of limited value unless amino acids requirement of fish is understood. The fish does not have true protein requirement but need a well-balanced mixture of essential and non-essential amino acids. Gross protein requirement of a fish is the requirement of essential amino acids and some non-specific nitrogen to maintain metabolic activities. With hydrolysis of protein, about 20 different amino acids are released, out of which 10 are essential, viz. arginine, histidine, isoleucine, leucine, lysine, methionine + cystine, phenylalanine + tyrosine, threonine, tryptophan and valine, which are not biosynthesized but required by fish (Table 31.2).

There exists a high correlation between dietary amino acid requirements and body composition of amino acids, and the data thus obtained suggest that EAA requirement profiles of catla, rohu and mrigal would not vary widely and also would not differ largely from those of other teleosts (Table 31.2), and therefore, formulating a balanced diet with common amino acids may not be a problem.

Table 31.2. Essential amino acid requirements (% dietary protein) of some fish and prawn species

Amino acid	Rohu	Catla	Mrigal	Common carp	Tilapia	Rainbow trout	Prawn	Milk fish
Arginine	5.75	4.80	5.25	4.3	4.2	5.0	3.7	5.2
Histidine	2.25	2.45	2.13	2.1	1.7	1.8	0.7	2.0
Isoleucine	3.00	2.35	2.75	2.5	3.1	2.0	0.6	4.0
Leucine	4.63	3.70	4.25	3.3	3.4	3.5	1.0	5.1
Lysine	5.58	6.23	5.88	5.7	5.1	4.5	3.2	4.0
Methionine	2.88	3.55	3.18	3.1	2.7	3.5*	1.2	2.5
Phenylalanine	4.00	3.70	4.00	6.5	5.5	4.5**	1.7	4.2**
Threonine	4.28	4.95	4.13	3.9	3.8	2.0	1.6	0.5
Tryptophan	1.13	0.95	1.08	0.8	1.0	0.5	0.5	0.6
Valine	3.75	3.55	3.50	3.6	2.8	3.2	2.0	3.6

*With cystine; **with tyrosine.

Lipids: Lipids are important source of energy, essential fatty acids and phospholipids, and provide a vehicle for absorption of fat-soluble sterols and vitamins. These also play a vital role in the structure of cell and cellular membrane and serve as the precursors of several hormones, in addition to their function for prostaglandin synthesis. Dietary lipids influence flavour and texture of prepared feeds and also flesh quality of fish. These are highly digestible in fish and are reported to spare protein. Excess dietary lipid suppress *de novo* fatty-acid synthesis and reduces ability of fish to digest and assimilate, resulting in reduced growth. Also, feeding excess lipids produces fatty fish and it will have deleterious effects on flavour, consistency and storage life of finished products.

Although, a wide range of variations (4-15%) in gross lipid requirement has been estimated for several species, 7-9% dietary lipids are generally considered optimum for practical diets of carps and prawns.

It is well known that human health benefit is attributed to the presence of long chain n–3 PUFA in fish lipids. Fish oil is the rich dietary source of PUFA, viz. eicosapentanoic acid (EPA) and docosa hexaenoic acid (DHA). As in other vertebrates, fish cannot synthesize n-3 (linolenic) and n-6 (linoleic) polyunsaturated fatty acids (PUFAs) but fish have a requirement of these two essential fatty acids that are to be provided from exogenous sources (Table 31.3). Freshwater fish, in general, requires either dietary 18:2 n-6 (linoleic) or 18:3 n-3 (linolenic) acids or both. Marine fish have dietary requirement of eicosapentaenoic acid (EPA, 20:5 n-3) and/or docosahexaenioc acid (DHA, 22:6 n-3). Dietary phospholipids have beneficial effects on growth and survival of fish and prawn larvae.

Table 31.3. Essential fatty acid requirements of some fish and prawn species

Fish/ prawn	Requirement
Common carp	1% 18:2 n-6 and 1% 18:3 n-3 or 0.5-1% HUFA n-3
Grass carp	1% 18:2 n-6 and 0.5-1% 18:3 n-3
Catla	Combination of n-3 and n-6
Seabass	1.0-1.7% HUFA n-3
Channel catfish	< 1% 18:3 n-3
Magur	18:2 n-6 and 18:3 n-3
Singhi	18:2 n-6 and 18:3 n-3
Rainbow trout	1% 18:3 n-3 or 1% HUFA n-3
Tilapia zilli	1% 18:2 n-6 or 20:4 n-6
Oreochromis niloticus	0.5-1% 18:2 n-6 or 1% 20:4 n-6
Macrobrachium rosenbergii	HUFA n-3

Cholesterol is synthesized in the body, but some crustaceans, like prawns, require cholesterol in the diet. Feeding of diets incorporating sterol and cholesterol at 0.25% and 0.5% levels yielded beneficial effects in prawns. The Indian major carps and marine shrimp have requirement of phospholipids to the tune of 4% and 1-2%, for enhancing larval growth and survival rates. Supplementation of n-3 and n-6 PUFA is also required for broodstock diet which is done by providing vegetable oil and fish oil of marine source and this greatly influences gonadal maturation, breeding efficiency and spawn recovery of Indian major carps. Dietary incorporation of 3% shrimp (marine) head-oil, being a source of n-3 fatty acids, improved feed efficiency in *Macrobrachium rosenbergii*.

Carbohydrates: Like proteins and lipids, carbohydrates are also another source of energy. Fish do not have specific dietary requirement, but carbohydrates are always included in fish diets as they are inexpensive energy source and act as pellet binder. Carbohydrates also serve as precursors for formation of various metabolic intermediates needed for growth. Carbohydrates have a sparing effect on utilization of dietary protein in many aquaculture species. Proper dietary balance of carbohydrates would enable fibre to move other nutrients in gastrointestinal tracts for proper digestion. Carps, tilapia, milkfish and prawns efficiently utilize carbohydrate as source of energy. However, the ability of fish to utilize dietary carbohydrate varies considerably and most carnivorous species have limited ability to metabolize it. In the absence of adequate dietary carbohydrates, fish utilize protein for energy at the cost of growth.

Several species of carp are considered herbivorous in nature and hence use of low-priced sources of digestible energy becomes an important consideration. Carps are able to utilize D-glucose, fructose, sucrose, dextrin and raw potato starch. Given herbivorous feeding habits of some of the cyprinids in their natural habitat, utilization of cellulose by cyprinids is reported. Cellulose is not utilized well as other digestible carbohydrates by common carp, but fish utilizes rice or tapioca starch well.

Rainbow trout efficiently utilizes dextrin and gelatinized starch. A small inclusion of starch in salmon diet is always beneficial. It is assumed that seabass, *Lates calcarifer* efficiently makes use of poly-and di-saccharides. Carbohydrates being 55-60% digestible in carps, form an important dietary constituent for herbivorous and omnivorous species. The optimum dietary requirement of carbohydrates is 22-26% for Indian major carps and medium carps, 30-40% for common carp, less than 25% for rainbow trout, 6-15% as gelatinized starch for *Salmon* spp. and 20% with proper balance with lipids and protein. However, carbohydrate levels generally do not exceed 30% in carp diets. The commercial diet of prawns normally contains 35-40% carbohydrates.

Energy: Energy is not a nutrient, but is a property of nutrients, which is released during metabolic oxidation of proteins, lipids and carbohydrates. Energy is defined as the capacity to work, but in biological definition, it refers to muscle activity, energy for chemical reactions in body, to enable movement of molecules against a concentration gradient and for other biological as well as physiological functions in the body. Fish do have a low energy requirement because no energy expenditure is involved for maintenance of body temperature and due to its neutral buoyancy. Other explanations for low energy requirement are less muscle activity to maintain their position in aquatic ecosystem as many fishes have swim bladders, and less energy expenditure for excretion of ammonia, which is 85% of metabolic wastes that are excreted directly through gills into surrounding water. Physical activities like swimming, escaping from predators and stress, temperature, size, growth rate, species and food are some of the factors that affect energy requirements of fish. Proteins, lipid and carbohydrates contain 5.6, 9.4 and 4.1 kcal of gross energy (GE/g) respectively.

Dietary protein : energy ratio: The condition where energy intake is inadequate, energy is drawn from protein sources. Excess protein is not only wasteful and uneconomical but also causes stress to fish and aquatic pollution as well. Diets containing excess energy lead to lipid accumulation resulting in fatty fish. Therefore,

a balance between protein and energy is considered important in fish diet, so that energy spares protein for growth. The optimum protein and energy (P:E) ratio is known to be size-related and is higher in small fishes (Table 31.4).

Table 31.4. Dietary protein:energy (P:E) ratio for optimum growth of fish and prawn species

Species	P:E ratio (mg/kcal)
Catla fingerlings	97.3 (40% dietary protein) 109 (45.8% dietary protein)
Rohu fry	113 (40% dietary protein)
Rohu fingerlings	95 (38% dietary protein)
Silver barbs	84.5 (30% dietary protein)
Common carp	103
Tilapia	103
Magur	87.6
Rainbow trout	92-105
Macrobrachium malcolmsonii	97.4 (25% dietary protein)
M. rosenbergii	90-95 (35-40% dietary protein)

Vitamins and minerals: Vitamins are required in trace amounts; are essential for fish growth and to fight against diseases. And they are required for metabolism of other nutrients in tissue components. Many of the water-soluble vitamins also act as co-enzymes. Fishes derive required vitamins from natural food, which become limited in intensive fish culture due to high stocking densities. Minerals are required for osmotic balance of various metabolic processes and for structural functions in fish. Some minerals such as calcium are directly obtained by fish through gills and skin or both, while others are made available from natural food and ingested detritus. Vitamins and minerals are, therefore, provided as premix in balanced artificial feeds.

The fish requires 11 water-soluble vitamins, namely thiamine, riboflavin, pyridoxine, niacin, pantothenic acid, inositol, folic acid, choline, biotin, ascorbic acid and B_{12} as also four fat-soluble vitamins such as A,D,E and K. Water-soluble vitamins, when taken in excess over tissue storage, are excreted after metabolizing vitamins required for the fish. Excess fat-soluble vitamins in the diet result in abnormal growth and liver diseases.

There are 20 recognized inorganic mineral demands, which perform essential functions in the body. The minerals required by fish are calcium, chlorine, magnesium, phosphorus, sodium and potassium along with trace elements cobalt, copper, iodine, iron, manganese, selenium, zinc, aluminium, chromium and vanadium. Calcium and phosphorus are closely related in metabolism. Phosphorus and calcium are required for bone formation. Calcium plays a major role in blood clotting, muscle function and proper nerve impulse transmission. Phosphorus is involved in energy transformation, permeability of cellular membrane, genetic coding and general control of reproduction and growth (Tables 31.5-31.7).

Table 31.5. Vitamin requirements (mg/kg dry diet) of certain finfish species

Vitamin	Catla	Rohu	Mrigal	Common carp	Catfish	Seabass	Rainbow trout
Thiamin	-	-	-	2-3	1-3	R	1-12
Riboflavin	-	-	-	7-10	9	R	3-30
Pyridoxine	-	-	-	5-10	3	5-10	1-15
Pantothenic acid	-	-	-	30-40	25-50	15-19	10-50
Niacin	-	-	-	30-50	14	-	1-150
Folic acid	-	-	-	NR	R	-	5-10
Vitamin B_{12}	-	-	-	NR	R	R	0.02
Myo-inositol	-	-	-	200-300	R	R	200-500
Choline	-	-	-	1,500-2,000	400	-	50-3,000
Biotin	-	-	-	1-1.5	R	-	Na
Ascorbic acid	-	-	650-700	30-50	60	700*, 25-30**	100-500
Vitamin A (IU)		2,000		1,000-2,000	1,000-2,000	-	2,000-15,000
Vitamin D (IU)	-	-	-	NR	500-1,000	-	2,400
Vitamin E (IU)	98.4-150	131.19	99	80-200	30	-	30-50
Vitamin K (IU)	-	-	-	R	R	-	10

NR, Not required; R, required but not estimated; Na, no information available. *Crystaline ascorbic acid; **ascorbyl-2-monophosphate-Mg or ascorbic acid glucose.

Table 31.6. Mineral requirement (% or mg/kg feed) of certain species

Species	Calcium (%)	Phosphorus (%)	Potassium (%)	Magnesium (%)	Iron (%)	Copper (mg)	Manganese (mg)	Zinc (mg)	Iodine (mg)	Selenium (mg)
Common carp	<0.1	0.6-0.7	R	0.05	150	3	13	15-30	R	R
Channel catfish	<0.1	0.45	R	0.04	30	5	2.4	20	1.1	0.25
Rainbow trout	<0.1	0.6	R	0.05	R	6	13	15-30	1.1	0.15 -0.3
Tilapia	-	0.9	R	0.06	R	3.5	12	20	R	R
Japanese eel	0.27	0.3	R	0.04	170	R	R	R	R	R
Mrigal	0.19	0.75								
Rohu	0.19	0.75								

R, required but no estimated.

Commercial grade vitamin and mineral premix (Table 31.7) are generally used in preparation of feeds, which should not exceed inclusion level of 2% for each in carp feeds.

Additives: The common additives and other components such as cholesterol, mould inhibitor, antioxidants, pellet binder, moncalcium phosphate, minerals, vitamins, choline chloride, vitamin C (coated), inositol, immunostimulants, pigments, etc., are used in small quantities in feed industries in India to improve the dietary quality.

Practical diets: The supplementary feed used in aquaculture generally consists of rice bran and groundnut oilcake which are compounded in 1:1 and some farmers use mustard oilcake in place of groundnut oilcake. Cake-bran mixture in conjunction with natural fish-food organisms is still a practice for semi-intensive carp farming in India. This mixture is not nutritionally balanced, and is normally used to supplement protein

Table 31.7. Recommended levels of vitamins and mineral in prawn diet

Vitamins	Quantity/kg diet	Minerals	Quantity/kg diet
A	5,000-10,000 IU	Calcium	10-18 g
D_3	100-200 IU	Phosphorus	18 g
E	100-200 IU	Magnesium	0.8-1 g
K	200-400 mg	Sodium	6 g
C	50-100 mg	Potassium	9 g
B_1	30-50 mg	Sulphur	0.2 g
B_2	30-50 mg	Manganese	20 mg
B_6	0.02-1 mg	Zinc	50-100 mg
B_{12}	0.5-1 mg	Iron	5-20 mg
Biotin	400-2,000 mg	Cobalt	10 mg
Choline	5-10 mg	Selenium	1 mg
Folic acid	200-300 mg	Chlorine	Traces
Inositol	100-150 mg	Molybdenum	Traces
Niacin	50-100 mg	Chromium	Traces
		Fluorine	Traces
		Copper	25 mg

and energy. Stocked species receive about 50% protein, 8% lipid and 27% carbohydrate and 4 kcal/g gross energy from natural food organisms like plankton and of animal origin. Phytoplankton provides high quantities of n-3 and n-6 PUFAs. Owing to non-availability of commercial feeds and economic reasons, more than 90% farmers use farm-made feeds of cake-bran mixture or improved version of the feed mixture in carp culture. The farm-made feeds are prepared based on ingredient availability and feeding experiences. In Andhra Pradesh, farmers use defatted rice bran and groundnut oilcake in 7:3, and a farmer in Punjab is reported to enrich his traditional cake-bran mixture with animal protein, sugar industry by-product rich in minerals and feed is further supplemented with vitamins and minerals. Inter-linking of artificial feeding with natural fish food organisms has been found beneficial as latter influences dietary efficiency and economic utilization of former. There has been a rapid shift from traditional feeding to pellet feeding of nutritionally complete diet.

Feed resources

Several agro-based ingredients have been identified and analyzed for their use in fish feeds (Table 31.8). The ingredients that contain less than 20% protein and 18% fibres are classified as energy supplements. The bottom dweller candidate species appear to take maximum advantage of energy supplements added in practical diets that spare protein for their growth because benthic fish food organisms are inadequately available; these do not adequately support their growth and survival.

A protein deficit occurs when absolute protein requirement of the fish population stocked per unit area is higher than available protein from natural fish food organisms needing protein supplementation from exogenous source. The ingredients that contain 20% or more protein are grouped as protein supplements (Table 31.9).

Table 31.8. Major conventional and non-conventional feed ingredients available in India

Ingredients	Quantity (million tonnes)	State producing major quantity
Rice bran	5.7 (2007-08)	Andhra Pradesh, Asom, Bihar, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Tamil Nadu, Uttar Pradesh,West Bengal
Wheat bran	2.73 (2007-08)	Bihar, Gujurat, Haryana, Himachal Pradesh, Jammu and Kashmir, Madhya Pradesh, Punjab, Rajasthan, Uttar Pradesh
Groundnut oilcake	6.0 (2007-08)	Gujrat, Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka, Madhya Pradesh, Rajasthan, Punjab, Haryana, Uttar Pradesh, Odisha
Sunflower cake	1.0 (2007-08)	Karnataka, Andhra Pradesh, Maharashtra, Tamil Nadu, Punjab, Haryana, Uttar Pradesh, Bihar
Soybean meal	7.13 (2007-08)	Madhya Pradesh, Maharashtra, Andhra Pradesh, Rajasthan, Karnataka, Chhattisgarh
Rapeseed/ mustard cake	3.78 (2007-08)	Uttar Pradesh, Rajasthan, Punjab, Hayana, Gujarat, Madhya Pradesh, Chhattishgarh, West Bengal, North East Region
Salseed cake	0.1 (2007-08)	Odisha, Madhya Pradesh, Chhattishgarh
Sesame	0.5 (2007-08)	Gujarat, Rajasthan, Tamil Nadu, Madhya Pradesh, Chhattishgarh, Andhra Pradesh, Karnataka, Maharashtra, Uttar Pradesh, Uttarakhand, West Bengal, Odisha
Linseed	0.11 (2007-08)	Madhya Pradesh, Chhattishgarh, Uttar Pradesh, Maharashtra
Safflower	0.15 (2007-08)	Maharashtra, Karnataka, Andhra Pradesh
Niger	0.07 (2007-08)	Madhya Pradesh, Bihar, Maharashtra, Odisha, Tamil Nadu
Cotton seed cake	8.5 (2007-08)	Gujarat, Maharashtra, Andhra Pradesh
Maize	18.96 (2007-08)	Karnataka, Andhra Pradesh, Bihar, Punjab, Uttar Pradesh, Madhya Pradesh, Gujarat, Himachal Pradesh
Sorghum	8.0 (2002-03)	Maharashtra, Karnataka, Uttar Pradesh, Gujarat, Madhya Pradesh, Andhra Pradesh, Rajasthan
Fish meal (including imported fish meal)	0.21 (2002-03)	Maritime states
Shrimp waste	0.03 (2002-03)	Maritime states
Squilla	0.06 (2002-03)	Maritime states
Clam meat	0.004 (2002-03)	Kerala, Karnataka
Sergisted shrimp (Acetes)	0.05 (2002-03)	Maritime states
Mussel meat	0.001(2002-03)	Kerala, Karnataka, Odisha, West Bengal, Andhra Pradesh
Poultry offal	0.15 (2002-03)	All states
Silkworm pupae	0.04 (2002-03)	Karnataka, Jammu and Kashmir, North East Region, Uttar Pradesh, West Bengal, Odisha, Tamil Nadu, Asom, Madhya Pradesh

Table 31.9. Chemical composition of some feed ingredients in per cent dry matter (DM)

Ingredients	Moisture (%)	CP (%)	EE (% DM)	Fibre (% DM)	NFE (% DM)	Ash (% DM)
Groundnut oilcake	7-10	40-43	4-8	6-7	30-33	8-10
Soybean meal	8-10	50-55	1-2	4-5	30-32	5-6
Rice-polish	8-12	12-18	12-14	7-10	40-48	5-8
Rice bran	7-10	12-16	12-14	8-12	40-45	5-8
Deoiled rice bran	8-10	15-18	1-2	10-15	45-50	8-12
Rapeseed cake	11-12	32-38	5-7	11-15	30-35	6-7
Salseed cake	8-10	7-8	3-4	10-13	62-68	10-12
Til oilcake	7-10	35-42	3-6	10-15	40-48	10-13
Mustard oilcake	8-10	25-38	6-9	10-16	35-40	10-12
Cotton seed cake	7-10	32-35	6-8	12-16	35-40	8-12
Sunflower oilcake	10-12	30-32	4-8	15-18	30-35	8-10
Copra cake	8-12	20-25	6-10	12-17	35-40	5-8
Maize flour	10-12	5-6	3-4	2-3	70-80	2-3
Barley grains	10-12	8-10	2-3	4-6	70-80	2-3
Wheat flour	10-15	8-11	2-4	1-4	65-80	1-3
Fish meal	8-10	45-65	8-12	-	-	20-40
Tapioca flour	10-12	3-6	2-3	-	75-82	2-3
Shrimp waste	10-15	22-34	2-7	-	-	10-20
Squila meal	10-14	40-46	1-3	-	-	12-18
Squid meal	8-12	70-75	4-8	-	-	3-5
Clam meal	8-10	48-50	8-11	-	-	4-6
Silkworm pupae	8-10	40-45	15-25	-	-	12-15
Deoiled silkworm pupae	8-10	60-70	2-5	-	-	6-7
Blood meal	10-15	85-90	1-2	-	-	2-4
Meat meal	8-10	50-70	4-9	-	-	10-15

CP, Crude protein; EE, ether extract/ crude fat; NFE, nitrogen-free extract/soluble carbohydrate.

Table 31.10. Apparent digestibility of protein and energy for various feed ingredients in Indian major carp species

Ingredients	Apparent digestibility coefficient (%)					
	Rohu		Catla		Mrigal	
	Protein	Energy	Protein	Energy	Protein	Energy
Soybean oilcake (solvent extracted)	94	90-96.18	94.1	-	92.8	81.27-89.33
Soybean meal	84	-	-	-	-	-
Sesame oilcake	89.1	-	-	-	89.6	-
Mustard oilcake	88.2	63.14-64.33	86.6	-	89.5	50.27-55.75
Linseed meal	82	-	-	-	-	-
Groundnut oilcake	83.8	78.36-82.98	-	-	88.2	76.82-81.97
Rocket salad	-	63.32-76.04	-	-	-	63.07-74.77
Silkworm pupae meal	85	66.46-68.01	-	-	-	58.34-60.27
Fish meal	74.1	69.34-72.64	76.1-90.4	-	73.6	53.97-58.03
Slaughter house waste	73.6	61.23-69.51	-	-	73.5	57.4-64.09
Rice bran/rice polish	88.3-90	43.55-48.80	90	-	84.4-91	45.82-49.07
Wheat bran	88.1-93	58.58-68.02	88.5-93	-	89.6-93	44.69-53.86
Pigeonpea dust	86.3	-	-	-	81.2	-
Yellow corn	86-96	-	86-96	-	86-96	-
Potato starch	86-96	-	83-98	-	85-98	-

Ingredient digestibility

Together with chemical analysis, the data on nutrients and energy digestibility provide a strong base for selection of dietary ingredients. The assessment of ingredient digestibility is essential for least-cost diet formulation, screening of feedstuffs in relation to raw material quality, processing and storage conditions, and for formulating diets to minimize aquatic pollution.

Fish meal, a highly sought after animal protein widely used in aqua-feeds, contains only few anti-nutritional factors and is well digested. The apparent protein digestibility (APD) of fish meal, sesame oilcake, linseed oilcake and mustard oilcake for different carps including Indian major carps are 73.6-93, 78.9-89.6, 82-85.8 and 85.3-89.5% respectively. Protein digestibility of fish meal has been reported to a maximum of 95%, and the variation in fish meal protein digestibility may be due to differences in origin and processing of the material. There is no difference between APD values (90-91%) of soybean meal and fish meal in grass carp. The protein digestibility of 86-92% was reported for some plant ingredients in Indian major carp yearlings. Depending on the water temperature, the APD of defatted rice bran, wheat flour, silkworm pupae range between 60 and 88, 78 and 80 and 86 and 88%, respectively, in common carp when evaluated against water temperature of 15, 20 and 25°C.

The protein of shrimp meal, copra meal and rice bran is equally digestible as that of fish meal. The APD values are reported to range from 99.09 to 99.85% in these 4 ingredients. The apparent protein digestibility which is in the range of 90.9-94.6% for groundnut oilcake is higher than 74.0-76% as observed in channel catfish. The APD values of fish meal, soybean meal (defatted) and ipil-ipil for milkfish of different size

Table 31.11. Apparent digestibility of protein and energy for various feed ingredients in exotic carps at different temperatures

Ingredients	Apparent digestibility coefficients (%)	
	Protein	Energy
White fish meal (65.8% CP)	90-94	86-89
Fish meal (63.5% CP)	74-93	86-87
Meat meal (69% CP)	91-95	76-82
Silkworm pupae meal (52.6% CP)	86-88	79-82
Maize gluten meal (64.3% CP)	82-93	73-85
Maize meal (8.2% CP)	80-82	70-73
Defatted wheat germ meal (31.3% CP)	92-94	70-77
Defatted rice bran (18.8% CP)	60-88	48-76
Rice bran (12.0% CP)	88-94	89-92
Wheat flour (15.8% CP)	78-80	49-79
Sesame oil cake (35.5% CP)	89-92	83-84
Sunflower (32.0% CP)	88-90	80-82
Mustard oil cake (34.0% CP)	88-92	81-83
Groundnut oil cake (42.0% CP)	88-90	85-87
Green gram husk (24.0% CP)	80-84	75-78
Black gram husk (27.0% CP)	80-82	80-82

groups held in seawater range from 2 to 71, 54 to 74 and 41 to 47%, but protein digestibility of ipil-ipil in 165 g milkfish, held in seawater, showed a negative value. The apparent lipid digestibility (ALD) has been reported as 93.08-100% for fish meal, 78.42-100% for rice bran, 91.95% for mustard oilcake and 19.52% for maize meal in carps, tilapia, catfish and seabass. The apparent energy digestibility (AED) in different size groups of Indian major carps vary widely. The data on digestibility of different ingredients for various important species of fishes and shellfish are presented in Tables 31.10 and 31.11.

Improved farm-made, formulated diets and feeding practices

A common balanced diet is delivered to the 6 species of carps stocked in composite carp culture. Generally for semi-intensive carps and prawn polyculture a feed containing 24-25% protein and 6-8% lipids meet the nutritional requirement of the crop. To prepare a feed containing above percentage of protein and lipid one can chose any one of the formula given bellow (Table 31.12) according to the locally available feed ingredients.

Table 31.12. Some formulation for farm-made feed with locally available ingredients and their on farm cost (*based on 2009 price index)

Ingredients	Ratio	Total CP	Total CL	Cost/kg (₹)*
Groundnut oilcake (OC): rice bran	50:50	25	8.5	15.00
Mustard OC: RB: linseed OC	40 :40 :10	25	7.0	10.80
Sunflower OC: RB: silkworm pupae	65:30:5	25	9.0	09.50
MOC : LOC: RB:silkworm pupae	45:15:35:5	24	10.0	11.00
Sesame OC: RB	60:40	25	6.4	10.20

Generally feed is applied in the form of powder or dough. But feed pellet showed better performance than the dough. Small pelletizers are now available to prepare the feed pellets. This is handy and portable from one place to other. In a village cluster some fish farmers can collectively procure and use this machine for fish feed preparation. Some guidelines are given below for pellet feed preparation at farm site.

How to make feed pellets

- Ingredients in required quantities are milled and mixed together
- Grinding and mixing can be done by a portable mini grinder cum pulveriser
- Add 2-3% of wheat flour *(maida)*/ cassava as binder
- Steam the mixture with some water, to reduce the anti-nutrient factors if any
- Cool the mixture, may add 1% commercial vitamin and mineral premix
- Add required amount of water and make the dough
- Dough is the ready-mix to prepare feed pellets
- Process the dough in a portable mini pellet machine

- Use desired dice to get feed pellets
- Sun dry the pellets and use in aquaculture pond
- Pellets can be crumbled by the above grinder to small pieces for nursery and juvenile rearing.

Storage and preservation of farm made feed

- Farm made feed pellets should be used as fresh as possible
- It can be stored for a month
- Use polythene gunny bag to store the feed pellets
- Avoid moisture contamination as far as practicable to keep the feed in dry condition
- Sun dry the feed pellet at least once in every fortnight to avoid the fungal growth
- Fungal infested feeds are not advised to be used in fish pond.

Application of farm made feeds

- One can broadcast the finely crumbled or powdered feed in the nursery pond
- Coarse crumbles are applied in basket as feed dispenser device
- Feed pellets are given to the grow-out fish or brood by hanging tray or basket at different depth of the water in the pond.
- Apply the feed pellet in splited dose as per the consumption.

Fish larvae accept formulated diets immediately after yolk-sac absorption on the fourth day of hatching. The formulated diets containing 26-45% crude protein, 8-10% lipids, 26-30% carbohydrates, 3.0-3.5 kcal/g gross energy are generally provided to carp larvae in conjunction with natural fish food organism. While balancing protein and energy, attention is given on balancing PUFA (n-3 and n-6) and vitamin C to ensure better survival and growth. Use of micro-encapsulated egg diet has been reported for indoor larval rearing of carp larvae. This diet fortified with vitamins and minerals has primary advantage of each particle having nutritional balance as that of whole egg.

Lately, dietary supplementation of probiotics (yeast and bacteria) and phospholipid compounds (soylecithin) has gained popularity in India, the diets containing single cell proteins have been found very effective in indoor trials for larval growth and survival, and results were comparable with those of zooplankton. A basal diet for carp larvae has been developed utilizing a commercial source of live culture of *Saccharomyces cerevisae* and *Lactobacillus coagulans* supplemented at 30% level in liver-starch-cud liver oil based diet. The formulated diet is suitable for indoor hatchery rearing system, ensuring 100% survival and fast larval growth.

Realizing the need for efficient utilization of natural lipids as also for meeting high energy demands of growing fish and prawn which are incapable of *de novo* synthesizing or inadequately synthesizing phospholipid compounds, dietary incorporation of soylecithin at 4% level along with vegetable and fish oil (1:1) is optimum for carp larvae, and feeding of diet greatly influenced tissue level deposition of phospholipids in 3 species of Indian major carps (Table 31.13).

Table 31.13. Feed formulations for Indian major carp spawn

Feed	Ingredients	Composition (%)
1	Fresh liver	50
	Bioboost forte (probiotics supplement)	30
	Starch	13
	Cod-liver oil	5
	Mineral premix	1
	Vitamin premix	1
2	Finely powered soybean meal	10
	Finely powdered groundnut oilcake	32
	Finely powdered fish meal	20
	Finely powdered rice-bran	30
	Vitamin and mineral premix	2
	Phospholipid (as soya lecithin)	4
	Veg. oil : fish oil (1:1)	2
3	Groundnut oilcake	40
	Roasted soybean meal	20
	Rice bran	10
	Fish meal	20
	Vegetable oil	4
	Fish oil	3
	Vitamin+mineral premix	2
	Bioboost forte	1

Feeding of balanced diets in presence of natural food in composite seed rearing and carp culture, improved survival rates of fry and fingerlings with their respective average values of 40 and 70% respectively. It is also not difficult to raise production level exceeding 8-10 tonnes/ha for table fish under optimum feeding and management. However, in nature, carp fry of 5-10 mm size subsist on unicellular algae and when they grow to 10-20 mm size, they feed on other food materials like protozoans, zooplankton, etc. Because of its high biological value, fish meal is added in practical feeds of carps at 5-20% level for preparing nutritionally balanced diets for fry, fingerlings, growers and brood carps. Over the years, due to easy availability and low prices, several other alternative sources of animal and plant proteins have been experimented to replace more expensive and scarce fish meal in aquaculture feeds. Agro-industrial byproducts and other animal and plant wastes are blood meal and other slaughterhouse wastes, meat meal, poultry wastes, feather meal, shrimp meal, marine trash fishes and other materials of animal origin.

Cake-bran mixture was compound with blood meal in 1:3:6 and used for feeding rohu fry, that registered faster growth. Fermented fish or poultry viscera silage was also used as animal protein in carp diets in place of fish meal. Diets incorporated either with defatted soybean meal, non-defatted or defatted silkworm pupae have performed as those of fish meal based diet in carp fry. Dietary inclusion of fermented silkworm pupae silage in feed of carp is superior to untreated silkworm pupae or fish meal.

Soybean meal is considered one of the most nutritious ingredients of all plant proteins and with supplementation of methionine and vitamins and minerals, it can totally replace fish meal in practical feeds of growing carps. Supplementation of 0.4-0.5%

lysine and 10% oil become necessary especially when soybean meal replaces fish meal partially or completely. It is established that mustard oil cake can be used up to 35% in carp feeds along with other plant materials. A combination of fish meal and mustard oilcake is found better, utilized with high rate of growth performance of fish in carp polyculture. Rapeseed meal can be used in carp diet up to 24% level. In intensive carp culture, 35% groundnut oilcake has been used along with rice bran, soybean, fish meal, vitamins and minerals at appropriate levels, that diet contains 30.27% protein, 8.95% lipid and 3.49 kcal/g energy (Table 31.14).

Table 31.14. Some feed formulations for fry and fingerlings of Indian major carps

Feed	Fry		Fingerlings and growers	
	Ingredients	Composition (%)	Ingredients	Composition (%)
1	Azolla powder	60.0	Rice bran	35.0
	Soybean meal	19.0	Groundnut oilcake	25.0
	Groundnut oilcake	13.9	Roasted soybean meal	25.0
	Sesame oilcake	4.0	Fish meal	7.0
	Rice bran	2.0	Vegetable oil	5.0
	Vitamin mineral mix	1.0	Fish oil	2.0
	Attractant (seeds of *Trigonella* and *Murraya*)	0.1	Vitamin-mineral premix	1.0
2	Groundnut oilcake	26.0	Groundnut oilcake	28.0
	Soybean meal	23.0	Soybean meal	20.0
	Rice bran	33.0	Rice bran	30.0
	Fish meal	16.0	Meat-cum-bone meal	20.0
	Vitamin mineral mix	2.0	Vitamin-mineral premix	2.0
3	Groundnut oilcake	28.0	Soybean meal	7.0
	Soybean meal	20.0	Groundnut oilcake	30.0
	Rice bran	30.0	Mustard oilcake	35.0
	Meat meal	20.0	Rice bran	26.0
	Vitamin mineral mix	2.0	Vitamin-mineral premix	2.0
4			Groundnut oilcake	40.0
			Soybean meal	20.0
			Fish meal	8.0
			Rice bran	30.0
			Vitamin-mineral premix	1.5
			Vegetable oil	0.5
5			Fermented silkworm pupae	6.7
			Rice bran	19.3
			Groundnut oilcake	62.0
			Groundnut oil	5.0
			Binder mix (tapioca flour, *maida* and rice flour in 6:3:1 ratio)	5.0
			Vitamin-mineral premix	2.0

Information on broodstock and diet development is scanty. Dietary inclusion of 33% crude protein and 14% crude lipid supplying both linoleic and linolenic fatty acids considerably improve ovarian development, spawning behaviour, fecundity, egg size and weight and number of viable spawn produced in Indian major carp (Table 31.15).

Feeding practices

The size of the prey should always match with mouth gap of an animal, and hence, the particle sizes of the prepared feeds are adjusted according to the mouth gap of the growing fish and prawn. Dust or fine particles, if present, may often clog gills causing great damage to fish. It should be borne in mind that specific demand of growing ones are satisfied through feeding properly sized feeds. Crumble feeding of formulated diets to fry or early fingerlings is always considered better than broadcast feeding. The feed particles and pellet sizes for various stages are as follows:

Stage of fish (carps)	Particle and pellet size
Fry	< 50-80 mm particle
Spawn	0.5 mm diameter of crumbled dry feed pellet
Fingerlings (3-4 g)	Crumbles of 1.5-2 mm diameter
Growers	2.5-3.0 mm diameter dry pellet

Feeding schedule followed in different phases of carp culture practices are as follows:

Spawn to fry (culture period 15 days)	Fry to fingerlings (culture period 90 days)	Grow-out culture (culture period 10-12 months)
4 times of initial body weight during first week and 8 times of initial body weight during second week in 2 rations	6-8% of biomass during first month, 5-6% of biomass during second month and 3-4% of biomass during third month in 2 rations	3-5% of biomass in the first month and 1-3% of the biomass in the subsequent months provided twice a day

Finely powdered feed is broadcast in ponds for spawn and fry rearing. In many advanced laboratories or hatcheries, automatic feeders are used for fish larvae, which provide feed at the desired intervals. Frequent feeding at 30 min to 1 hr interval in hatchery is known to yield good results in terms of growth and survival. For feeding fingerlings or growers, feed dough or dry pellets are provided in check-trays, feeding baskets or in perforated gunny bags, which are tied up in bamboo poles, and these are kept suspended in pond-water at several points. Perforated plastic fertilizer bags are also used for providing feed, which are kept hanging in water column with the help of bamboo poles. Each of these bags can hold about 20 kg feed. When fish nibbles near holes, certain amount of feed mixture comes out through the holes, thus acts as a demand feeder. Such feeding practices are common in carp farms of Andhra Pradesh. In Punjab, farmers use a number of feed baskets tied up in a row in a floating material which is kept floating across water-bodies. Floating pellets are suitable for feeding in cages. These types of feeding methods are useful to have a check on feed loss. Efforts are necessary to maintain good feed conversion ratio (FCR), not exceeding 1:2, under optimum pond and feeding management. Indoor trial for 1 or 2 days feeding of low protein diet, followed by 3 days feeding of high protein diet has shown advantage over high protein feeding for whole duration, which, however, is required to be evaluated in ponds.

Catfish diets

Clarias batrachus: Soon after absorption of yolk-sac on fourth day of hatching, larvae start feeding on mixed zooplankton. *Artemia* nauplii, molluscan meat, *Tubifex* and egg custard are provided as feed which contain 41-65% proteins. Vitamins and minerals are supplemented in egg custard preparation. A diet 'CIFAMA' was developed for 3-day-old magur at the Central Institute of Freshwater Aquaculture (CIFA) that contained a minimum level of 33% crude protein, 8% crude fat and 32% NFE and maximum levels of 5% crude fibre and 14% total ash. Based on experimental results, meat meal can partially replace fish meal in magur larval diet. In addition to CIFAMA already released by the CIFA, the above larval diet of magur under the trade name of Starter-M has been released for commercial production. Some feed formulations are given Table 31.15.

Table 31.15. Some feed formulations for magur fry, fingerling and juvenile

Feed	Ingredients	Composition (%)
1	Fry	
	Fish meal	60
	Roasted soybean meal	15
	Groundnut oilcake	10
	Baker's yeast	3
	Sunflower oil	2.5
	Cod liver oil	2.5
	Tapioca starch	4.5
	Vitamin and mineral premix	2
	Attractant (powdered seeds of *Trigonella* and roots of *Murraya*)	0.5
2	Fingerlings	
	Rice bran	32.8
	Groundnut oilcake	32.6
	Meat meal	32.8
	Vitamin and mineral mixture	2
3	Fingerling	
	Dried chicken viscera meal (CVM)	50
	Maize (ground)	10
	Groundnut oilcake (expeller)	29
	Vegetable oils	5
	Mineral and vitamin premix	5
	CM-cellulose	1
4	Juvenile	
	Fish meal	20
	Soybean meal (solvent extracted)	20
	Groundnut oilcake (expeller)	19
	Rice bran (full fat)	20
	Ground maize (yellow)	20
	Trace minerals and vitamin premix	1
5	Dried fish viscera	22
	Soybean meal (solvent extracted)	15
	Groundnut oilcake (expeller)	25
	Rice bran (full fat)	20
	Ground maize (yellow)	17
	Trace minerals and vitamin	0.1

Feeding practices: The spawn of magur (5.0-5.5 mm) are reared for 12-14 days in indoor rearing system and no feeding is required till fourth day. Though period of yolk absorption varies, feeding may be initiated with provision of little quantity of feed, and usual meal from fifth day onwards. The feed quantity may be adjusted depending on the density of spawn. Identification of acceptable feed and appropriate particle size are important considerations for larval feeding. Mixed zooplankton, *Artemia* nauplii, molluscan meat, *Tubifex* and egg custard with 40-65% proteins are used for larval feeding. Feed particle size or the size of natural fish food organism of 20-30 μ are considered ideal for initial phase of feeding, which is gradually increased to 50-60 μ for feeding 1-week-old magur fry.

The fry are usually reared indoor in tanks for a few weeks before releasing them into ponds, and during indoor rearing, they are fed with high energy and protein diets with main contribution from animal source and having a particle size of 0.3-0.5 mm. It is required that feeds are adequately fortified with water-soluble vitamins to compensate the leaching losses during feeding. Like spawn, fry in tanks must be fed several times a day and feeding at hourly intervals is always preferable.

In ponds, feed is normally dispensed from all sides to provide feeding opportunity to all fish. Feeding should be done twice daily. Acceptability and utilization of feed by catfish in pond is greatly influenced by level of dissolved oxygen and water temperature. With low dissolved oxygen in water, feeding activity of catfish reduces. The feeds, hence, need to have high degree of water stability. Either extruded or pelleted feed is ideal for feeding fish to minimize nutrient leaching and wastage unlike dust or dough feed, which needs to be discouraged. Pond feeding of artificial diets should be done in the presence of high density of zooplankton.

Supplemental feeding of fry in ponds is done soon after stocking. As size of the fish increases, diameter of pellet feeds needs to be increased. Crumbles of pellets should be used to feed fry and fingerlings whose size should be such that fish can easily ingest, to minimize dissolving of ingredients in water.

Other large catfishes

A good beginning has been made for development of a larval diet for freshwater shark *Wallago attu*. The 11-day-old larvae of freshwater shark were successfully reared with combined feeding of zooplankton and a dry feed containing either fish meal, meat meal or shrimp meal as animal protein along with groundnut oilcake (expeller), wheat-flour (whole), blackgram flour, cod liver and soybean oils, vitamins and minerals. The diet contained 40.3-41.9% crude protein and 11.2-12.1% crude lipid. The best larval growth and survival of fish are achieved with feeding of dry feed containing 60% fish meal in combination with live zooplankton under 24 hr red light exposure followed by meat meal based feed.

In the absence of information on nutritional requirements of non-conventional catfishes like *Ompok* spp., *Pangasius* spp. and *Mystus* spp., feeds are prepared in line with nutritional requirement of channel catfish.

Most catfishes like *Clarias* sp. and *Heteropneustes* sp. are bottom feeders; mostly subsisting on organic debris and benthic fauna in ponds. Catfishes like *Ompok* and *Mystus* show a preference for natural fish food organisms and also accept and thrive best on artificial diets incorporating natural fish food organisms. Catfish culture is generally done at semi-intensive level and supplementary feeds used are either single ingredient like chicken viscera, goat viscera, carcass wastes or a mixture of agricultural byproducts and wastes. Unlike *Pangasius pangasius* and *Clarias batrachus*, which accept supplementary feed and dry pellets, *Ompok* spp. and *Mystus* spp. need to be initially trained on exogenous feeding from their early stage.

Chicken viscera and fish meal were used as animal protein sources in a diet containing 30% protein and 3.50 kcal/g energy for feeding *Pangasius* fingerlings which grew well both in yard and pond with resultant FCR of 3:1 to 3.5:1. The other ingredients used were broken rice-flake, mustard oilcake and soybean meal. Unfortunately no standard feed is available in India for fish. The formulations for *Pangasius* fingerlings evaluated with 30% protein comprised fish meal 30%, rice bran 45%, soybean meal 24% and vitamin and minerals premix 1%, and that for grow-outs with 25% protein comprised fish meal 15%, soybean meal 15%, groundnut oilcake 25%, rice bran 30%, broken rice 15% and vitamins and minerals premix 1%.

***Ompok* spp. and *Mystus* spp.:** Not much is known about artificial diets and their feeding to these catfishes in India. However, finely powdered feed is prepared using fish meal, rice polish, groundnut oilcake, soybean meal, cod liver oil and vitamins mixture for feeding fry of *Mystus vittatus*, which are fed 4 times a day at 3% body weight. Though feeding trial is still in experimental stage, preliminary studies indicated that *Ompok pabda* accepts supplementary feed. Moist supplementary feeds are dispensed to *Ompok* at 2-3% of body weight and fish appears to prefer feeding in ponds partly covered with aquatic weeds. In ponds where natural fish feed is abundantly available, a diet containing 30% protein may be good enough for feeding fish while for others, a balanced diet containing 35% protein may be required.

***Pangasius*:** Like snakeheads, very little is known about culture and artificial feeding of *Pangasius* spp. in India. Basic knowledge regarding feeding can be obtained from practices followed in Thailand where fishes are cultured both in non-drainable ponds and cages installed in lakes and rivers.

The pond feeding strategy is decided by ingredients available in the area. Rice bran or a mixture of broken rice and small quantity of trash fish is fed to stocked fish for first 2 months. From third month onwards, fish are fed various formulated diets prepared using vegetable wastes, cooked broken rice, byproducts of fruit-processing industries like pineapple wastes and tender maize husk, trash fish and fish offal.

The moist feeds are provided to fish thrice daily at 10% body weight from fry to fingerlings, which reduce to 5% in juvenile and adult stages. Pond feeding is done for 8-12 months during which fish attain an average size of 1.0-1.5 kg with FCR values of 4.0 to 6:1. Trash fish and sometimes pelleted diets are used for feeding fish in cages, where fish production of 35-65 kg/m^3 is achieved after 8-12 months.

Snakehead diet

Snakehead is a popular fish cultured in Thailand, which thrives well on trash fish and fish meal mixture. In India, snakehead culture is at infant stage. Mixture of rice bran at 10-20% level with trash fish of 80-90% is the most common feed used by farmers of Thailand. The other common formulations consist of trash fish 50.0%, fish meal 17.5%, soybean meal 7.5%, broken rice 7.0%, rice bran 17.0% and vitamins and minerals premix 1.0%.

Feeding practices: Since little is known about practical feeding of snakeheads (*Channa* spp.) and more so about their formulated diets in India, the feeding strategies followed in Thailand are described. It is observed that murrels do not feed on floating pellets but rapidly feed on doughs when kept on a platform, just below the surface. The snakeheads are fed practical diets 3 times a day from fry (15 g) to fingerlings size (50 g). The practical diet contains 80% trash fish and 20% rice bran or cooked broken rice when fish reaches fingerling size. The mixture of feed ingredients is powdered using meat minced and placed on wooden platform along the pond sides. In places where trash fish is easily available, its minced is used as the sole feed to fish. Fish attains 1 kg weight within 6-7 months. *C. micropeltes* and *C. striatus* are generally cultured in cages and chopped trash fish is fed to them. The FCR in pond and cage culture of snakehead is about 4 to 1.

Trouts (brown trout, rainbow trout and snow trout) diet

In general, balanced diets for different coldwater fishes may include 20-60% proteins and 10-25% carbohydrates as well as 5-25% lipids, as non-protein energy sources, and should contain required amounts of essential vitamins and minerals. The major ingredients of formulated diets are mainly silkworm pupae, fish meal, starch, yeast, casein, vegetable meal supplemented with oil and vitamins and minerals.

Practical diets of rainbow trouts generally contain 42-48% proteins and 16-24% lipids depending on the life stage of the fish. The recommended levels of protein and fat in trout diets are as follows.

Fish stage (trouts)	Recommended level (%)	
	Protein	Fat
Starter diet (fry)	45-50	16-18
Grower diet (fingerlings)	42-48	20-24
Broodstock diet (maturing fish)	35-40	14-16

The FAO/UNDP recommended dietary incorporation of non-conventional feed sources for rearing trout fry and fingerlings. It contains 53% fresh bovine liver, 20% bovine lungs, 10% fresh bovine blood and 10% wheat bran and 6% wheat flour, which is supplemented with 0.5% bone meal and 0.25% each salt and vitamins mixture. The calculated levels of nutrients and energy in this diet are 50% crude protein, 1.6% methionine + cystine, 4.8% lysine, 1% calcium, 1.2% phosphorus and 4.0 kcal/g digestible energy (DE). A special diet developed for rainbow trout at Himachal Pradesh consists of fish meal, whole wheat, yeast powder, deoiled linseed oil, shark liver oil, vitamins and minerals, sodium alginate, di-methionine and choline, which contains moisture 9.97%, crude protein 57.68%, ether extract 9.38%, crude fibre 1.35%, total ash 11.58% and insoluble ash 0.35%.

At the Directorate of Coldwater Fisheries Research (DCFR), Bhimtal, Uttarakhand, a diet was developed using local ingredients for feeding trouts, which contains 2.76% moisture, 48.12% crude protein, 10.62% ether extracts, 24.74% nitrogen-pre extract (NFE), 1.92% crude fibre and 11.04% ash. Best results in raising fingerlings to table size fish at Kashmir Trout Farm were obtained with feeding formulated diet containing local ingredients, containing 9.02% moisture, 47.47% crude protein, 15.85% ether extract, 17.89% NFE, 1.37% crude fibre and 8.40% ash.

Feeding practices: There is a general principle that fry and fingerlings of rainbow trout should be over-fed for their growth, provided over-feeding does not pollute water. Rainbow trout are fed in the form of small particles from first feeding till they reach the size at which they become capable of ingesting small pellets (crumbles). As they grow, they are shifted to feeding with larger pellets. Feed pellets smaller than 1 mm size are being produced in many countries that provide further scope to switch over from crumbles to pellets for small fishes of 1.5-2.0 g size. Feed pellets are delivered by hand, mechanical feeding systems and demand feeders. Fry and fingerlings are generally fed at frequent intervals as much as 4-times per hour for first feeding fry and therefore, mechanical feeders are known to work best. Provision of demand feeders can also improve feed utilization and reduce wastage.

Mahseer diet

Generally, mustard oilcake, wheat bran, wheat middlings, rice polish and rice bran are used for raising mahseers. Various artificial diets have been formulated by the DCFR, Bhimtal, for rearing golden mahseer at its early stage. The formulated diets mostly comprise soybean meal, silkworm pupae, rice/wheat starch, casein, gelatin and cod liver oil fortified with vitamins and minerals at appropriate levels, containing about 45% protein. Feed containing rice bran, mustard oilcake, silkworm pupae, fish meal and a local herb (*Gymnura crapidoides*) has been found satisfactory for chocolate mahseer (*Neolissocheilus hexagonolepis*) as evaluated at Barapani Fish Farm in Meghalaya.

Diet prepared from 50% deoiled silkworm pupae, 22% rice bran, 10% groundnut oilcake, 17% tapioca flour and 1% vitamins and minerals, with proximate composition of 6.14% moisture, 40.04% crude protein, 5.69% fat, 14.6% NFE, 10.43% crude fibre and 14.60% ash, was quite effective for Deccan mahseer (*Tor khudree*). Incorporation of 17-alpha methyltestosterone at 7.5 mg/kg in a formulated diet has showed positive influence on growth of mahseer.

Seabass diet

Information on practical diets for seabass (*Lates calcarifer*) is a scanty. However, there exists an account of feed and feeding of seabass for its various stages of life

cycle. It is known that zooplankton is the most suitable nutritional food for early stages of larval rearing and micro-crustaceans are the most preferred natural food for fry.

Feeding practices: Two-day-old larvae start feeding from exogenous sources, and rotifers are most preferred by fish which are inoculated to rearing tank daily at 10-20 nos/ml of the water. Brine shrimp nauplii are provided to 8-10 day-old seabass fry at 1.0-1.5/ml, with further progression in age, food is changed gradually and 20-25 day old fry switch over to feeding of minced fish meat from brine shrimp. In South East Asia, raw minced or chopped trash fish is traditionally used for feeding fry. The fish meat is given mostly in the range of 20-30% of the body weight.

In South-East Asian countries, farmers use several types of feeds. The 25-day-old fry are fed on moist weaning diet prepared with minced trash fish added with vitamins and fed twice daily to satiation. The crumbled dry pellets are also fed in conjunction with moist weaning diet. Crumbled shrimp diets and top dressed with fish oil (8-10%) can also be used for feeding seabass fry. For day-to-day on-farm feeding, moist pellets and fresh feed thus is prepared daily. The formulated diet generally comprises fish meal, grains or grain byproducts, vitamin and mineral premix and fish oil. Floating or slowly sinking extruded dry pellets containing 50% proteins and 20% lipids are also found suitable. In Australia, extruded pellets are fed twice a day to fish weighing 20-100 g, which is reduced to one-time feeding a day for fish of more than 100 g weight.

Milkfish diet

Milkfish (*Chanos chanos*) is a highly potential candidate species for brackishwater aquaculture because of its fast growth, efficient use of natural food, disease resistance and readiness to accept variety of supplementary feeds. Not much information is available about artificial formulated diets being used in Indian aquaculture. However, detailed accounts of formulated diets and feeding practices reported for the species are discussed here.

Micro-bound larval diets using carrageenan as a binder were developed, showing high dietary performance. The micro-bound larval diets are fed in conjunction with rotifers till day 21. The artificial formulated diet is used to replace *Artemia nauplii*. Diet with 40% protein that comprised 30% fish meal, 20% soybean meal, 15% squid meal or shrimp meal, 25.45% wheat flour, 8% marine fish oil, 10 vitamin mix, 0.5% trace minerals, and 0.05% antioxidants was found quite effective.

The fish is a herbivore. Compound diets containing 23-27% protein are found suitable in deep-water pond culture in Taiwan. Though milkfish use proteins of animal origin better than those of plant materials, yet diets prepared from swamp cabbage, sweet-potato, *ipil-ipil*, cassava replacing 15% fish meal were utilized efficiently. The fish accepts formulated diet in moist form as those of dry sinking or floating pellets. The broodstock diets, however, should contain high quality protein and marine fish oil enriched with PUFA, and diets should have extra vitamins and minerals. Diet with 25% fish meal and 34% soybean as major protein supplements together with other ingredients was found suitable for broodstock development.

Feeding practices: On absorption of yolk sac, live fish food organism such as rotifers (*Brachionus* spp.) are fed to fish larvae for 14-days, and from 15 to 21 days they are fed with newly hatched brine shrimp (*Artemia nauplii*). Feeding rates are decided according to fish size, water quality (temperature, salinity and dissolved O_2), feeding frequency, nutrients and energy content of diets. For diets containing 40% protein and 3.45 kcal/g GE, daily feeding rate of 20% of the biomass is found optimum for 7.7 mg fish as observed in indoor trials. The fish of 0.6 g are fed at 9% of the body weight. In presence of natural fish food organisms in ponds, the fish are fed 23-27% protein diets at a daily rate of 3-4% of body weight. In ponds, fish are fed 2-3 times a day. Diets are offered by hand or by automatic feeders. Automatic feeders are commonly used in Taiwan and in intensive culture in the Philippines.

Freshwater prawn and marine shrimp diets

The traditional feed of prawn larvae consists of zooplankton, chopped fish and mussel meat. Most preferred larval food is *Artemia nauplii*. Steamed chicken egg custard is used for indoor larval rearing. Rotifers, cyclops, copepods and insect larvae can also be fed to prawn larvae along with *Artemia* in prawn hatchery. *Acetes* spp. (fresh/ frozen) are used for feeding shrimp larvae. Many hatcheries continue to prepare their own larval feed because of high cost of commercial feeds, and live foods remain an essential feeding component of hatchery operation. Micro-particulate feed containing 8% moisture, 58% crude protein, 16% crude fat, 1% crude fibre, 8% ash and 0.2% NFE is reported to be a good larval feed. Other larval feeds that are developed are micro-encapsulated and micro-bound diets.

In majority of diet formulations, soybean meal may be used as a source of plant protein replacing fish meal up to 45% in feed. Fish oil is found best for juvenile prawns, followed by beef tallow, soybean oil, copra oil and pork liver in descending order. Cod liver oil and soybean oil in 1:1 has proved effective in diets for juveniles. The FCR values for the shrimp feeds available in India as estimated by the Central Food Technology Research Institute, Mysore, vary between 1.0:1.2 and 1.8 for imported feeds and 1.0:2.2 and 2.9 for indigenous feeds. The Central Institute of Freshwater Aquaculture, Bhubaneshwar, has come out with standardized diet formulations for various stages of giant freshwater prawn, *Macrobrachium rosenbergii* using local ingredients. The proximate compositions of different diets are crude protein 36%, crude fat 8% and energy 3.8 kcal/g for broodstock diet; crude protein 50%, crude fat 8% and energy 4.5 kcal/g for larval diet; crude protein 45%, crude fat 8% and energy 4 kcal/g for post-larval diet; and crude protein 32%, crude fat 5% and energy 3.6-3.8 kcal/g for grow-out diet. These have been developed and have commercial application.

Feed composition and pellet size vary according to age and size of prawn or shrimp. Squid meal, shrimp meal, mussel meat meal, fish meal, shrimp-head meal, earthworm meal and fish meal are generally used as animal protein in crustacean diet formulation. Ingredients like shrimp-head, *Squilla*, small shrimp and crab are not only very good source of minerals but also of pigments. Fish meal is the main source of animal protein used in prawn and shrimp feeds.

Some of the formulation developed for grow-out culture of freshwater prawns *Macrobrachium* spp. are: (*i*) fish meal 15%, soybean meal 15%, groundnut oilcake 42%, rice bran 26%, and vitamin and mineral premix 2%; and (*ii*) fish meal 15%, soybean meal 15%, groundnut oilcake 60%, rice bran 8% and vitamin and mineral premix 2%.

In addition to amino-acid balance, other critical nutrients as required for prawn/ shrimp reproduction are long chain polyunsaturated fatty acids, steroids and carotenoids, which are derived from the marine sources. Balanced shrimp feeds require essential amino acids at higher levels and lipids rich in PUFA along with specific feed attractants, n-3 fatty acids (EPA, DHA) and vitamins, ascorbic acid, and some specific minerals are also required for better growth and survival.

The Central Marine Fisheries Research Institute, Kochi, has developed shrimp feed named as Mahima (Table 31.16). As in carps, probiotic and phospholipids supplementation in shrimp feed is also on the rise, improving feed quality. The probiotics (yeast and bacteria) in live form or as processed materials and soylecithin as phospholipids compounds are used in artificial feeds. Probiotics are also directly added to water to enhance level of natural microflora in pond ecosystem or in the gastrointestinal track. Its supplementation has positive impact on growth and survival and provides resistance against diseases while improving feed efficiencies. Beneficial effects phospholipids on growth and survival of shrimp are well known. The phospholipids containing choline or inositol and essential fatty acids are most effective.

Table 31.16. Formulations of different shrimp diets

Feed	Ingredient	Composition (%)
1 (Mahima feed)	Soybean flour	20
	Rice-bran	20
	Mantis shrimp meal	10
	Prawn head meal	15
	Coconut oilcake	12
	Wheat-flour	20
	Sardine oil	1
	Vitamin/mineral premix	2
	Vitamin-mix	0.5
2	Fish meal	27
	Meat and bone-meal	10
	Soybean meal	15
	Expeller sesame cake meal	5
	Expeller groundnut meal	5
	Maize	4
	Coconut cake	10
	Extracted rice-bran	10
	Leaf meal	5
	Tapioca	8
	Vitamin-mix	1
3	Fish meal	16.3
	Shrimp meal	13.2
	Soybean meal	24
	Ricebran	21.4
	High gluten wheat-flour	15
	Nutribinder	5
	Oil (type not stated)	2.5
	Dicalcium phosphate	1.9
	Trace mineral-mix	0.2
4	Fish meal	15
	Squid meal	15
	Shrimp head meal	15
	Extracted soybean meal	15
	Rice bran	14
	Bread flour	15
	Cod liver oil	5
	Soybean lecithin	2
	Vitamin/ mineral mix	3
	Cholesterol	1

Feeding practices: The freshly hatched *Artemia nauplii* are fed to larvae 4-5 times a day during early larval stages (stage-II to VI) and at later period, once during late evening in combination with wet larval feed which is usually given during the day time. The brine shrimp nauplii are fed at 5-50 nauplii/ larva/day and about 2 kg of *Artemia* is needed to produce 100,000 post-larvae. Egg custard, minced fish, molluscan meat (more than 50% protein) are considered as wet larval feed which are fed to

Table 31.17. Level of acceptance of some larval diets by giant freshwater prawn, *M. rosenbergii*

Diet	Level of acceptance
Principal diets	
Artemia spp. *nauplii*	Highly acceptance to all larval stage
Tubifex spp. cut pieces	Good acceptance
Acetes spp. suspension	Good acceptance
Freshwater mussel (*Lamellidens* spp.)	Good acceptance of gonad and foot tissue
Mussel meat + egg custard + milk powder + vitamin mineral-mix	Active feeding by Zoea IV to Zoea XI
Fish flesh + egg custard + wheat flour + milk powder + vitamin mineral-mix	Active feeding by Zoea IV to Zoea XI
Secondary diets	
Mushroom (cut-pieces)	Active feeding by Zoea IV to Zoea XI
Soybean products	Active feeding by Zoea IV to Zoea XI
Freshwater snails	Gonad tissue only
Marine bivalves	Gonad tissue only
Stomatopod meat (*Squilla* spp.) suspension	Moderate acceptance of the tissue
Earthworm (cut pieces)	Active feeding by Zoea VI to Zoea XI
Fish flesh	Good acceptance
Egg custard	Good acceptance

prawn larvae at hourly intervals at 50-250 g/larva/day depending on the larval stage (Table 31.17).

On acclimatization to freshwater, post-larvae (considered as seed) switch over to feeding of formulated diets which are fed at 100% body weight of the prawn stocked. However, with progress of culture period the rate feeding is gradually reduced depending on the prawn size. Towards the end of the culture period, it is restricted to only 2-3% of biomass. In grow-out ponds, feeds are provided by broadcasting all along the pond margin and also in check-trays that are placed at different points in pond. As prawns are more active during night, it is always desirable that feeding is done during late evening and early morning.

In marine-shrimp farming, practical diets are provided at 10% body weight/day for post-larvae, which is gradually reduced to 2-3% body weight. Daily observations on feed consumption and pond water quality are recorded for deciding feed quantity to be delivered.

Marine ornamental fish diets

Formulated feed for marine ornamentals is not indigenously produced and its demand is met through imports with a price tag in the range of ₹ 4,000/ kg. With the closing of life cycles of several marine ornamental fish which includes the popular clown fish and damsel fish by Central Marine Fisheries Research Institute (CMFRI), Kochi, their maintenance in the aquaria (aquariculture) posed several challenges in their health and longevity. The fish should be healthy and should retain their color for long for which food and feeding has to be very appropriate. The CMFRI has developed and launched dry formulated feeds named Cadalmin™ Varna. (*Varna* means colour in almost all Indian languages.)

Varna series of scientifically evaluated formulated feeds is an import substitute. These feeds contain 40% protein, 9% fat, 39% carbohydrates, 7% ash and less than 2% fiber, marine protein, soy protein, wheat flour, oil, colour imparting nutrients like carotenoids from natural sources, nutraceuticals (immune promoters), microbial products (probionts) and antioxidants. They are slow sinking crumbles available in three particle sizes, 0.25 mm, 0.75 mm and 1 mm produced through twin-screw extrusion technology which is the state-of-the-art in aquatic feed production. Most of the ornamental fish feeds are imported mainly from South East Asian countries without any assurance about their quality and quantity. It is in this scenario, import substitutes developed through indigenous research by CMFRI made an impact.These feeds available through the Agriculture Technology Information Centre (ATIC) of CMFRI are sold in 50 g pouches and containers costing ₹ 20/ pouch, i.e. ₹ 400/kg. The CMFRI is on the lookout for a commercial partner for upscaling the product and making it available in the open market. These feeds being used for feeding freshwater ornamental fish in the farms of Kerala Aqua Ventures International (KAVIL), Kerala and by the Ornamental fish Farmers Association of Kerala in their homesteads. Another series of feeds which is less costly and meant for freshwater ornamentals is developed and evaluated.

Feeding directions: As a thumb rule feed @ 2-3% of the fish body weight once in a day. Feeding quantity can be calculated from the indicators given here.

Indicators: Fish length-weight indicator (clown fish and damsel fish; values are indicative and may vary).

Length (mm)	*Weight (mg)*	*Feeding rate*
• <10	<200	6 mg
• >10-20	300-800	15-24 mg
• >20-30	900-1,500	18-45 mg

- 1 pinch of 0.25-0.50 mm feed = 100 to 150 mg (sufficient for feeding 20-30 fish of <10 mm)
- 1 pinch of 0.75 mm feed = 150-200 mg (sufficient to feed 10 - 20 fish of >10-20 mm)
- 1 pinch of 1.0 mm feed = 200-250 mg (sufficient to feed 5 - 10 fish of >20-30 mm)

SILO feed

The waste generated during processing of tuna was converted into a liquid protein source for animal feed preparation. From this, a fish feed under the brand name of SILO feed was developed jointly by the CIFT and CMFRI under NAIP. Feeding trials conducted by the CMFRI revealed that it is a promising feed for cultivable fishes such as sea bass, grouper and cobia. The feed was also for trout and catfishes tested at the CIFA and DCFR. An average 3,000 tonnes of tuna wastes will be generated annually at Lakshadweep islands, and fishermen bury the wastes in the beach itself creating serious environmental problems and health hazards. The estimated tuna wastes at Agatti alone are 550 tonnes. After conducting the feasibility study, proposal for establishing a feed mill in one of the islands will be proposed. In the feed, protein content is 40% and fat 8% on a dry weight basis.

Techno-economic viability of Silo feed: In Agatti island 1,378 tonnes of tuna are landed annually and 550 tonnes of tuna wastes are generated. The wastes are buried in the beach by the fishermen and on decomposition the wastes are leached into the sensitive coral reef ecosystem creating environmental and health hazards to the islanders. The dry feed that could be produced from the wastes will be 550 tonnes with the addition of other ingredients. The estimated cost of production on a laboratory scale is ₹ 34/kg. The cost of feed currently available in the market is ₹ 60/kg. There is a heavy demand for fish feed as fish farming activity has been on the up rise recently due to the availability of hatchery produced seeds. Recently CMFRI succeeded in hatchery production of a high value fish cobia and heavy demand for the seed is expected as this is a fast growing fish. The revenue generation expected from sale of feed is ₹ 2.2 crore if the feed is sold at ₹ 40/kg. The capital cost for establishing a feed mill to produce 500 tonnes/annum is ₹ 60 lakh. The technology will be transferred to the entrepreneurs after a feasibility study.

Mechanical feeders

Different types of mechanical feeders have been developed to reduce labour cost involved in feed management. Each feeder essentially consists of a hopper, a regulator, a dispenser and a controller. The feeders are classified as non-demand feeders and demand feeders. Auger, disc, drop and pneumatic feeders are non-demand feeders, which have different dispensing mechanisms to release required quantities of feed at regulated intervals in a farm. Demand feeder delivers feed in ponds upon receiving signals from fish and demand feeding is always desirable as it allow fish to feed *ad lib.* (Table 31.18).

Table 31.18. Advantages and disadvantages of common feeding practice in aquaculture

Type of practice	Advantages	Disadvantages
Hand feeding to satiation	Best assurance of maximum feeding effectiveness; may decrease size variation; higher food consumption; higher growth rates	Labour intensive; may result in higher FCR; carcass fat levels may increase
Use of feeding charts (in conjunction with automatic feeders)	Less labour intensive	Large pond sizes preclude accurate estimates of fish biomass; low predictability of feed consumed at different temperatures; capital-intensive
Demand feeders	Labour saving; permit fish to feed *ad lib.*	Size variation higher; all individuals may not be able to feed to satiation; hierarchy is manifested

Feed preparation must be done on logical approach to simple formulations that should be location-specific and resource-oriented using a large proportion of alternative protein sources with due consideration for less-expensive feeds to support sustainable and economically sound aquaculture. Establishment of regional feed centres should be given due priority to understand and identify fish feed related problems for redressal that may go a long way to village-level production of improved farm-made feeds

through small feed mills, particularly by small farmers, who account for more than 80% in India.

Issues

- Competition between fish, poultry and dairy feed industries for common feed ingredients.
- Non-availability of cost-effective quality fish meal and fish oil for fish feed.
- Lack of adequate knowledge of fish farmers on feed technology for farm made feed preparation, storing and application.
- Road map for industrial production of fish feeds.

Recommendations

- Use of feed pellets to reduce the feed pilferage and efficient utilization nutrients and also to reduce the nutrient and organic load in the culture environment for sustainable and eco-friendly fish farming.
- Use of more and more locally available non-conventional agro-byproducts as fish feed ingredients.
- Improvement of digestibility and nutrient availability of conventional and non-conventional fish feed ingredients.
- Popularization of farm made feed preparation, feeding methods and feed storage techniques among fish farmers.
- More and more specialized fish feed plants are to be established under public-private partnership, and the animal and poultry feed plants are to be encouraged to produce aqua feeds as well.
- Establishment of cottage feed/mini feed industries should be given priority.
- The existing regulations are to be imposed on the fish feed industries for quality assurance. While formulating standards for quality, feed particle and pellet size, fiber content, water stability and permitted inclusion levels of steroids antibiotics, pigments etc. need to be monitored.
- The aquaculture feed industry should be granted a waiver on tax concession for the fish feed ingredients.

32. Fish and Shrimp Health Management

Fish are poikilothermal aquatic animals, to survive they need continuous acclimation with the environmental changes which occur due to alterations in the water quality and because of other anthropogenic factors. Knowledge of the environmental requirements is essential to maintain good growth and health of fishes.

Biological requirements of fish and presence of toxic factors in water-bodies

Temperature: Fishes are often subjected to the hazards of rapid temperature changes in tropical waters either due to daily variations in water temperature in shallow waters or thermocline in deeper water-bodies, due to thermal effluents or simply due to stocking of fishes into warmer receiving waters. These temperature changes, though sub-lethal, can place a stress of considerable magnitude on the homeostatic mechanism of fishes, both on defence mechanism and susceptibility to disease. In winter, due to low water temperature, the immune system of fish remains depressed, making the fish very susceptible to infection.

Light: Normal orientation, movement, colouring, feeding and other physiological activities like breeding, gonad maturation are dependent on light. Sudden spot lighting sometimes causes fishes to panic, they attempt escape and a greater shadow can be fatal. Excess of light stops photosynthetic action and may cause sunburns of fishes. Use of bulb at night to increase water temperature during winter may heavily attract fish to the light source leading to loss of orientation, gas accumulation and death of fishes.

Dissolved gases: Dissolved oxygen (DO) and nitrogen are of great importance for fishes. Concentration of oxygen in air is 260 mg/litre but it is scarce for fishes in water (0 to 14 mg/litre). Nitrogen is biologically inert. Oxygen is essential for survival of fish and depletion of dissolved oxygen in water below 2-4 ppm will result in asphyxia and death in fishes. The minimum amount of dissolved oxygen required for good growth of fish is 5 mg/litre. However, supersaturation of both oxygen and nitrogen in water may cause gas embolism. In acid water, carrying capacity of haemoglobin is reduced. CO_2 is very soluble in water but its minimum presence in water is due to its less availability in air (0.04%). For healthy growth of fish 3 mg/litre or less of free CO_2 is permissible in water-bodies. High CO_2 concentrations are almost always accompanied by low DO concentrations.

***p*H:** The recommended *p*H range for optimum growth of fish is between 6.5 and 9.0. Fish and other vertebrates have an average blood *p*H of 7.4. A desirable range for conducive water *p*H would be close to that of fish blood (i.e. 7.0 to 8.0).

Alkalinity: A total alkalinity of 20 mg/litre or more is necessary for good productivity and for good growth of fish, the ambient water should have alkalinity more than 180 mg/litre.

Ammonia: Ammonia in water is extremely toxic, and even relatively low levels pose a threat to fish health. It is known that NH_4^+ is harmless to fish but NH_3 is toxic. Fish continually excretes metabolic ammonia directly into the surrounding water via gills where it gets diluted in natural waters but not so in confined waters.

Hydrogen sulphide: It is produced by chemical reduction of organic matter in water-body that accumulates and forms a thick layer of organic deposit at the bottom. The bottom soil turns black and a rotten egg smell is discharged. The maximum acceptable level of undissociated hydrogen sulphide is 0.002 mg/litre.

Suspended solids: These are solid particles (> 0.45 μm) arising from natural weathering of rocks, land erosion or wastes associated with certain industries like coal mining, sound and gravel extraction. It affects the gill tissues of the fishes depending on the nature of the solid. Turbidity caused by suspended solids may also reduces the water transparency and thus primary productivity.

Metals: Effluents from mining industry and from domestic use are the most common source of heavy metals, namely copper, lead, mercury, zinc, chromium, cadmium, manganese and iron. The toxic effects of metals on fish are inhibition of various metabolic functions in fish. Most metals dissolve more easily in acid water (*p*H < 7). Therefore acid waters usually contain higher concentrations of metals than neutral or alkaline waters.

Pesticides: The pesticides enter the water-bodies through various means like direct and intentional use for parasite control, through run-off from sprayed agricultural field, or as washings of spraying equipment, plant crops in water etc. The pesticides of importance causing pollution in water are (*i*) organochlorines, which are very stable but are more toxic to fish; (*ii*) organophosphates, which are less stable; and (*iii*) carbamates. At high doses, pesticides may cause acute mortality, and in low concentrations they inhibit various metabolic pathways leading to low fish survival and poor growth, low breeding success and suppressed fish immunity.

Sewage: Sewage effluents discharge frequently reduces the water quality for fishes. Oxygen depletion due to its high Biological Oxygen Demand is the most common result of such discharge that may often lead to mass fish mortality. Sewage-derived inorganic nutrients (phosphate, ammonia and nitrate) may stimulate excessive algal blooms. Sewage may also be a potential source of heavy metals and polychlorinated biphenyls.

Biological organisms: Animals other than fish may be reservoirs of infection as well as intermediates in the life-cycle of many parasites. Toxin-producing algae like *Microcystis* and *Anabaena* spp. under suitable environmental conditions produce bloom condition. The viscous scum of algae causes its mass mortality. The dead and decomposing cells release enough breakdown products or toxins harmful to fish. Microorganisms above certain critical concentrations in water may cause various pathological conditions in fish.

Anatomy and physiological mechanism of fish

Anatomical features of fish

Skin and scales: The skin is semi-permeable and helps save the fish from the problems due to osmosis. The mucous cells of the skin give protection against an adverse environment by reducing permeability of epidermis and protection against infection. Scales give added protection to the fish by preventing entry of pathogens.

Fins: Dorsal, pectoral, pelvic, caudal and anal fins of fish help in maintaining upright position, turning, steering, propulsion or braking. However, for movement in water fishes have to face great resistance termed as fluid drag. To overcome the resistance, body muscles help in dragging the fish through water by wriggling movement from the anterior end to the posterior end of the body.

Muscles: Fishes have two types of muscles – dark and white. Dark muscles are capable of producing energy through aerobic mechanism as they are richly vascularized. White muscles produce energy through anaerobic process and build up lactic acid which is the end-product of carbohydrate metabolism.

Gills: Respiratory organs of fishes are their gills, though some fishes have accessory respiratory organs. Freshwater fishes use their gills for excretory purposes also. There are four pairs of gills in teleosts. These are borne on the first four branchial arches. Each gill filament is composed of several lamellae. Lamellae receive venous blood through afferent artery from ventral aorta and the blood carries away oxygen from lamellae through efferent arteries to the dorsal aorta. Oxygenation of blood is done by the process of diffusion. There are chloride cells at the base of the gill filaments to regulate osmosis.

Swim bladder: It is an organ for maintaining buoyancy of the fish. Generally there are two types of swim bladder, namely physostomous and physoclistous, having connection with oesophagous or not respectively. Naturally, fishes having physoclistous swim bladder takes a longer time in their vertical movement.

Digestive tract: Like all other vertebrates, digestive tract of fish starts with the mouth which may be either a tubular sucking type or a grinding grasping type. However, according to food preference, fishes are classified as herbivores, carnivores and omnivores. Accordingly mouth of fishes show variations; some fishes have teeth and others do not. From buccal cavity (which has taste buds) the food passes to the stomach (absent in cyprinids). In stomach, the food gets mixed with mucous and gastric juices which is acidic. Rest of the alimentary canal is alkaline in nature because the secretions therein are alkaline. As such, the whole length of alimentary canal of cyprinids is alkaline. The intestine opens to the exterior through the anus which lies adjacent to the urinogenital aperture.

Haematopoetic tissue: Blood-forming organs of fishes are anterior kidney, liver, spleen and thymus. Haemoblasts give rise to small and large lymphoid haematoblasts. Small lymphoid haematoblasts are transformed into erythrocytes (RBC) and probably into thrombocytes. Large lymphoid haematoblasts are transformed into granulocytes. However, circulating macrophages may have relation with both small and large lymphoid haematoblasts cells.

Sensory organs: Sensory organs of fishes are: (*i*) olfactory sacs, each of factory sac possess two apertures of which the anterior is provided with a valve. However, nostrils are not meant for smelling. Smelling and testing facilities in fishes are dependent on a chemoreceptor system. Chemoreceptors are distributed over the body surface in

some fishes; (*ii*) Barbels, these serve the purpose of touch and taste. Taste buds are generally present in mouth but may be found in oesophagus also. Barbels are of great help in bottom dewelling fishes, where eyes are of little use; (*iii*) Eyes are specialized organs in fish for looking in aqueous medium. The eyes of a fish has spherical lens which is covered by cornea and the same is supported by retractile muscles and ligaments. Eyes of certain fishes (which prey in air) are specialized, can see in air and has capacity to change refractive index; (*iv*) Auditory organ, specialized otolith and lateral line are the auditory organs of fish. The former is mainly a gravity detector helped by three semi-circular canals. Lateral line system of a fish is composed of several units, each opening through a scale. Each unit is a chamber which receives stimulus from an adjacent chamber through a pore and sends information to the other adjacent chamber through another pore. Thus the chambers, arranged in a row, form a continuous tube. In each chamber exists, an organ known as cupula which receives nerve fibres. Each cupula is a sensor of a neuromast organ and is composed of sensory hair or neuromast hair. Neuromast organs extend on either side of the trunk and tail.

Physiological mechanisms in fish

Swimming: All fishes can swim but swimming capabilities differ. Some are very active while others are sedentary. A fish has to swim through a medium which is 800 times denser than air. Energy requirement to swim fast is multiplied manifold when the normal speed of a fish is doubled.

Respiration: Like all other organisms, fishes need oxygen for their metabolic activity but they live in an environment where the concentration of oxygen is lower than in air and it fluctuates greatly. Transfer of oxygen from water to the blood of a fish is a physiological process of diffusion. But this transference becomes complicated or difficult when the ambient water itself is deficient in dissolved oxygen.

Digestion: The food taken in by the fishes is digested by different enzymes which act upon carbohydrates, fats and proteins. Pepsin secreted by stomach acts on protein. Liver secretes bile to emulsify fat and to transform the same into glycogen. Pancreas secretes pancreatic juice to act upon proteins, carbohydrate and fat. The ducts of both these glands open in the anterior part of the intestine.

Blood-circulating mechanism: Blood is a fluid which interacts with every organ of a fish flowing through arteries, capillaries and veins. The ventricle acts as a pump where the pressure for flow is generated. The pressure falls when blood reaches the gills, falls further as it reaches dorsal aorta. The pressure becomes almost nil when the blood flow reaches the capillaries. The blood reaches the auricle back into the heart, by almost a negative pressure as if by suction and by rhythmic squeezing of fish muscles during swimming. During a state of stress, epinephrine has a role to play in regulating blood flow. Two hormones– acetylcholine and adrenaline–regulate blood flow through gill filaments. The former controls the flow when the demand for oxygen is low, keeping the blood in the internal cavities of the gill filament. During stressed condition of a fish under the influence of adrenaline epinephrine, blood flow is routed through gill lamellae when the gas exchange is maximum.

Osmoregulation: Freshwater fishes live in a hypotonic medium while marine fishes live in a hypertonic medium. As such, osmoregulation of a fish is a complex process which mainly governs homeostasis of a fish. In freshwater fish a lot of ambient water gets diffused in the fish through gill epithelia. So to maintain salt water balance the fish excretes almost ion-free urine. Marine fishes live in a hypertonic medium; so a lot of water containing Na^+, K^+, Cl^- ions comes out of fish gill epithelia. As such for osmoregulation, a marine fish has to spend a lot of energy to maintain homeostasis. Kidneys of a freshwater fish also play an important role in osmoregulation and resultant homeostasis.

Mechanism of the endocrine system: Endocrine systems of fishes have some diffused as well as some clear-cut glandular structure devoid of ducts. Pituitary, interrenal, corpuscles of stannius, chromaffin body and urophysis are the usual ductless glands while thyroid and pancreas are the diffused ones. Pituitary secretes prolactin, adrenocorticotropin hormone, thyroid-stimulating hormone, gonadotropins, somatotropic hormone, melanocyte-stimulating hormone and corticotropin. Thyroid secretes thyroxin, calcitonin is secreted by corpuscles of stannius. Estrogen and testosterone are secreted by the gonad; corticosteroids (including cortisol and cortisone) are secreted by interrenals (adrenal). Pancreas secretes both insulin and glycogen. Several urotonsins (Arginine, vasotocin) are secreted by urophysis. Pituitary controls the activities of other ductless glands but the pituitary itself is controlled by the brain of fish.

Environmental stress and related fish diseases

Fish stress: The aquatic environment is dynamic and constantly subject to changes in its physical, chemical and biological components. These changes along with the procedure involved in intensive fish culture technologies, which collectively we call stressors severely stress the physiological systems of fishes.

It is obvious that the duration and magnitude of stressor will determine the impact on fish and stress it will produce. The physiological response elicited initially is adaptive, i.e. they help maintain homeostasis. However, they may ultimately become maladaptive in chronic situations.

For assessing impact of stress in fisheries a useful framework developed is to consider stress response in terms of primary, secondary and tertiary changes that involve succeeding higher levels of biological organization.

1. Primary response: Perception of a stress by central nervous system stimulates synthesis and release of hormones, cortisol and epinephrine from the interrenal cells and chromaffin tissue from the head kidney into the blood stream.
2. Secondary response: Blood and tissue alterations visualized are elevated blood sugar and reduced blood-clotting time. Diuresis begins followed by blood electrolyte losses and osmoregulatory dysfunction. Tissue changes include depletion of liver glycogen and interrenal Vitamin C, hypertrophy of interrenal body.
3. Tertiary response: It is manifested in reduction in growth, resistance to diseases, reproductive success and survival. Decreased recruitment to succeeding life stages results in population decline.

Stressors for fish: The stressors which elicit morphological and physiological responses in fish fall into four categories. These are:

(i) Chemical: These include stress due to water quality, pollutants and metabolic wastes.
(ii) Physical: Stress caused due to temperature and gas supersaturation.
(iii) Procedural: Stress due to handling, transportation, stocking or disease treatment.
(iv) Biological: Stress due to population density, confinement, diet composition and availability.

A fundamental management objective of all fish-rearing practices is to avoid and minimize stress on fish. This requires an understanding of stressors and their effects on fish and an ability to recognize fish that are under stress.

Stress diagnosis in fish: The various stresses commonly encountered by fishes can be due to sub-optimal water quality or due to cultural procedures. Deterioration of water quality such as decreased oxygen, increased ammonia or low or high *p*H and increased temperature, stress the fish, and are unsuitable for fish growth.

Some examples of stress response in fish are discussed here.

Temperature stress: A rapid sub-lethal temperature increase from 28°C to 35°C causes significant blood changes in carps. Increase in cortisol and decrease in interrenal ascorbic acid occurs. Hypercholesterolemia, hyperglycaemia and hyperlactemia are also evident accompanied by increased blood haemoglobin, haematocrit and stable protein levels. Compensatory responses are initiated within 72 hr. It is thus evident that fishes subjected to sub-lethal temperature stress should be given a metabolic recovery period of 72 hr prior to further stress being applied. Obviously in response to the stressors, the compensatory mechanism sets in for attainment of homeostasis in fish.

Cultural procedure stress: Fishes are frequently subjected to the stress of cultural procedures adopted by farmers like handling, crowding, transportation or a combination of all the three. These effects often become additive or synergistic with those of other stimuli (e.g. low unionized ammonia and dissolved oxygen) and can place a stress of considerable magnitude on the homeostatic mechanism of fishes.

Fishes subjected to crowding, handling and transportation stress in hundis for 1 hr are also subjected to additional stress of perceptible water quality changes. It is observed that there is a gradual depletion of dissolved oxygen from initial 6.8 mg/litre to 1.8 mg/litre, UIA from nil to 0.1 mg/litre and CO_2 from 2.0 to 6.6 mg/litre. Thus a hypoxic condition is created along with toxicity produced by rise in unionized ammonia levels. These stressors significantly alter some of the blood and tissue parameters in the fishes, namely plasma cortisol, glucose, lactic acid and liver glycogen, haemoglobin and haematocrit, compared to normal values. However, it is also observed that the fishes recover after 48 hr post-stress period. It indicates that the cultural procedures frequently adopted by the farmers significantly stress the fishes resulting in post-stocking mortality. For proper fish-health management fishes subjected to such stressors should not be further stressed within 48 hr for their metabolic recovery.

Thus it is apparent that the homeostatic mechanism of fish is continually being impacted by the normal demands of the aquatic habitat itself; coupled with it are the effects of aquatic pollutants and in many cases fish cultural practices, like handling, crowding and transportation. Although fishes very often do survive stressors for limited periods because of their homeostatic capabilities, marginal conditions should not be created in the aquatic environment. Knowledge generated on the physiological capabilities of fish should be used to set priorities and tolerance limits that will protect fish and aquatic ecosystem health.

Stress-mediated diseases: The incidence of fish disease is an indicator of environmental stress that is receiving serious attention as a method of biological monitoring for environmental quality. Fish diseases usually do not have single causes; they are outcomes of the many interactions among fish, their pathogens and the aquatic environment. If the environment deteriorates, stressed fish may be unable to resist the pathogens that they normally can ward off or coexist with. The fish disease in aquaculture facilities, often indicates that environmental conditions are marginal or poor, particularly if facultative pathogens are involved. In freshwater fishes, the stress-mediated diseases that indicate that the acclimation tolerance limit has been exceeded are those due to facultative bacterial pathogens normally present in surface waters.

Table 32.1. Stress-mediated diseases of fishes encounteded in freshwater-bodies

Disease (causative agent)	Environmental factors involved
Furunculosis	Crowding, handling and low level of D.O. in water
Gill disease (bacterial) (environmental)	Crowding, chemical irritants such as elevated ammonia, excessive particulate matter, low level of D.O.
Columnaris disease	Crowding, handling and higher temperature
Aeromonas spp. and *Pseudomonas* spp. Haemorrhagic septicemia	Low D.O. in water, handling, crowding, prior external parasitic infection, unhygienic condition and low temperature
Gill necrosis	Over-drugging with formalin chemical
Eye disease of *Catla catla* (bacterial)	Poor sanitary condition of ambient water
Dropsy of carps and catfishes (bacterial)	Poor sanitary condition of ambient water, over-stocking and chronic exposure to low D.O.
Parasite infestations (*Dactylogyrus*, Trichodinid parasites coppods)	Over-crowding, low oxygen, large-scale variation in rearing facilities, excess feed or fertilizers
Reddish blotches of *Hypophthalmichthys molitrics*	Poor sanitary conditions of ambient water, over-stocking and chronic exposure to low level of D.O.
Tail and Fin rot	Crowding, low D.O., improper diet, chronic exposure at sublethal level to contaminants
Epithelial ulcerations	Chronic, sublethal contaminant exposure
Epithelial tumours	Chronic, sublethal contaminant exposure
Skeletal anomalis (Scoliosis/lordosis)	Chronic adverse water quality, vitamin C deficiency
Trichodiniasis	Crowding, low level of D.O. and high levels of UIA in ambient water
Gas embolism	Supersaturation of O_2, N_2 in water
Exopthalmia	Deficiency of Vitamin B in diet
Impaired growth	Deficiency of essential amino acid in diet, unhygienic condition, low D.O., metabolite accumulation in ambient water

D.O., Dissolved oxygen.

The stress-mediated diseases of fishes encountered in the freshwater-bodies are given in Table 32.1.

Infectious diseases

These are diseases caused by living agents. These diseases can be grouped together according to the nature of their aetiology as described:

Pathogenesis: A successful pathogen, must first attach, evade host's defence mechanisms and multiply before onset of the disease. This is not easy because the body of fish is covered with scales and there are indefinite number of epidermal cells which secrete mucus to get rid of a pathogen trying to get lodged on a susceptible fish. Water taken in through mouth is also thrown out by means of gills and opercular space. It is, thus, difficult for a fish pathogen to find its entry into its host. If it finds a way through the mouth, the pathogen is to survive in the acid and alkaline media of the alimentary tract. An easier way, which a pathogen gets entry in its host is a lesion on the skin or though other openings like mouth, eye, nostrils etc. As soon as the pathogen enters into the circulatory system of its host, the former meets with various defence mechanisms of the latter.

Protozoans

Ichthyophthiriasis: The white spot disease or 'ich' is a common disease of freshwater carps. Affected fishes exhibit minute sugar grain like white nodular spots on the skin, fins and gills and are restless. The causative agent is *Ichthyopthirius multifilis.* The infective stage in the host is the migratory thereont which infests fish skin or gills. Here it grows as trophont (adult parasitic) and on reaching 1 mm size escapes from the host, moves slowly with the characteristic horseshoe-shaped macronucleus and encyst (to mont) on a convenient substrate. The tomont break to release the infective thereonts which remain infective for four days. The control of this infection is concentrated on the life stages outside dermal tissue of the host. This parasite can be controlled by daily bath treatment for 1 hr in 2-3% NaCl solution or 1:5,000 formalin for 30 min daily for 7 days. One of the best treatments for aquarium fishes is, to add 1 ml of 1% methylene blue solution in 5 litres of aquarium water and repeat the treatment for 1-2 days alternatively till recovery. Pond treatment advocated is application of 0.5 ppm $CuSO_4$ every week or 0.15 ppm malachite green.

Trichodiniasis: Various life stages of Indian major carps and catfishes are affected by this disease. Affected fishes show pale gills with a creamish coating due to excessive mucus secretion and mild hyperplasia. The causative agents are urecolariid ciliate species of the genus *Trichodina, Tripartiella* and *Trichodinella.* These are beautiful looking with the shape varying from a flat disc to a bell-shaped one. It attaches to the fish gills by means of the adhesive disc constituted by skeletal elements. It reproduces by binary fission. The presence of these ciliates in numbers >20 in 0.05 ml of gill mucus indicates deteriorating water quality. The treatment methods adopted are (*i*) water-quality improvement, (*ii*) diminishing stocking density of fish, (*iii*) bath treatment of fishes with 2-3% NaCl or 100 ppm formalin and (*iv*) pond treatment with 4-5 mg/litre $KMnO_4$ or 25 mg/litre formalin.

Costiasis: Heavy infestation by the parasites of the genus *Costia* (*Ichthyoboda*) causes this disease. It infests the gills and external surfaces of all species of freshwater fishes and is reported to proliferate at lower temperature (25°C). The affected fishes show bluish-white shade on the body surface. The parasite is oval or pea-shaped of about the same size as the skin cell. They are obligate parasite and the trophozoit cannot survive long without the host. Hence transmission occurs from fish to fish. These parasites are controlled by (*i*) bath treatment with 2-3% NaCl or 50 mg/litre $KMnO_4$ or 100 mg/litre formalin with aeration, and (*ii*) pond treatment with 25 mg/litre formalin or 5 mg/litre $KMnO_4$.

Myxosporean disease (white spots on gills or scales): Indian major carps gills are infected with white to creamish cysts ranging from 1 to 4 mm or more. In heavy infection the cysts assume a cauliflower shape, blocking the entire respiratory surface of gill with excessive mucus secretion and hyperplasia. Affected fishes are lethargic. The causative agents are the encysted spores of *Myxobolus bengalensis, M. catlae, M. hosadurgensis* and *Thelohanellus catlae.* Besides the gills, scales and body surfaces are also heavily infected with the cysts in *C. mrigala* and *L. rohita.* Affected fishes are lethargic with loose perforated scales and ulcerations. The causative agents are the encysted spores of *Myxobolus mrigalae, M. sphericum* and *M. rohitae*. The infective stage of the myxosporeans is the mature spore which is ingested by the fish from the water-body. On entering the fish the infective sporoplasma of the spore comes out as a small amoebula and penetrate the gut wall. This amoeba reaches the infected tissue possibly through blood stream where it becomes a trophozoit and increases in size to form a cyst. Here the mature spores develop. The life-cycle of myxosporeans offers them a high degree of protection against most control measures. Life-cycle stages which are vulnerable to control measures, occur within the tissues of the host and are not easy to reach. The spore though exposed outside is very resistant to chemicals. Thus the control measures are limited to prophylactic measures like (*i*) control spores from entering fish ponds, (*ii*) segregation of age groups as fry and juveniles are more susceptible. Therapeutic measures done are disinfections of pond after dewatering with Calcium oxide and drying for a month.

Helminth

Dactylogyrosis and gyrodactylosis: This disease affects fry, fingerlings and adults of the cultured, Indian major carps causing extensive losses. In dactylogyrosis the colour of the gills fades and there is excessive mucus secretion. In gyrodactylosis there is a fading of the normal body colour, dropping of scales and excessive mucus secretion. In general there is growth reduction and morbidity in affected fishes for both the diseases. Adults of these monogeneans attach to the host by a characteristic attachment organ called haptor, which produces damage to the attaching site. These monogeneans have a direct life-cycle involving a single host. *Dactylogyrus* is oviparous laying eggs which liberate free-swimming larvae. These larvae on locating a new host, become attached and

metamorphose into a mature worm. *Gyrodactylus* sp. is viviparous and liberates young worms which attach to a new host. The parasites can be controlled by therapeutics: (*i*) bath treatment with 3-5% NaCl for 10-15 min or 100 mg/litre formalin with aeration, (*ii*) pond treatment with 25 mg/litre formalin or 5 mg litre $KMnO_4$.

Black spot disease: Indian major carps and exotic carps *H. molitrix* manifest the symptom of black ovoid spot on the body surface. Their number may be few to hundreds. Affected fishes show growth reduction. The back pigmented spots or patches are overlaying cysts of the metacercarial larva of the parasite *Displostomum pigmentata* and other *Diplostomum* sp. These digenetic trematodes are oviparous and release eggs in water. A ciliated larva called miracidium hatches out and after swimming locates a molluscs, the first intermediate host. Here it transforms into a cercaria larva which is locomotary. It swims out and finds a suitable fish host, i.e. the second intermediate host. It penetrates and encysts into a metacerearial larval stage, prominently seen as black spots on the body surface. The life-cycle is completed when the fish infected with metacercaria is eaten by the final host, the bird. The control measures are primarily removal of the resident molluscan pollution (first intermediate host) in the affected water areas and the aquatic birds (final host) around it.

Ligulosis: Indian major carps in reservoirs and lakes are affected by this disease. Diseased fishes are dark coloured anaemic and the abdomen is distended because of the presence of large number of infective stage of the parasites. The causative agent is the plerocercoid stage of the parasite *Ligula intestinalis.* A typical avian cestode life-cycle represented by *Ligula* sp. commences with the release of its eggs along with the faceal matter of bird. They hatch out into a free-swimming caracidia larvae which are swallowed by cyclopoid copepods. Here they transform into procercoid larvae. These copepods when eaten by fish the larvae transform into the infective larval form, the plerocercoids. The life-cycle is completed when the infected fish is eaten by a bird *Anhinga melanogaster* in India. Control methods for lingulosis are limited to extermination of the definitive host, the ichthyophagous birds.

Acanthocephalan diseases: Indian major carps, catfishes and many other freshwater fishes are parasitized by these helminthes. There are no visible external symptoms to determine infection. These parasites inhabit the alimentary tract of fishes attaching themselves by their proboscis. The attachment site of the intestinal epithelia gets damaged and become foci of secondary infection. The causative agents of significance are acanthocephalans, *Acanthogyrus acanthogyrus, Acanthosentis antespinus* and *Pallisentis* sp. The eggs of these parasites are released along with the faecal matter by the infected fish. It contains the acanthor larvae. The eggs are eaten by an invertebrate host (arthropod) where the acanthor larva hatches out and penetrates the host body cavity and develops into the cystacanth larva. This intermediate host when eaten by fish the cystacanth develops into an adult worm. Proper treatment methods have not developed.

Crustaceans

Argulosis: Indian major carps are often affected by this parasitic disease. The affected fishes are restless with erratic swimming behaviour and loss of appetite. Sometimes, the infestation may be very heavy causing growth retardation and death. Attachment site of parasites shows sign of ulceration. The causative agent is the branchiuran parasites *Argulosus foliaceus, A. bengalensis* and *A. siamensis* in Indian fishes. The adult parasite is oval, flat and transparent to wheatish with two conspicuous black spots. It is visible moving freely on the surface of the host fish and is distinguishable into cephalothorax, thorax and abdomen. It matures inhabiting the host fish. After copulation the female leaves the host and lays sticky eggs on the submerged vegetation, rocks, sticks etc. The nauplius and other developmental stages, which are free living are parasitic to fish. The minimum period required for completion of the life-cycle of *Argulus* sp. varies between three and six weeks. Argulosis occurs when parasitized fishes enter unaffected water areas. It is controlled by (*i*) bath treatment with 3-5% NaCl or 100 ppm $KMnO_4$ or 2,000 ppm lysol for 5-10 seconds, (*ii*) pond treatment with $KMnO_4$ @ 5 mg/litre, (*iii*) mechanical removal of *Argulus* sp. sticky eggs by hanging bamboo mats or corrugated sheet in the water area and its removal and drying under the Sun after a week for killing the eggs. Pesticides are generally used by farmers, but it is often unadvisable and must not be used to treat the breeding stock.

Ergasilosis: The disease occurs in Indian major carps and exotic carps. Infestation occurs in gills, buccal cavity, operculum and gills. The parasitic copepods look like white bodies less than 2 mm long. Surfacing, lethargy and restlessness occur in affected fish. Infection increases with size of the fish causing damage to the gill tissue and retardation in growth. The causative agent is the adult female of the species of genus *Ergasilus*. The parasites are controlled by pond treatment with potassium permanganate @ 5 mg/litre or bath treatment of affected fish with 2-3% sodium chloride. Bath treatment with 1:1,000 glacial acetic acid for 5 minutes immediately followed by dip in 1% NaCl for 1 hr is also effective.

Lernaeosis: The disease is prevalent in Indian major carps. Heavily infected fishes become moribund with erratic movement and emaciation. Attachment areas on host exhibit sloughing off and ulceration. The causative agents are *Lernaea chockoensis, L. bengalensis* and other species of *Lernaea*. The adult female of this parasitic copepod, anchors to the fish by cephalic processes of the modified head. The parasites can be controlled by the same treatment as followed for *Ergasilus* sp.

Non-infectious disease

Gas bubble disease: Small fry and fingerlings of *C. mrigala* and *L. rohita* are affected by the disease. The young fishes show erratic movement and gradually die exhibiting a whirling movement. The abdomen is swollen. The balance of the fish is lost due to accumulation of large gas bubbles in the intestine. The disease normally occurs in water areas, where load of organic fertilizers is high at bottom of the pond. In the anaerobic condition existing at the bottom of such water areas the fertilizer or manure undergoes decomposition releasing gases in the form of bubbles. The fingerlings try to ingest them mistaking it for planktonic food and accumulate in the intestine thereby disturbing the fishes balance. The diseased condition can be avoided

by (*i*) stopping application of excess feed or fertilizer and (*ii*) by addition of freshwater to the water areas.

Gill disease: It is caused by a variety of water-borne irritants. These are suspended matters of < 0.45 μ size arising out of coal washings, cement or dust of silt arising out of various factory discharges. Besides these particulate irritants, other chemical irritants of the gills are ammonia, nitrite, fluctuating *p*H or low dissolved oxygen. The early sign of this gill disease is that fish respires heavily with greater opercular movement. Fish tends to use one pectoral fin only with excessive mucus secretion. In advanced cases fish cannot fully close the operculum because of gill swelling due to hyperplasia. The condition can be checked by proper water-quality management.

Algal toxicosis: Some organisms co-existing with the fish as components of the same environment might become harmful or lethal. Fry, fingerlings and adult of Indian major carps, exotic carps and other catfishes get affected. Surfacing of fish occurs with erratic movement. There is clogging of the gills by the algae causing respiratory distress and mortality in some cases. The causative agent is the bloom condition of blue green algae, *Microcystis* and *Anabaena* sp. It is often encountered in eutrophic water areas. The pea soup-coloured bloom of algae may occur due to excessive use of fertilizer and feed. Overcrowding of algae causes its mass mortality. The dead and decomposing cells release enough breakdown products or toxins harmful for fish. The bloom condition can be controlled by (*i*) copper sulphate application @ 0.5 mg/litre and (*ii*) sprinkling cowdung @ 200 kg/ha over surface of water or covering it with water-hyacinth thereby blocking sunlight.

Nutritional diseases

Normal health of the fish is a manifestation of proper feed availability in the water-body. Nutritional diseases are difficult to specify since a pathological condition cannot always be attributed to nutritional inadequacies. Some of the disease conditions are:

Starvation: A starved condition of fish in a water-body can result from (*a*) complete deprivation of food, (*b*) inadequate supply of feed and (*c*) non-acceptability of feed. The symptoms of starvation are enlarged head and very slender body, darker colour, retarded growth, emaciated bodies, soft flesh and pale gills. These fishes harbour higher parasitic load than normal fish. The starved condition can be avoided by providing nutritionally balanced diet. This requires an understanding of the nutritional components, namely proteins, carbohydrates, lipids and vitamins, causing deficiencies in fishes.

Scoliosis/Lordosis: Irregular development of skeleton cartilage occurs resulting in spinal deformities. The vertebral column may exhibit horizontal or vertical deformities.

Management and surveillance of fish disease

Fish disease is the culmination of an interaction between the susceptible fish, the pathogen and the environment. An optimum environment always helps in the good growth of fish, whereas a bad environment favours multiplication of pathogens. The triad relationship is very evident where stressful environment is an important predisposing factor in the outbreak of infectious disease in fish.

Indicators of health condition of fish stock

Escape reflex: External agitation such as quick motion, stamping on the bank, sound etc. cause healthy fishes to quickly submerge under water. Sick fish do not react and can be caught easily.

Defensive reflex: A healthy fish caught from water toss about quite violently when placed on ground and calm down after a while. Sick fish are sluggish in water as well as out of it.

Tail reflex: When the fish is held by the head and posterior portion is free it keeps the posterior fin in a horizontal position or even slightly obliquely upward while the caudal fin is always stretched in a fan shape.

Strategy for preventing disease

A primary objective of rearing fish is to maintain healthy fish populations that are optimally feeding, growing and normally functioning. The key to achieving this objective is through stress management, preventing and minimizing stress to fish in the culture environment by understanding and managing the various environmental factors that cause stress. Maintaining fish health is accomplished by individually and collectively managing environmental quality factors as near to optimum for fish as possible essentially within fish range of tolerance.

Water source: The source of water in fish-rearing facilities is an important aspect of fish-disease prevention. The sources of water are mostly rainwater or river water or irrigational canal water or sometimes groundwater. Direct rainwater is always ideal for rearing. Irrigation water is not always ideal. There are chances of pathogens as it traverses a long distance before entry into ponds. Where river water is ingressed into fish-rearing facilities, the water quality is not ideal. There is possibility of it being loaded with sewage as well as pathogens. Thus to maintain optimum water quality of rearing facilities free of pathogens, the incoming water should be first channeled into a storage-cum-filter tank where treatment can be done for settling of organic load and killing off pathogens.

Disinfection of water: Maintaining optimum water quality is essentially for disinfecting undrainable water areas. *Mahua* (*Bassia latifolia*) oil-cake @ 250 mg/litre and lime are used as disinfectants in ponds for maintaining water quality. It kills the wild fish species, molluscs, tadpoles, frogs etc., and at the same time disinfects and fertilizes the water and soil.

Disinfection of appliances: Fishing appliances such as nets, buckets and hapas very often serve as carriers of pathogens from one water-body to another. To prevent transmission of pathogens they should be disinfected and dried before use. During fish-disease outbreak these appliances should be disinfected with 2 mg/litre bleaching powder before use.

Disinfection of fish: This is a generally done by bath treatment as a routine procedure before stocking in ponds or during sample netting. The chemicals used are 2 to 3 % sodium chloride or 20 mg/litre potassium permanganate.

Stock of fish: High stocking density of fish frequently acts as predisposing factor for disease outbreak. Stocking beyond optimum level exerts undue pressure on the space, food and oxygen available in the habitat thereby creating stress to fish. Moreover, crowding of fish in an ecosystem results in easy transmission of bacterial, protozoan, monogenetic, trematode and crustaceans parasites from one fish to the other.

Adequate food: Optimum amount of food should be present in the ecosystem to sustain the fish population. If natural food is not sufficient it must be supplemented with good quality and quantity of food.

Separation of young and brood fishes: Adult and brood fishes often serve as carriers of various pathogens without exhibiting outward symptoms. They sometimes are survivors of previous epizootics due to built up immunity, but may retain some of the pathogens. Often spawners, after breeding, are kept with fry or juveniles due to paucity of ponds where chances of transmission of pathogens to young ones occur. To avoid such risk young ones should be separated from the brood and other fishes.

Entry of wild fish: Wild fishes are often the carriers of various pathogens, which do not manifest in serious disease outbreak in their native environment. These wild fishes, when they are brought and reared in confined water areas with high stocking density, disease outbreak occurs. The parasites causing such outbreaks are one having direct life-cycle like the parasitic copepods. Fish farmers receiving their water supply from irrigational canals or rice fields often receive wild fish and have a high risk of infections to farmed fishes. This was evident during outbreak of Epizootic Ulcerative Syndrome disease.

Harmful associated organisms: These are the intermediate hosts or carriers of various serious pathogens. Snails, copepods or birds serve as intermediate or definitive host of various digenetic trematode and cestode diseases. *Argulus* sp. is reported to serve as vector for other pathogens.

Raking: This method of hanging some weight in a rope and dragging it from one side of the water to the other ensures agitation of the bottom muck. This release the obnoxious gases like ammonia, hydrogen sulphide and methane in the form of bubbles upward.

Introduction of exotic fishes: Many of the introduced fishes in the country are infected with pathogens. In India importation of various exotic fishes for culture or as ornamental fish is being carried out without restriction or quarantine. Within the country there is continuous transfer of post-larvae, fry and fingerlings from one state to the other. Evidences indicate that these movements caused fish-disease outbreaks in various parts of the country. To prevent this spread of pathogens, quarantine is one of the most important systems of preventing introduction of exotic pathogens or transporting pathogens from one part of the country to the other. Fish quarantine units supported by legislation should be urgently developed in our country.

Surveillance and monitoring: Reports of incidence of fish mortality that occurs in our water-bodies are less. The reason for inadequate reporting is that monitoring of such information is yet to find a place in the framework of fish-health management practices prevailing in this country. Fish mortality is not the only determinant for evaluating the effect of fish disease. Even morbidity, which leads to weight loss and poor growth in surviving fish, contributes substantial losses to the farmers.

Microbial diseases

Bacterial diseases in fish

A large number of diseases are caused in fishes by bacterial pathogens worldwide and several of them are reported from India. They occur in nursery, rearing and grow-out ponds causing serious concern to fish farmers. Some of them may wipe out the entire fish stock. Symptomatology, clinical pathology, microbiology and molecular diagnosis are carefully correlated to arrive at the diagnosis of the diseases caused by these organisms.

Fin-rot and tail-rot: Fin-rot and tail-rot in hatcheries, nurseries and grow-out ponds is one of the most common diseases in India. The tail and fin gets necrosed, discoloured and sloughs off in affected fishes. This is mostly caused by *Cytophaga* group bacteria, but there may be mixed infections with other bacteria like *A. hydrophila* and *Pseudomonas fluorescens*. Stressful environment and bad water quality precipitates the disease. Control measures adopted are bath treatment in 1:2,000 copper sulphate for 1-2 minutes or in 1-2 ppm benzylokonium chloride for 1 hour, or swabbing of wound with diluted (1:10) tincture iodine or concentrated copper sulphate solution in the affected fish. Improvement in water quality and reduction in stocking density are essential for long-term management of the disease.

Dropsy: Dropsy is frequently encountered in composite fish culture systems during season winter. Indian major carps are the most commonly affected group, but the disease is also common in aquarium fishes. Clinically, the epidermis and body cavities get filled with fluid and scales protrude out from their pockets leading to severe anaemia and heavy mortality. It is caused by virulent *Aeromonas hydrophila* and few other motile *Aeromonas* species. The disease is best controlled using Terramycin in the feed.

Eye diseases: Epidemic form of the disease has been reported in culture ponds in India, the causative organism identified is *A. liquifaciens* infecting the eyes of catla, and sometimes in rohu and silver carp. The cornea of the eyes get vascularized leading to opacity and complete necrosis and even mass mortality of fish has been recorded. It has been noted that optic nerves and brain are the primary sites of the infection. Investigators have isolated *Staphylococcus aureus* from the affected eyes of diseased fish. Chloromycetin bath @ 8-10 mg/litre water has been found effective in controlling the disease at an early stage. Disinfecting the environment with $KMnO_4$ @ 0.1 ppm followed by liming @ 300 ppm can check the disease.

Ulcerative disease: Many workers have reported ulcerative disease in *C. calta* where bilateral ulcerations of the opercula and the head are observed. In several cases the ulcerations have been reported to have penetrated the opercular bones and cranium. In most of the cases *A. hydrophila* could be isolated, although several other bacterial forms were also present as secondary invaders who play important role not only in necrotizing the muscle tissue but also damaging the internal organs like kidney, liver and spleen.

Columnaris disease: Raised whitish or grayish patches develop over the head and back. The disease is caused by *Flexibacter columnaris*. Bath treatment in 5 ppm of $KMnO_4$ for 2-5 minutes or 5-10 ppm Chloramphenicol or 10-20 ppm Oxytetracycline for an hour is effective in curing the disease. Treatment of pond water with 3-5 ppm $KMnO_4$ and improvement in water quality also control the disease.

Edwardsiellosis: It is a septicaemic disease affecting brood fish population. *Edwardsiella tarda* has been isolated from the diseased fish showing anaemia, pin point haemorrhagic patches over skin and tail, and gas filled abscesses in the muscle. Although the mortality rate was not high, but extreme morbidity has been reported. Large-scale mortality in the spawn of Indian major carps in hatcheries has also been reported by this microbe. The young ones showed anatomical deformities and greyish-white discolouration of the body within 48 hours of post-hatching and died within 72 hours. Although treatment with Iodophor or Tetracycline has been found to be effective, water-quality improvement in the hatchery is the most essential component for keeping this disease away.

Epizootic ulcerative syndrome: The EUS, causing mass mortality in fishes, has become a matter of tremendous concern not only among the fishermen and fish farmers, but also among general public, entrepreneurs, administrators and planners. Since its first report of occurrence in Assam (*now* Asom) in 1988, the disease has spread more or less in all the states of the country. One common feature of the disease is that it initially affects the bottom-dwelling species like murrels followed by catfishes and weed fishes. Subsequently other fishes including Indian major carps are affected. Although the extent of economic loss has not been properly quantified, loss incurred by the fisheries sector due to this particular disease runs to several crores of rupees.

The lesions starts as small grains to pea-sized haemorrhagic spots over the body which ultimately turn into circular deep ulcers of the size of a coin with greyish slimy central necrotic areas surrounded by as zone of hyperemia. The diseases affects to such an extent that they starts rotting while still alive and eventually die.

A number of bacteria, namely *Aeromonas hydrophila. A. punctata, Flavobacterium* sp., *Pseudomonas* sp., *E. tarda, V. parahaemolyticus* and *Streptococcus* sp., and fungus like *Aphanomyces invadens* have been isolated from the affected fishes. It is presumed that a diverse group of microbes like viruses and bacteria, and even ectoparasites, initiate skin lesions which is further colonized by the highly invasive fungus *A. invadens*, ultimately leading to EUS. Histopathological studies revealed complete loss of epidermis in the ulcerative area of the skin where the dermis and hypodermis showed characteristic granulomatous changes. The fungus invades into muscles, bones and visceral organs producing characteristic mycotic granuloma. The disease is diagnosed by its characteristic high rate of mortality in several species, especially among bottom dwellers, deep ulcers and granulomatous lesion. Monoclonal antibody (MAb) based immunoblot has been developed for early detection of EUS.

Several methods have been tried or are being tried to control the disease. Many antibiotics, sulfonamides, chemicals, herbal preparations etc. have been advocated as preventive and curative measures. Generalized treatments like lime @ 100-600 kg/ha, $KMnO_4$ @ 4 ppm, or bleaching @ 0.5 ppm in pond water were accepted widely among the fish farmers of the country until the formulation of CIFAX, developed by the

Central Institute of Freshwater Aquaculture (CIFA), Bhubaneshwar. Marked improvement of the ulcerative condition is noticed within 7 days of application of the medicine and the ulcers are healed up within 10-14 days. The medicine acts as a preventive also.

Bacterial gill disease: It affects Indian major carps and other freshwater fishes and is caused by a number of bacteria, but *Flavobacterium branchiophila* is the most important one. Gills of affected fishes become discoloured, gill fringes become uneven or torn, with grey patches of necrosis. The disease occurs in many states of the country. Morbidity and mortality goes up to 100 and 50% respectively. To manage the disease problem, avoid over-stocking and wastage of feed in pond, and give aeration. Restricted use of 8-10 ppm Chloramine-T for 1 hour gives good results. Careful bath treatment with 1-2 ppm $KMnO_4$ can control the disease.

Antibiotics in aquaculture: A number of antibiotics are being used in aquaculture, very often in unscientific manner. Antibiotics are mostly used as a prophylactic or therapeutic measure (Table 32.2) by farmers or sometimes as feed preservative by feed manufacturers with some beneficial, at the same time, with some undesirable effects. The adverse effect of antibiotic is because of its action on the aquatic micro-flora, retention of harmful residues in aquatic animals and fishes and development of drug- resistant bacteria and pathogens.

Table 32.2. Antibiotics currently used in systemic treatment in India

Antibiotics	Brand name	Remarks
Oxytetracycline	TM-50	Feed supplement. Contains 50 g activity/500 g
Chlorotetracycline	Aurofac-20	Feed supplement. Contains 44 g of Chlorotetracycline/kg
Doxycycline	AFS Forte	Feed supplement. Doxycycline activity 150 ppm
	Vetrodox	Feed supplement. 10 g/ activity/kg
Nitrofurazone + Furazolidone	Bifuran	Combination of Nitrofurazone 25% and Furazolidone 3.6% (not to be used for treating food fish, but to treat ornamental fish only)
Furazolidone	Groviron	Feed supplement. Contains Furazolidone 20% w/w (not to be used for treating food fish, but to treat ornamental fish only)
Sulphadiazine + Trimethoprim	Bactrisol	Water-dispersible powder contains 100 mg Sulphadiazine and 20 mg Trimethoprim/g

Bacterial diseases in shrimps

Vibriosis: The term vibriosis is used to refer to all types of infections caused by bacteria of the genus *Vibrio*. Vibriosis is most frequently encountered in cultured shrimp and majority of the stressed shrimps have the presence of *Vibrio* spp. Since *Vibrio* spp. are opportunist pathogens, they attack stressed shrimps.

One month mortality syndrome: Sudden mortality of young *Penaeus monodon*. The causative agent is very often decomposing materials formed at the pond bottom during early stages of shrimp culture due to death of benthic algae. The young shrimps after moulting come in contact with these decomposing materials on which profuse

number of *Vibrio* spp. have developed. These *Vibrio* spp. infect the stressed shrimp which die within a month.

Black spot disease: The disease occurs both in *Penaeus monodon* and *Macrobrachium rosenbergii*. Black lesions are visible in muscle, abdomen, gill and other organs. The causative factor is again *Vibrio* spp. present in deteriorating water quality that stresses the prawn. This result in chronic *Vibrio* sp. infection and development of black areas due to deposition of melanin pigment.

Septic hepatopancreatic necrosis: Certain portions in *Penaeus monodon* hepatopancreas turn black and are degenerated. Deteriorating water quality stresses the prawn and proliferation of *Vibrio* sp. present in water occurs resulting in *Vibrio* sp. infection in the hepatopancreas. The species of the genus *Vibrio* commonly associated with vibriosis in India are *V. parahaemolyticus, V. alginolyticus, V. anguillarium, V. vulnificus, V. fluvialis*.

Vibriosis is associated with the water quality of the culture area of shrimp. Most of the stressed and moribund shrimp have some *Vibrio* sp. infection. Thus treatment of vibriosis must always involve improvement of the habitat. The management practices to be adopted are:

- Prophylactic: (*i*) Maintain proper water quality with low bacterial biomass; (*ii*) Maintain a constant phytoplankton bloom and balanced feeding schedule;

Table 32.3. Pathlogical features of some important pathogens of fish and shrimp

Pathogen	Disease/pathological feature
Fish	
Aeromonas salmonicida	Furunculous
A. salmonicida, atypical strain	Carp erythrodermatitis
A. hydrophila	Haemorrhagic septicaemia, dropsy, skin lesions, Fin and tail rot
Vibrio anguillarum, Vibrio spp.	Vibriosis
Yersinia ruckeri	Enteric red mouth disease
Renibacterium salmoninarum	Bacterial kidney disease
Edwardsiella tarda	Edwardsielosis (Haemorrhage, septicemia)
E. ictaluri	Enteric septicaemia of channel catfish
Flexibacter columnaris	Columnaris disease
Pseudomonas spp.	Septicaemia, haemorrhage, eye disease
Nocardia spp.	Granulomatous lesions
Mycobacterium spp.	Granulomatous lesions
Staphylococcus aureus	Eye disease
Clostridium botulinum	Botulism
Shrimp	
Vibrio alginolyticus, V. parahaemolyticus, Aeromonas sp., *Pseudomonas* sp.	Bacterial shell disease
Vibrio alginolyticus, V. parahaemolyticus, V. anguillarum	Septicaemic vibriosis
Leucothrix mucor, Flexibacter sp., *Cytophaga sp., Flavobacterium* sp.	Filamentous bacterial disease
Monodon baculovirus	Monodon baculovirus disease (MBV)
White spot syndrome virus	White spot syndrome
Prawn	
Vibrio sp., *Aeromonas* sp., *Pseudomonas* sp.	Black spot disease
V. alginolyticus, V. anguillarum	Vibriosis

(*iii*) Sterilize or filter recirculated water; (*iv*) Regular monitoring of shrimp and water quality.

- Therapeutic: When prophylactic measures fail, therapeutic measures are undertaken which is antibiotic therapy. However, antibiotic therapy is only successful if simultaneously the pond water quality is improved. Antibiotic Oxytetracycline or Erythromycin should be applied for 5 days @ 50-90 mg/ bath treatment and 500-1,000 mg/kg feed treatment. However, utmost precaution has to be taken for antibiotic therapy as resistant variety may develop and their is a risk of residue remaining in prawns. The important disease/pathological features and associated pathogens are presented in Table 32.3.

Fungal diseases in fish

Saprolegniasis: The disease is caused by various *Saprolegnia* species, is one of the major health problems in fry and fingerlings of major carps. It is characterized by a white to brown cotton like growth, consisting of colonies of mycelium and filaments which appear as small to large patches on various parts of the body like fins, gills, mouth, eyes or muscle. The infection starts due to netting injury and over-crowding or lesions caused by other diseases. *Saprolegnia* also often infects the fertilized eggs causing huge economic loss to hatcheries. The infected eggs become white, darken gradually and finally become black and fail to hatch. Presence of *Saprolegnia* infection in hatcheries or water-bodies is an indication of stress and unsanitary condition. The disease in ponds etc. can be treated by bath treatment with 3-4% common salt or 1:2,000 $CuSO_4$ daily for 3-4 days or with 1:1,000 malachite green for 30 sec. In hatcheries eggs may be dipped in 2-5 ppm good-quality malachite green for 1-5 min or 1:500 diluted formalin for 10-15 min, followed by washing in flowing freshwater.

Fungal gill rot or branchiomycosis: Branchiomyces infection is another problem causing gill rot in fish. These pathogens invade the blood vessels of gills causing necrosis of gills and surrounding tissues. Grossly the gill becomes inflamed or enlarged visible from outside. Dipping of fish in 3-5% common salt solution or 5 ppm potassium permanganate or 1:2,000 $CuSO_4$ for 1 min, is effective. Ponds can be treated with 1 ppm $CuSO_4$ with caution, followed by liming.

Apart from these, *Aspergillus flavus*, *A. ochraceous* and *Fusarium moniliforme* have been reported from some of the ulcerative syndrome (EUS)-affected specimens. A flush treatment for 1 hr in malachite green (0.1 ppm) is found to be quite effective in curbing fungal infection.

Viral disease in fish

Noda virus infection is an emerging disease with heavy mortality in several marine fish species. The disease is characterized by abnormal swimming behaviour, and extensive cellular vacuolation and neuronal degeneration in the brain and retina. The disease is also referred as viral encephalopathy and retinopathy (VER) or viral nervous necrosis (VNN). It caused high mortality in larvae and juveniles of *Lates calcarifer* and mortality rate may reach up to 100%. The disease is caused by a non-enveloped, icosahedral RNA virus belonging to the Nodaviridae family. The virus spreads both horizontally and vertically. Early detection of the virus, pathogen-free broodstock and regulated movement of fish may help in control of the disease.

Fungal diseases in shrimps

Monodon type baculo virus disease: The post-larvae and neo adults of *Penaeus monodon* are affected and are lethargic and come to the surface or sides. Fouling organisms infest the shrimps. There is necrosis of the hepatopancreatic tubules leading to dysfunction of the organ. The virus forms prominent eosinophilic, multiple round bodies within hypertrophied nuclei of hepatopancreatic tubule and mid-gut epithelium cells. The causative agent is *Monodon* baculovirus. Poor pond environment, high density culture, secondary bacterial infection including vibriosis and infestation by fouling organisms are shown to reduce host resistance and render prawn susceptible to viral infection.

Yellow head disease: Adult *P. monodon* is affected mostly. The affected prawn exhibits light yellow to pinkish cephalothorax due to discolouration of hepatopancreas, hence called the yellow head disease (YHD). They are lethargic, off fed and show reddish discolouration of body and appendages with empty gut. The hepatopancreas of affected prawns show degeneration. Necrosis of tubules, and haemocytic infiltration occur. Large densely stained eosin basophilic bodies are found in the interstitial cells, in intercellular spaces, in tubuler lumen, necrosed areas and gill lamellae. The bodies are suggestive of YHD infection. The causative agent is Yellow Head Disease Virus. It is a non-occluded baculo virus, now recognized as RNA virus of rhabdo virus group. Environmental factors such as poor water quality, poor pond bottom trigger the disease outbreak, leading to mass mortality.

White spot disease: Since the first report of white spot syndrome in 1994 in Andhra Pradesh, the disease has caused major economic loss to the shrimp culture sector in India. *Penaeus monodon* is principally affected, although caridean shrimps, lobsters, crabs, branchiopods, stoamtopods, copepods, rotifers etc. may be infected and act as carrier. Infected prawns are lethargic, stop feeding with empty gut and develop gradually white spots of variable size, prominently seen on the carapace. The spots first appear on carapace region and then at the last abdominal segment, later spreading to the cuticular surface all over the body. Within 5-10 days 100% mortality may occur. The target tissue for the virus are thought to be the hypodermal, epidermal and epithelial cells, haematopoietic tissues, connective tissues, haemocytes, lymphoid organ, and atenal gland. The non-targeted tissues are hepatopancreas, epithelial cells of mid-gut, muscular cells and parenchymal cells of gonads. At the early stages of infection, eosinophilic intranuclear inclusion bodies are seen in the infected cells. Hypertrophy, necrosis, degeneration and presence of basophilic bodies are noted in the later stages of infection. The disease is caused by a large, enveloped, ellipsoid to bacilliform shaped, double-stranded DNA virus belonging to the family Nimaviridae. The virus spreads both horizontally and vertically, and arthropod vectors may bring the virus into a farm. Investigation of the disease in India revealed involvement of multiple viruses like white spot baculovirus (WSBV), monodon baculovirus (MBV) and hepatopancreatic parvovirus (HPV) in the disease condition. Although several chemicals, drugs and other management norms are adopted by farmers with variable efficacy, use of SPF seeds is recommended in preventing the disease onset.

Monodon baculovirus: The MBV, type A occluded baculovirus, infection has been reported in coastal India since 1994. The disease is more prevalent with high mortality rate in post-larval and early juvenile stages. The affected shrimps are pale bluish to grey black in colour, with poor feeding, stunted growth, fouling of the body surface, sluggish movement and appearance of white mid-gut line that can be seen in severely affected larvae and post-larvae.

Loose shell syndrome: It is a disease of unknown aetiology affecting about 40 to 50% of *P. monodon* farms in India, with annual crop loss of 12 to 25%. Affected shrimp develops loose exoskeleton and spongy muscle, with poor feeding and growth rate. The disease is more or less incurable.

Prawn noda virus disease: This disease has been reported in *M. rosenbergii* and named white tail disease or white muscle disease. The disease affects hatchery reared post-larvae and the juveniles. The affected animals develop characteristic whitening of abdominal muscle giving rise to the appearance of whitish tail, with lethargy, poor feeding and 30-90% mortality. The virus has been named as *M. rosenbergii* noda virus (MrNV). Diagnostic PCR kit has been developed by the Central Institute of Brackishwater Aquaculture (CIBA), Central Institute of Freshwater Aquaculture (CIFA) and C. Abdul Hakeem College, Tamil Nadu.

Fouling disease: It is a common manifestation of parasitic infestations in prawns. The condition is seen in bad quality waters and is caused by protozoan parasites like *Epistylis*, *Zoothamnium*, *Vorticella*, *Acineta* etc. The parasites may affect gills, body surface, and appendages disrupting mobility and feeding by the animal. Mortality is infrequent but may occur in severe cases.

Treatment measures for viral diseases of prawn

Chemical: Viral diseases in general are difficult to treat. Viruses normally use the host cell for their metabolism, growth and reproduction. Hence any chemical/drug selected for killing the virus adversely affects the host cell. Though some antiviral drugs have been found effective against a number of viral diseases of animals *in vitro* and in laboratory animals but their use is restricted due to cell cytotoxicity.

Physical factors: Certain physical factors have been found effective in containing viral epizootic such as (*i*) Viruses are sensitive to enhanced *p*H, irradiation, sunlight and dessication; (*ii*) They are sensitive to oxidizing agents like chlorine, iodine and their products; and (*iii*) They are unable to survive free in sea-water for a number of days.

The disease-prevention strategy followed currently in India are:

- Majority of the prawn viruses are known to be inactivated or die within 4-5 days when they remain free in water, as such every farm owner is advised to have one reservoir pond and inlet water should be kept 4-5 days prior to use.
- The water in reserviour needs to be sedimented, disinfected and aerated prior to use in culture. Disinfection is normally done by applying chlorine @ 30 mg/litre (calcium hypochlorite 60% a. i.).
- Entry of wild prawn, crabs or other fish in the culture area is prevented.
- After culture, dry the pond completely, remove a layer of bottom soil and use disinfectants so as to kill the carriers and microbes.
- Avoid use of fresh food like trash fish, crabs and other crustaceans, which are thought to be the potential carriers, in the culture ponds.
- Carefully select healthy post-larvae, because viral diseases can be transmitted from broodstock to the post-larvae.
- Avoid over-stocking. Prawns are more resistant to bacterial and viral infections when cultured in extensive and modified extensive systems of culture. Maintain good and stable water quality during culture.

Feed intake by prawn should be monitored regularly and any drop in feed consumption should be regarded as an alarm for health problems.

Fish introduction, quarantine and health certification

Many of the exotic ornamental and table fish species are invasive and are threatening biological integrity of native fish species in rivers, wetlands, reservoirs etc. Besides the introduction and spread of fish species itself, entry of new pathogens is one of the major risks for aquaculture industry and aquatic biodiversity during the movement of live aquatic animals. Consequently, disease outbreaks are becoming a major threat to aquaculture production and trade. Implementation of quarantine measures will provide a strategic framework and integrated approach to assess the risks associated with movement of live aquatic animals and promote sustainable production. Planning of aquatic animal quarantine should include technical evaluations of the optimal balance of the application of specific pre-border, border, surveillance and response procedures to ensure prevention of entry, early detection post-entry and cost-effective eradication of potential exotic organisms. The country needs an effective quarantine system on priority so as to avoid introduction of exotic pathogens. In addition, development of standard disease surveillance and reporting system will assist in the identification and distribution of pathogens affecting aquaculture industry. These measures would provide early warning of disease emergence, facilitate more specific contingency planning and strengthen international confidence on the health status of fin and shellfish of the country.

As a part of national preparedness, the National Bureau Fish Genetic Resources (NBFGR) has prepared two important documents, namely National Strategic Plan for Aquatic Exotics and Quarantine and Aquatic Exotics and Quarantine Guidelines. These are aimed at safe introduction of exotics for aquaculture, while safeguarding biodiversity and preventing economic loss. A key element for health certification is designation of competent authority, which will involve recognition of accredited laboratories across the country.

Fish immunology

The immune response of fish in general is well developed and integrated and is evolutionary intermediate between invertebrates and high vertebrates. The immune defence of fish can be divided in two types, non-specific immune defence and specific immune system.

Non-specific immunity is the first line of defence, active against all types of pathogens and forms a major part of the immune response in contrast to higher vertebrates. Skin, scales and intact epithelial living are the primary defence barriers. The mucus rich in proteins, carbohydrates, non-specific precipitins, agglutinins, C-reactive protein and lysozyme, prevents colonization of parasites, bacteria and fungi, through a continuous loss and replacement. Internally, mucus lining of gastro-intestinal tract along with *p*H and enzymes serve as important defence against pathogens.

Lysozyme: Lysozyme is secreted by leukocytes and are widely distributed in serum, egg, mucus, skin, gills and intestine. It lyses the peptidoglycan layer of gram-positive bacteria, ultimately killing the bacteria. It is also somewhat toxic against gram-negative pathogens. Lysozyme promotes phagocytosis as an opsonin and activates phagocytic cells. Serum lysozyme level decreases in fish during stress, winter and smoltification and increases during spawning.

C-reactive protein (CRP): It is an acute phase protein that appears in plasma in response to tissue damage infection etc. Fish CRP can recognize phosphorylcholine in cell wall/surface structures of bacteria, fungi or parasites and activates complement system.

Transferrin: It is an iron-binding glycoprotein. Iron is an essential element in the establishment of infection by most pathogens and transferrin limits the amount of endogenous iron available to the pathogens by chelating the metal and making it unavailable for bacterial use.

Lectins: These are proteins of non-immune origin that bind sugar moieties and thus agglutinate cells or precipitate glycoconjugates. Fish egg lectin inhibits the growth of pathogenic bacteria and fungus, thus protecting the developing eggs until the immune system reaches a level of sufficient competence. Fish skin mucus also contains lectins that agglutinate bacterial cells and provide some inhibition of bacterial growth.

Interferons: Interferons are proteins or glycoprotein that are secreted by virus-infected cells and inhibit virus replication in these and other cells.

Complement: The complement system is an integral part of the immune system and includes a number of proteins that are activated either by an antigen-antibody complex (classical pathway) or directly by lipopolysaccharide of gram-negative bacteria (alternative pathway). Activation of complement system leads to lyses of bacterial cells, virus-infected cells or the parasite. The bactericidal activity of fish serum is attributable mainly to the activation of alternative pathway, rather than the classical pathway. Some of the complement components like C3 have opsonic activity that promotes phagocytosis of opsonized particle. Besides these bacterial/viricidal/parasiticidal or opsonin activities, activation or complement pathways result in many biologically important peptides that are involved in inflammatory responses in fish. Seasonal variations in complement activity have been observed.

Other substances: Thus mucus or serum of fish contains substances such as haemolysin, proteinase, α_2-macro globulin, chitinase, α-precipitin etc. that play roles in non-specific defence mechanism of fish.

Phagocytic cells: A variety of leukocyte types are involved in non-specific cellular defence of fish. Macrophages and granulocytes are mobile phagocytic cells found in blood and secondary lymphoid tissues and are important in inflammation. Eosinophilic granular cells are involved in the host response of bacterial and helminth pathogens at mucosal sites like gills and gut. All these functions are antigen or pathogen non-specific, and unlike specific defences has no memory. Besides the phagocytic activity, phagocytes play an important role in specific immunity development by processing the antigen and presenting it to lympocytes. These cells also secrete soluble mediators like interleukin-1 that stimulate proliferation of T cells and antibody production.

The leukocytes of several teleost species also are capable of spontaneous killing (non-specific cytotoxicity) of virus-infected cells, protozoan parasites etc. Direct physical contact is required for killing.

The specific immune system: The component of specific immune system is antigen specific and has immunological memory. The humoral component of specific response is antibody or immunoglobulin. Teleost immunoglobulin is a tetramer composed of four monomeric subunits, each containing two heavy peptide chain (72K Da) and two light chains (27K Da). Upon exposure to antigens B-lympocytes proliferate and mature into plasma cells which secrete antibody molecules that uniquely bind to the inducing antigen only. The most direct effect of antigen-antibody interaction is the physical blocking of critical functions of the antigen resulting in neutralization (virus neutralization or toxin neutralization) and loss of biological activity of the toxin or infectivity, uptake by phagocytic cells or complement lysis. Another effect of interaction is formation of large lattice of antigen and antibody (precipitation/agglutination) that are easily removed by phagocytosis or complement mediated lyses. Another component of specific immune response is the cell mediated immunity (CMI) mediated by T-lympocytes, independent of antibody.

Immunodiagnostic methods for fish diseases

Nearly all the immunodiagnostic techniques are based on either the detection of an antigen with antibody of known specificity or detection of an antibody with a known antigen. The antigen and antibody molecules are complementary antibody with a known antigen. The antigen and antibody molecules are complementary to each other when mixed, the reaction being manifested either by the precipitation or by the agglutination etc.

The immunodiagnostics have great prospects in fish-disease diagnosis since they can specifically detect different microbial diseases with great sensitivity. The advantage of these methods over other conventional tests is that they can differentiate between closely related strains of same species of bacteria or virus. This is an important aspect in case of fish pathogen, as many of the bacteria are normal inhabitant of aquatic bodies with only some strains being pathogenic to the fish.

On the basis of the type of antigen-antibody reaction, immunodiagnostic methods commonly used in fish-disease diagnosis are of the following types.

Agglutination test: The test is based on the visible clumping (agglutination) of a particulate antigen with antibody when the two test reagents are mixed together on a glass slide. The test is mostly used for diagnosis of bacterial diseases in fish, e.g. *Edwarsiella tarda.* Its modifications are:

1. ***Quantitative agglutination test:*** In this method different dilutions of antiserum are allowed to react with a fixed quantity of antigen or vice versa. The lowest dilution which shows positive reaction is taken as the titre.
2. ***Latex agglutination test:*** In this method antigen is adsorbed on latex beads to increase the size of clumps. Such method increases the sensitivity of the test.
3. ***Haemagglutination test:*** In this method either antigen or antibody is adsorbed on RBC surface. There are certain viruses which directly cause agglutination of RBC.

Precipitation test: The basic principle of this test is as the agglutination tests except that here the antigen is in soluble form and the reaction with antibody results in development of precipitation band. Its modifications are:

Agar gel precipitation test: In this method (AGPT) antigen and antibody are allowed to diffuse through agar until they meet to form a precipitation line. This method can be modified suitably for a quantitative AGPT wherein antigen is placed in the central well and different dilutions of the antibody are loaded in surrounding wells.

Immunoelectrophoresis: In this method the diffusion of antigen and antibody is enhanced by applying an electric field across the slide. Its modifications are:

Counter immunoelectrophoresis test: This test (CIE) is performed in agar gels where *p*H is chosen so that the antibody is positively charged and the antigen is negatively charged. By applying a voltage across the gel the antigen and antibody move towards each other and precipitate. The principle is the same as the immunodiffusion but the sensitivity is increased by 10 to 20-fold.

Rocket immunoelectrophoresis: In this method the antigen is quantitated by electrophoresing them into an antibody containing gel. The *p*H is chosen so that the antibodies are immobile and the antigen is negatively charged. Precipitin rockets form the height of the rocket, which is proportional to antigen concentration, and unknowns are determined by interpolation from standards.

Enzyme linked immunosorbent assay (ELISA): It is a highly sensitive test which is probably the most widely used of all immunological assays since a large number of tests can be performed in a relatively short time. The test is based on the recognition of antigen by antibody-enzyme conjugate, or recognition of antigen-antibody complex by anti-species conjugate. ELISA is often quantitative. The following types of ELISA are widely used in clinical diagnosis:

Competitive ELISA: The antigen/antibody in test sample competes with known concentrations of antigen/antibody for binding with antibody/antigen respectively.

Sandwich ELISA: The target/test antigen binds with two types of antibodies (like in sandwich) one of which is pre-coated on the plate.

Dot ELISA: Here, nitrocellulose membrane is used as a base for reaction instead of plastic plates. The colour reaction appears in the form of a dot on the membrane.

Diagnostic kits

- **Spot agglutination kit**, for diagnosing bacterial gill disease, developed by the CIFA.
- Aeromonasis and Edwardsiellosis, for detection of specific antibody, developed by the CIFA.
- **Dot-ELISA kit** for diagnosis of bacterial gill disease and *Edwardsiella tarda* infection.
- **Antigen captured ELISA kit** for diagnosis of *Aeromonas*, *Edwardsiella* and *Pseudomonas* infections, septicaemic condition.
- **Competitive ELISA kit** for routine seromonitoring of bacterial gill disease, *Aeromonas hydrophila* and *Edwardsiella tarda*, infection of freshwater fishes.
- **Monoclonal antibody (MAb)-based diagnostic kit**, for detection of EUS fungus, developed by the Central Institute of Fisheries Educatiaon (CIFE).
- **An immunodot test based on MAb**, developed for detection of WSSV in shrimps.

Fluorescent antibody technique: This technique uses fluorescin dye tagged antibody to detect specific pathogen inside the tissue itself. The fish tissue suspected to contain a particular pathogen is processed to make sections for microscope. This is then treated with antibody-fluorescein conjugate and the slide is examined under the ultra-violet light microscope. The parts of the tissue (containing antigen) that bind the fluorescein-tagged antibody fluoresce under the fluorescence microscope. This can be used to detect a particular microbial pathogen, as well as, to know the part of tissue being attacked or damaged by the pathogen.

Immunoprophylaxis

Majority of the fish diseases are caused by pathogens. Pathogens like bacteria, virus, parasites etc. or the toxic products elaborated by them cause diseased conditions and to obtain protection, immunoprophylaxis may be employed. This can be of two types: the active immunization (inoculation of antigen- vaccination) and the passive immunization (directly acquiring antibody through inoculation of antisera or from mother).

In the former, the pathogen or their toxins are administered in a harmless form offering immunity to the host. This develops antibodies, needs some time and immunity is observed as a prophylactic measure. In the latter, antibodies are formed in a foreign homologous or heterologous animal and the preformed antibodies, after extraction, are administered along with the serum to the host to be protected. This passive immunization, however, offers immediate protection. Sometimes, active and passive immunizations are carried out simultaneously.

In active immunization, fish can acquire immunity associated with production of humoral antibodies through oral administration of live or dead pathogens. For example, in the infectious abdominal dropsy (IAD) of carps cultured in pond, the immunoprophylaxis is seen by using a polyvalent inoculum of dead bacteria of *Aeromonas*. This is reported to reduce mortality rates. This type of immunity has been observed in case of another disease, the furunculosis also. In passive immunization of fish, serum (immunized animal or fish) may be used for the purpose. Thus, antisera obtained from salmon against *Aeromonas* can be injected to protect fingerlings of *Oncorhynchus* against artificial infection by *Aeromonas*. The passive immunization, obtained for relatively shorter periods, is cost and labour oriented for the reasons of preparation and administration of larger quantities of fish serum, thus, it finds comparatively lesser application for practical purposes. Active immunization is more practical for protection of fish stock by inoculation. In principle, immunoprophylaxis against parasitic diseases is also possible.

The main aspect of developing immunity against specific pathogens by active immunization is to stimulate the specific defence mechanisms (antibody or CMI) in fish. Since the antigens present in the organisms develop antibodies in host, obtaining immunogenic and protective antigens of the pathogens seems to be the prime requirement. Whole microorganisms like bacteria or virus or part of it like its toxin, membrane antigen etc. can be used for active immunization. On an experimental basis, inoculum from killed, attenuated or live but less virulent variants can be used. Live inoculum sometimes can be used for immunoprophylaxis of viral fish diseases. Administration of live bacteria, although exhibits satisfactory immunization in fish, it may sometimes lead to development of the disease in the stock. Killed vaccines are most safe and widely practised in all sphere of human and animals health management. Use of chemical and physical agents like phenol, formalin, thiomersal, chloroform, alcohol etc. or simple heating/boiling can kill most of the pathogens. Killing of organisms by formalin (final concentration 0.2%) seems to be the most convenient method of preparation for inactivation and preservation of the antigens while retaining their immunogenicity. The toxic products elaborated by fish pathogenic bacteria are inactivated and for this a formal maturation or some sort of modification of exotoxins are done from *Aeromonas* and *Vibrio*. The compounds obtained are called toxoids, This is reported to exhibit good results. Mixing with formalin produces formol-toxoids and this is non-toxic but immunogenic in fish. Fish can be injected with a single type of antigen (monovalent) or a mixture of antigens (polyvalent) from more than one pathogen. For diseases like IAD Furunculosis Vibriosis etc. polyvalent vaccines seem to be the most successful. Based on the number of serotypes of a pathogen from which the vaccine is prepared, one can have monovalent, bivalent, trivalent or polyvalent vaccines. This can stimulate an immunity against one, two, three or several types of pathogens. Because of difficulty in fish vaccination, if a single vaccine can bring forth immunity against many types of pathogens, its success of immunoprophylaxis will be much more in fish. For development of an effective polyvalent vaccine, studies on prevalence of what antigen types of a pathogen, or prevalence of various diseases in the locality is very important. Most effective vaccines, like the vibrio vaccine, are prepared on such basis. Also the preparation of polyvalent vaccines can be facilitated when groups of pathogens are having a relatively homologous antigen structure (e.g. *Vibrio anguillarum, Aeromonas salmonicida, Chondrococcus columnaris*). Conversely, preparation of polyvalent vaccine may be different with pathgens(s) having heterogenous antigens. An example of a polyvalent *Vibrio* vaccine is Vibrichthyn which is manufactured in Germany.

The success of immunoprophylaxis against fish diseases also depends on nature, frequency and dosages of antigen administration. Investigations on different routes of injection of particulate or dissolved antigens have revealed that intraperitoneal or intranmuscular injection is the most suitable mode of administration for several fishes. The antigenic and immunogenic actions of an injection are considerably strengthened by mixing an adjuvant such as aluminum hydroxide, potassium aluminium sulphate etc. to the antigen. Sometimes, an improvement in active immunization is achieved by repeated injections to obtain boostering effect. The second injection is given usually after 10-15 days of the first injection.

Because of difficulties in administration of antigen through injection in fish, oral vaccines have been experimentally tried and found to exhibit mixed responses. Effective immunoprophylaxis in fish against natural infections by *Aeromonas* and *Vibrio* can be achieved by oral vaccines. The oral immunization depends on the nature of antigen, frequency of administration as well as the species of fish. The same is usually carried out by addition of a vaccine concentrate or lyophilisate to the feed. Another method of administering antigen is by hyperosmotic infiltration. Here, fish is immersed in hypertonic salt solutions and then transposed to a 2% antigen solution for about 2 minutes. By this way, the antigen penetrates the host.

Effective vaccination also depends on water temperature in poikilothermic animals like fish. At lower temperatures, immunization slows down or becomes ineffective. Vaccination should preferably be done at the optimum temperature for the fish species. Since antibody is protein, starvation or imbalanced diet may result in ineffective vaccination or vaccine failure.

Probiotics and immunostimulants: Because of difficulties in use of antibiotics and lack of effective vaccines, alternate health-management strategies are use of probiotics, phages and immunostimulants. There are several bacteria in aquatic environments that antagonize or inhibit pathogenic microorganisms and thus increases the survival rate of fish/shrimp stock. For example, *Vibrio anginolyticus* has been used as probiotic in *Penaeus vannamei* larviculture for protection against WSSV.

There are several microbial cell-wall products and plant extracts that non-specifically stimulates the immune systems and protects the animal against disease. For example, dietary α-1,3-glucan increases the resistance of shrimp against WSSV. The CMFRI has tested several plant preparations that boosts the immune system of fish and may be used for disease control in near future.

Bacteriophage therapy: This is an important emerging method of fish and shellfish disease control. There are several phage viruses that are parasites on pathogenic bacteria. Some of the double-stranded RNA (dsDNA) phages, belonging to Siphoviridae family, have been used in phage therapy in marine environment.

RNA interference

Introduction of certain dsRNA can lead to development of resistance against viral infections and has been used in the human and animal health management. Long dsRNA produced by viral infections are processed into short 21-23 nucleotide RNA duplexes that are incorporated into RNA-induced silencing complex which then cleaves the homologous mRNA in the cytoplasm leading to non-translation or silencing of the viral gene. RNA interference or post-transcriptional silencing of gene expression has proved its efficacy against shrimp viruses like WSSV, Yellow head virus, and Taura syndrome virus.

Application of molecular diagnostic methods

Successful health-management programme depends on prompt, efficient and accurate diagnosis of the disease. Over the years, microbiologists have searched for more rapid and efficient means of microbial identification and characterization. The identification and differentiation of microorganisms has principally relied on microbial culture, growth and morphological characteristics. Advances in molecular biology have opened new avenues for microbial identification and characterization, which has revolutionized the diagnosis and monitoring of infectious diseases. Nucleic acid techniques such as plasmid profiling, DNA-restriction fragment analysis, randomly amplified polymorphic DNA (RAPD), restriction fragment length polymorphism (RFLP), polymerase chain reaction (PCR) are making increasing inroads into clinical laboratories. Molecular methods have surpassed traditional methods of culture and detection of many organisms, both in terms of sensitivity and rapidity.

Polymerase chain reaction techniques: It is a very sensitive and rapid diagnostic technique and useful in cases where other methods fail to detect the causative factor. Polymerase chain reaction (PCR) is a rapid and inexpensive way of preparing specific DNA segment by cyclic amplification, which can be used in characterizing the pathogen and disease condition. In PCR, target DNA is amplified over a million times in a few hours using specific primers, DNA polymerase and nucleotide mixture in a PCR machine or Thermal cycler. Thus from a small segment of DNA microgram quantities of DNA can be produced. The basic requirement of PCR is to design specific primer sequence for target gene of importance that can be able to characterize and differentiate specific strain/species of organism or animals.

Now-a-days PCR is widely used in fish disease detection, both in research and ex-farm or on-farm clinical laboratories. DNA is rapidly extracted from target fish tissue sample and is amplified using a set of primers targeting a number of organisms. The PCR product is separated in gel and visualized. Presence of any specific band indicates presence of specific disease-causing organism. Because of the utmost sensitivity, both disease condition, as well as sub-clinical and carrier states, can be effectively diagnosed by PCR.

Reverse transcription-polymerase chain reaction: DNA-dependent DNA polymerase enzyme used in PCR cannot amplify RNA. Reverse transcription (RT) PCR makes use of reverse transcriptase enzyme which makes complementary DNA from RNA; the complementary DNA prepared is then amplified by PCR. Because many fish viruses have RNA as genetic matter, straight forward PCR cannot be done and RT-PCR is required for their detection.

Nested polymerase chain reaction: Another important modification technique of PCR, which has gained importance in diagnostics, is Nested PCR, which is basically designed mainly to increase the sensitivity, using two sets of primers. One set of primer is used for generation of a bigger segment of DNA, in first round of amplification, which consists of 15-30 cycles. The amplification product of first reaction are then subjected to a second round of amplification with another set of primers, that are specific for an internal sequence that was amplified by the first primer pair. Nested PCR has extremely high sensitivity because of the dual amplification process and extensively used in diagnosis.

Multiplex PCR: This is another important technique used in diagnostic laboratory. A number of pathogens can simultaneously be detected using the process of PCR amplification called Multiplex PCR. In this method two or more sets of primer pairs specific for different targets are introduced in the same tube. Thus, more than one unique target DNA sequence in a specimen can be amplified and detected at the same time. For diagnostics use, multiplex PCR can be set up to detect internal controls or to detect multiple pathogens from a single specimen. Once standardized, this technique can be popularly used for detection of multiple pathogens in sample at a time. This technique reduces the analysis time and is more cost effective and the results of screening trial can be easily interpreted.

Real-time PCR: Another latest and important development in PCR technology is Real-time PCR. This technique is the most practical, as it does not require time- consuming post-PCR manipulation and processing of the reaction. Real-time PCR can be accomplished with the fluorogenic 5'-nuclease assay called TaqMan and a spectrofluorometric thermal cycler. A silicon chip-based spectrofluorometric thermal cycler called Advanced nucleic acid analyzer (ANAA) has been developed that is handy, more sensitive and can be used in the field and offers real-time monitoring. Such techniques are not only highly sensitive, requiring only few minutes, compared to days as required by other methods, but can also be applied in cases where other methods fail to detect the pathogen. Hence, these techniques have wide scope of application in disease diagnosis and quarantine programme.

The PCR technique has been applied by different researchers for detection of WSSV, MBV in shrimp and this would be more useful in screening of samples under field condition. Besides detection of shrimp viruses, PCR has been used for detection of bacterial pathogens of public health importance in fish and fish products, indicating its scope of application in food quality control. In our laboratory PCR have been applied to detect WSSV, *V. parahaemolyticus* and *V. cholerae* in culture or tissue samples and found quite effective and sensitive in detection of such pathogens. The tests are now being standardized for other pathogens.

Kits developed

- DNA-based Nested PCR diagnostic kit for WSSV has been developed and commercialized by the CIBA, Chennai.

- PCR-based diagnostic kits for WSSV have been developed by Mangalore Fisheries College and the CMFRI, Kochi.
- Improved semi-nested PCR technique for early detection of WSSV has also been developed by the CIFT.
- Detection procedure standardized for yellow head virus in shrimp, Noda-virus in fish and freshwater prawn by the CIFT, CIBA and CIFA.
- An immunodot blot test for WSSV (CIBA IMMUNODOT) developed for early detection of WSSV in shrimp.
- Nine patents have been filed by the CIBA for various diagnostic kits and methods.

Nucleic acid probes and hybridization technique: Detection of DNA with direct or culture-amplified gene probe technology has been applied to several organisms including bacteria, viruses, fungi and parasites. The unique characteristic of genomic material of bacteria, viruses and cells that constitute the animal, make them to be differentiated and identified. This technique of genomic identification and characterization has been extensively used in molecular biology by specific hybridization with oligonucleotide strands or DNA probes. The technique is popularly known as dot blot hybridization and also applied in detection of pathogens of aquatic animals. Nucleic acid probes are capable of identifying microorganisms at species and strain level. The quantity of target detectable by the method depends on the size and homology of the probe chosen and the nature of the original specimen. DNA probes facilitate the identification of pathogens that do not grow well/rapidly or not easily cultured or cannot be cultured at all under laboratory conditions. The CIFRI has prepared and used non-isotopic DNA probes for detection of *Aeromonas hydrophila*, *V. parahaemolyticus*, *V. cholarae* and WSSV in tissues sample using DNA dot blot hybridization ECL (enhanced chemiluminescine) technique.

Genotyping techniques: A major breakthrough in pathogen identification and characterization has been achieved with the introduction of molecular methods like Randomly amplified polymorphic DNA (RAPD), Restriction fragment length polymorphism (RFLP), Pulse-field gel electrophoresis (PFGE), Ribotyping, Plasmid profiling techniques etc.

Randomly amplified polymorphic DNA (RAPD) technique: RAPD based on PCR amplification technique (RAPD-PCR), also referred to as Arbitrary primed PCR (AP-PCR), is increasingly being used in identification, classification and differentiation of strains of animals, plants, fungi and bacteria. The RAPD fingerprinting allows detection of DNA polymorphism by randomly amplifying multiple regions of the genome through PCR using short and arbitrary primers designed independently of the target DNA sequence. The RAPD analysis also helps assess paternity and kingship relationship in large offspring samples, to analyze mixed genome samples and generating novel genomic or species specific probes for use as diagnostic RAPD marker. RAPD is probably the simplest DNA-based subtyping method to-date, although its usefulness for epidemiological investigation remains to be determined, particularly with regard to reproducibility concerns.

Ribotyping: Ribotyping assays have been used to differentiate closely related

bacterial strains, called ribotypes, and to determine the serotypes most frequently involved in outbreaks. This technique is especially useful in epidemiological studies for organisms with multiple ribosomal operons, such as the members the family of Enterobacteriaceae. Ribotyping simplifies the micro-restriction patterns by rendering visible only the DNA fragments containing part or all of the ribosomal genes. The technique is less helpful when bacterial species under investigation contains only one or two bands, which limits its utility for epidemiological studies. However, both these techniques have wide scope of application in fishery and aquatic microbiology for pathotyping analysis, microbial biodiversity, ecological and evolutionary studies.

Future thrust areas

Because fish and shrimp diseases are major cause of economic loss to the fisheries sector in India, a concerted approach for fish and shellfish health management is needed. Some of the research and development aspects in fish and shellfish health management are:

- Development of diseases surveillance and reporting systems: Disease surveillance and reporting is essential for any national strategy on aquatic animal health and forms an integral part of aquatic animal biosecurity. Active surveillance helps in rapid detection of new pathogens; accurate description of the distribution and occurrence of diseases provides evidence for freedom of diseases and assessment of control measures.
- Development of skilled manpower and clinical laboratories for fish-disease diagnosis.
- Study of prevalence of various pathogens in wild population and identification of carriers of various diseases.
- Development and refinement of molecular methods for early detection of carrier, sub-clinical and clinical conditions.
- Development of effective vaccines and their delivery mechanisms against important diseases.
- Development of antibiotic and non-antibiotic drugs exclusively for use in aquaculture sector.
- Development of quarantine system in various parts of the country to prevent spread of pathogens from import consignments and spread through fish seed and aquarium fishes.
- Formulation of guidelines to be routinely followed by fish farmers for disease control.
- Concerted research effort in aspects like probiotics, vaccines, RNAi and other molecular approaches of disease control.
- Development and maintenance of specific pathogen-free broodstock for disease-free and quality seed production.

33. Climate Change – Impact and Mitigation

The earth's climate is showing perceptible changes on both global and regional scales. Climate change and its warming effects are now being felt across many parts of the world including India. In a developing country like India, climate change could represent an additional stress on ecological and socioeconomic systems that are already facing tremendous pressures due to rapid urbanization and economic development. The unequivocal warming of the climate system is now evident. With large and growing population and low-lying coastline, and an economy that is closely tied to its natural resource base, India is considered vulnerable to the impacts of climate change.

Changes in the atmospheric abundance of greenhouse gases (carbon dioxide, methane, nitrous oxide, chlorofluorocarbon and ozone) and aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust), solar radiation and land surface properties alter the energy balance of the climate system. These changes are expressed in terms of radiating force, which is used to compare how a range of human and natural factors drive warming or cooling. Since the Third Assessment Report (TAR) by Intergovernmental Panel on Climate Change (IPCC), new observations and related modeling of greenhouse gases, solar activity, land surface properties and some aspects of aerosols have led to improvement in the quantitative estimates of radiative forcing. Increasing concentrations of the greenhouse gases (GHGs) and other trace gases have changed the radiative forcing of the atmosphere leading to a net warming. From ice core samples spanning many thousands of years, the IPCC, in its Fourth Assessment Report (2007), has reconfirmed that the global atmospheric concentrations of the GHGs have increased markedly as a result of human activities since 1750 AD and has now far exceed pre-industrial values. The CO_2, methane and nitrous oxide concentrations in atmosphere were 280 ppm, 715 ppb and 270 ppb in 1750 AD; these values have increased to 379 ppm, 1,774 ppb and 319 ppb, respectively, in 2005. The increase in GHGs was 70% between 1970 and 2005. The global increases in carbon dioxide concentration are primarily due to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily from agriculture.

These increases in GHGs have resulted in warming of the climate system by 0.74°C between 1906 and 2005. Eleven of the last 12 years (1995-2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). The rate of warming has been much higher in recent decades. This has, in turn, resulted in increased average temperature of the global ocean, sea level rise, decline in glaciers and snow cover. There is also a global trend for increased frequency of droughts, as well as heavy precipitation events over most land areas. Cold days, cold nights and frost have become less frequent, while hot days, hot nights and heat waves have become more frequent.

Evidence of climate change

Some observed changes in climate parameters in India have been consolidated by India's First National Communication, 2004 (NATCOM) submitted to United Nations Framework Convention on Climate Change (UNFCCC). Some of the changes of relevance to fisheries are described here.

Surface temperature: At the national level, increase of 0.4°C has been observed in surface air temperatures over the past century.

Rainfall: While the observed monsoon rainfall at the all-India level does not show any significant trend, regional monsoon variations have been recorded. A trend of increasing monsoon seasonal rainfall has been found along the west coast, northern Andhra Pradesh, and north-western India (+10% to +12% of the normal over the last 100 years) while a trend of decreasing monsoon seasonal rainfall has been observed over eastern Madhya Pradesh, north-eastern India, and some parts of Gujarat and Kerala (-6% to -8% of the normal over the last 100 years).

Extreme weather events: Trends are observed in multi-decadal periods of more frequent droughts, followed by less severe droughts. There has been an overall increasing trend in severe storm incidence along the coast @ 0.011 event per year. While the states of West Bengal and Gujarat have reported increasing trends, a decline has been observed in Odisha.

Impacts on Himalayan glaciers: The Himalayas possess one of the largest resources of snow and ice and its glaciers form a source of water for the perennial rivers such as the Indus, the Ganga, and the Brahmaputra. Glacial melt may impact their long-term lean-season flows, with adverse impacts on the economy in terms of water availability and hydropower generation. The available monitoring data on Himalayan glaciers indicate that while recession of some glaciers has occurred in some Himalayan regions in recent years, the trend is not consistent across the entire mountain chain. It is accordingly, too early to establish long-term trends, or their causation, in respect of which there are several hypotheses.

Sea level rise: Sea level has remained fairly stable for the last few thousand years. However, the mean global rate of sea level rise during the 20^{th} century was nearly 2 mm/year, which is 10-fold higher than the average of the past several millennia. In its Fourth report, the IPCC has projected that the global annual seawater temperature and sea level would rise by 0.8 to 2.5°C and 8 to 25 cm, respectively, by 2050. The historic sea level rise for Cochin (southwest coast) is estimated as 2 cm in the last one century. However, the rate of increase is accelerating, and it is projected that the sea level may rise at the rate of 5 mm per year in the coming decades. Considering this, it is possible that the sea level may rise by 25 to 30 cm in 50 years. An increase in mean sea level will affect waves, currents and bottom pressure in the near-shore region. In general, an increase in mean water depth will be accompanied by an increase in mean wave height, resulting in a more severe wave attack on the coast and a greater wave induced littoral drift. The erosion due to sea level rise for the region is estimated as 7,125 m^3 per year, implying an erosion rate of 0.3×10^6 m^3/year, which could be attributed to the effects of wave attack. Using the extreme conditions of wave height and sea level rise, future erosion potential is expected to increase by 15.3% by the year 2100. Besides destruction through increased rates of erosion, the sea level rise situations also increase the risk of flooding. This will damage or destroy many coastal ecosystems such as mangroves and salt marshes, which are essential for maintaining many wild fish stocks, as well as supplying seed to aquaculture. Higher sea levels may make groundwater more saline, harming freshwater fisheries, aquaculture and agriculture and limiting industrial and domestic water uses.

Inland fisheries

Impact of climate change on freshwater ecosystems

Freshwater is a finite resource and the basic amount of freshwater supply provided by the hydrological cycle does not increase. Water anywhere on the planet is an integral part of the global hydrologic cycle. A rise in average temperature in mountainous regions can alter the precipitation mix between rainfall and snowfall, with substantial increases in precipitation coming down as rain and a reduction in the amount coming down as snow. This change means more flooding and more runoff during rainy season, and less water held as snow and ice in the mountains for use in the dry season. Some of the changes in the hydrologic system that are relevant to fish and fisheries are: flood magnitude and frequency could increase owing to more intense precipitation events; increase in water temperature; low flows would be more severe owing to increased evaporation; peak stream flow would move from spring to winter owing to earlier thaw. This is evident in the USA where an increase in the proportion of annual precipitation associated with extremes has been occurring since the early 1900s and future scenarios suggest that this will continue into the future.

India is considered rich in terms of annual rainfall and water resources available at the national level. However, these resources are unevenly distributed and result in spatial and temporal shortages, thus limiting availability across regions. Climate change and variability are likely to worsen the existing situation by further limiting water availability. Under a changed climatic regime for any given region, the combined effect of rainfall and more evaporation would have dire consequences. Both these would lead to less run-off, substantially changing the availability of freshwater in the watersheds. Also, potential changes in temperature and precipitation might have a dramatic impact on the soil moisture and aridity level of hydrological zones. With changes in the flows, annual runoff, and groundwater recharge, water available for usage will further be decreased.

Rivers: The comparison of water balance components expressed as percentage of rainfall for control as well as climate change scenarios is given in Table 33.1. The impacts are different in different catchment areas. The increase in rainfall due to climate change does not result in an increase in the surface run-off as may be generally predicted. For example, in case of the Cauvery river basin, an increase of 2.7% has been projected in the rainfall, but the run-off is projected to reduce by about 2% and the evapo-transpiration to increase by about 2%. This may be either due to increase in

Table 33.1. Comparison of change in water balance components as percentage of rainfall

Basins	Scenario	Rainfall (mm)	Run-off (mm)	As a proportion of rainfall (%)	Actual ET(mm)	As a proportion of rainfall (%)
Cauvery	Control	1,309.0	661.2	50.5	601.6	46.0
	GHG	1,344.0	650.4	48.4	646.8	48.1
Brahmani	Control	1,384.8	711.5	51.4	628.8	45.4
	GHG	1,633.7	886.1	54.2	698.8	42.8
Godavari	Control	1,292.8	622.8	48.2	624.1	48.3
	GHG	1,368.6	691.5	50.5	628.3	45.9
Krishna	Control	1,013.0	393.6	38.9	585.0	57.7
	GHG	954.4	346.9	36.4	575.6	60.3
Luni	Control	317.3	15.5	4.9	316.5	99.7
	GHG	195.3	6.6	3.4	207.3	106.1
Mahanadi	Control	1,269.5	612.3	48.2	613.5	48.3
	GHG	1,505.3	784.0	52.1	674.1	44.8
Mahi	Control	655.1	133.9	20.4	501.0	76.5
	GHG	539.3	100.0	18.5	422.7	78.4
Narmada	Control	973.5	353.4	36.3	586.8	60.3
	GHG	949.8	359.4	37.8	556.6	58.6
Pennar	Control	723.2	148.6	20.6	556.7	77.0
	GHG	676.2	110.2	16.3	551.7	81.6
Tapi	Control	928.6	311.2	33.5	587.9	63.3
	GHG	884.2	324.9	36.7	529.3	59.9
Ganga	Control	1,126.9	495.4	44.0	535.0	47.5
	GHG	1,249.6	554.6	44.4	587.2	47.0
Sabarmati	Control	499.4	57.0	11.4	433.1	86.7
	GHG	303.0	16.6	5.5	286.0	94.4

Source: Ministry of Environment and Forest, Government of India 2004. ET, evapo transpiration; GHG, Green House Gases.

temperature and/or change in rainfall distribution in time. Similarly, a reduction in rainfall in the Narmada is likely to result in an increase in the run-off and a reduction in the evapo-transpiration that is again contrary to the usual myth. This increase in run-off may be due to intense rainfall as a consequence of climate change. Therefore, it is important to note here that these inferences have become possible since a daily computational time step has been used in the distributed hydrological modeling framework. This realistically simulates the complex spatial and temporal variability inherent in the natural systems. It may be observed that even though an increase in precipitation is projected for the Mahanadi, Brahmani, Ganga, Godavari and Cauvery basins for climate change scenario, the total run-off for all these basins has not necessarily increased. For example, the Cauvery and Ganga show a decrease in the total run-off. This may be due to an increase in evapo-transpiration on account of increased temperatures or variation in the distribution of rainfall. In the remaining basins, a decrease in precipitation is projected. The resultant total run-off for the majority of the cases, except for the Narmada and Tapi, is projected to decline. As expected, the magnitude of such variations is not uniform, since they are governed by many factors such as land use, soil characteristics and status of soil moisture. The Sabarmati and Luni basins are likely to experience decrease in precipitation and consequent decrease of run-off to the tune of two-thirds of the prevailing run-off. This may lead to severe drought conditions. The vulnerability of water resources has been assessed with respect to droughts and floods. Rainfall, run-off and actual evapo-transpiration have been selected from the available model outputs, since they mainly govern these two extreme impacts due to climate change.

Rivers differ a great deal in the amount of water they carry depending upon the precipitation in their catchments and other sources of water (e.g. snowmelt) as well as factors that determine run-off, infiltration and evaporation. Flow is an important factor determining the physical structure of a river and thus maintaining in-stream habitats. The range and variability of flows are just as important as the volume of water within a system. Flows also differ in their seasonal flow patterns, size and frequency, duration and the rate of rise and fall of a flow event. Changes in any of the flow characteristics are marked by a reduction in habitat complexity and the diversity of plants and animals. River flows interact with groundwaters, which may be recharged or contribute to the river flow (discharge) at different times of the year.

Further, flow variability directly affects many life cycle stages of fish, for example, flooding or its receding serves as a cue for migration and spawning (Fig. 33.1).

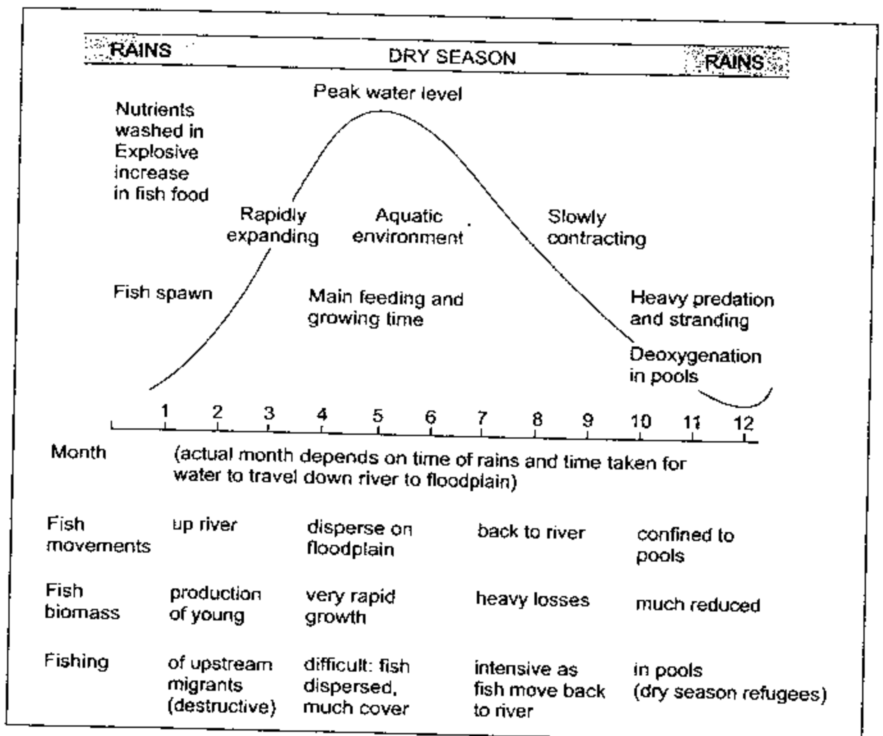


Fig. 33.1. Effects of flood and seasonal flow variation on fishes.

Wetlands: Hydrological processes in the watershed, and the rate of downstream discharge determine the depth, duration and frequency of inundation of the floodplain, which periodically becomes a part of the river. The area immediately adjacent to the floodplain, which is influenced by the river, is often distinguished as the riparian zone. Thus, riparian zone and the floodplain are important riverine habitats and form a critical link between terrestrial and aquatic ecosystems. Hence the river flows determine the nature and strength of a river's interaction with its floodplain, and consequently the diversity of habitats and biotic communities. Any human activity that directly or indirectly impinges upon the flows has an impact on the fishery resources.

The open water wetlands that are critical habitats of many species would be replaced by damp land although some form of vegetation would remain there. Lower water-table would also leave some areas that currently have some form of wetland vegetation, dry for a longer period that would reduce biological productivity and in some cases would leave the land too dry to consider it as a wetland. A drier climate would also force farmers to increase irrigation, which would further reduce the water-table.

Water quality and pollutants: Warming effect could exacerbate the existing environmental problems for rivers and wetlands. It may change the chemical composition of water that fish inhabit; the amount of oxygen in water may decline, while pollution and salinity levels may increase.

Table 33.2. Lethal dissolved oxygen concentration for some freshwater fishes

Species	Lethal dissolved oxygen (mg/litre)
Catla catla	0.7
Labeo rohita	0.7
Cirrhinus mrigala	0.7
Hypopthalmicthys molitrix *	0.3-1.1
Ctenpharyngodon idella	0.2-0.6
Cyprinus carpio	0.2-0.8

Source: Varga and Chowdhury (1992).

Dissolved oxygen: Water holds less oxygen at higher temperature; and fish require more oxygen as temperature rises. Indian major carps and exotic carps cultured in India are appreciably tolerant to warm water and low oxygen conditions (Table 33.2). Many other Indian fish species of the families Anabantidae, and Heteropneustidae and other catfishes are capable of tolerating oxygen depleted conditions.

Eutrophication: Existing environmental problems for lakes and streams also could be exacerbated by climate change. Available information on potential interactions between climate change and traditional problems such as eutrophication and toxic substances are sparse. Increases in more intense rainfall events and winter rain events should increase run-off and increase external loading (increasing apparent eutrophication); reduction in precipitation should reduce run-off and reduce external phosphorus loading (decreasing apparent eutrophication).

Effect of pollutants: Global warming is an overall effect of anthropogenic pollution. Existing environmental problems for rivers and wetlands could be exacerbated by enhanced temperature due to climate change. The relative toxicity of a typical pollutant such as copper on fishes is strongly found to be temperature dependent. In fishes severe copper exposure is manifested in the form of structural damage to gill epithelia and disruption of ion regulation. The toxicity of many xenobiotics to fish is altered by changes in water temperature. Polycyclic hydrocarbons (PAHs) cause devastating tumors in ferel fish. Temperature alone may be a lethal factor with some thermal limits that may be altered by toxicants.

Impact on fish population

Breeding and recruitment of fishes in rivers: The Indian major carps constitute the most important fish species for inland fish production from the rivers and confined water bodies. The IMC breed naturally in rivers while in confined waters where aquaculture is practiced, it is bred artificially by hypophysation. The impact of climate change on the breeding of IMC has been different in the two aquatic ecosystems.

Scientists of Centre Inland Fisheries Research Institute (CIFRI) under the ICAR network on Impact of Climate Change on Inland Fisheries collected time series data on various climate variables and inland fisheries related to the Ganga river system, viz. water temperature, current velocity, rainfall, plankton availability, availability of spawn, fish landings etc., consulting approximately 200 scientific papers. The data were analysed and compared with the present data collected through the project to evaluate the impact, if any, on inland fisheries.

River Ganga: The fish spawn or seed availability of Indian major carps has declined in the middle stretch of river Ganga over the years (Fig. 33.2). The failure of recruitment of young ones to the system is because of failure of breeding of the IMC. The fish spawn availability index declined from 281.03 ml during 1970s to 27 ml during 1996-2000. It also showed a decreasing percentage of major carp seed (78.6% in 1961-65 to 34.5% in 2000-04) whereas minor carps increased (from 20.7% in 1961-65 to 53.0% in 1991 to 1995) and other fish seed showed an increasing percentage (from 0.7% in 1961-65 to 47.8% in 2000-04) in the total seed collection.

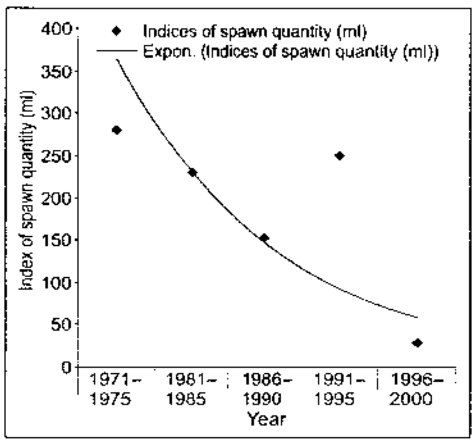


Fig. 33.2. Indices of spawn quantity in Ganga river system during 1971-2000

Majority of fishes in the Ganga river system breed during the monsoon months, i.e. June to August because of their dependence on seasonal floods, which is needed for reproduction. A decrease in precipitation during the breeding months alters the required flow and turbidity of the water essential for breeding of IMC.

Analysis of the monthly data for Allahabad from 1974 - 2003 split into three equal periods, P1 (January-April), P2 (May-August) and P3 (September-December), revealed that the percentage of total rainfall in the peak breeding period (May- August) declined

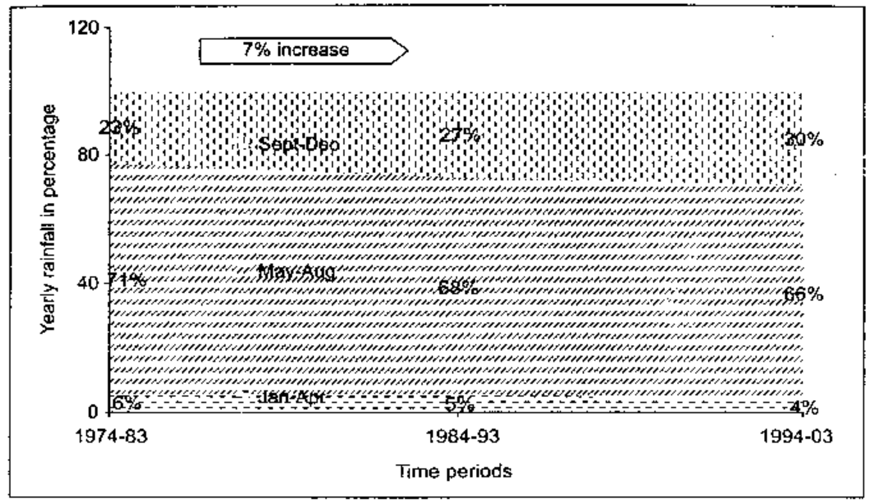


Fig. 33.3. Shifting of seasonal pattern of rainfall at Allahabad during 1974-2003.

by 5, whereas it increased by 7 in the post-breeding period when resorption of eggs of IMC sets in. This shift in the rainfall pattern (Fig. 33.3) during breeding season is a major factor responsible for failure in breeding and con3sequent recruitment of young ones of IMCs in the river Ganga.

Geographic distribution of fish in river Ganga: Temperature has long been a focus of biogeographic studies because of its overwhelming influence on the physiology of exothermic organisms such as fish. Survival, growth, egg development and even competitive ability of fish are temperature dependent. Biogeographic distributions often provide an insight into thermal limits of fish whose physiology and reproductive success are strongly influenced by temperature. These thermal limits can be used to project distributional changes following climate change by assuming fish will migrate along isotherms to remain within a suitable thermal envelope.

The distributional shifts of species includes abandonment of areas currently occupied if future temperature exceeds physiological tolerances as well as colonization of new areas if previously unsuitable temperature conditions are ameliorated. This approach has been termed forecasting from historical analogy. In freshwater we should expect to see fish distribution migration poleward or higher in elevation as the fish track the suitable temperature. Areas now supporting high yields of sport or commercial species may become marginal, whereas areas at the margin of species distributions may become optimal. Of course such changes in fish distribution assume that species will be able to migrate along watercourse to final suitable thermal habitat. Thus for predicting fish species response to climate change thermal limits based on biogeographic distribution is a useful approach.

With this background the distributional pattern of fishes of river Ganga were analysed by scientists of the CIFRI from the published records available. It revealed that a large number of fish species which were predominantly available in the lower and middle stretch of river Ganga in 1950s are now recorded from the upper Ganga stretch, i.e. up to Tehri. It is indicative of colonization of new areas.

There is a perceptible shift in geographic distribution of the fishes of river Ganga. The warm water fish species *Glossogobius giuris, Puntius ticto, Xenentodon cancila* and *Mystus vittatus*, which were earlier available only in the middle stretch of river Ganga are now available in the colder stretch of the river around Haridwar. In the Haridwar stretch during the period 1970-86 the annual mean minimum water temperature was 12.9°C, while during the period 1987-2003 it increased to 14.5°C, an increase of 1.6°C. As a result the stretch of river Ganga around Haridwar has become a congenial habitat fo· these warm water fishes.

The mahseer *Tor putitora* descended during December 2005- January 2006 for the first time up to Karnal where it formed 1.2% to 1.4% of total fish population. The average minimum atmospheric temperature during December 2005-January 2006 ranged from 5.1 to 8.9°C and maximum temperature between 17.3 and 21.4°C. The water temperature was 4.0- 8.5°C and 15.0-20.0°C respectively around Karnal. The descending run in river Jamuna up to Karnal may have been to avoid low temperature in the upland. The normal preferred temperature of the fish species is 15-28° C.

Impact on growth: Water temperature strongly affects fish metabolism, consumption, growth, behaviour, habitat selection, spawning foraging and predator-prey interaction. Growth rate potential provides a good measure of habitat quality and effectively incorporates biotic and abiotic characteristics of the environment in a metric that directly relates to the fitness of fish. Earlier investigations conducted in the Great Lake basin (Lake Michigan) indicated that increase in length of the thermal conditions for high growth rate was shown to be the main cause of increase in fish growth rate potential for all species under climate warming. Clearly any effect of climate warming on the top predators will depend on prey availability and prey fish populations. One of the more subtle effects of changes in the thermal structure is the impact on prey densities.

Climate warming may produce a large volume of thermal habitat for the fish and if the same number of prey is distributed across this large volume of habitat, prey densities encountered by a predator would be reduced. Reduced prey densities would reduce the predator encounter rate with prey, which would reduce predator consumption rate.

Breeding of fishes in hatcheries

The IMCs *Catla catla*, *Labeo rohita* and *Cirrhina mrigala* form the predominant species around which inland aquaculture is centered in India. These fishes, unlike in rivers where natural spawning occurs, do not breed in confined waters and are bred in captivity by hypophysation during their maturity in the monsoon season (June-August). However, in recent years the phenomenon of IMC maturing and spawning as early as March is observed. Investigation was conducted by scientists of the CIFRI under the ICAR Network project on Impact of Climate Change on Inland Fisheries to ascertain the impact of climatic variables, viz. elevated temperature and rainfall, on the breeding

of Indian major carps and impact on the fishers in the 50 fish hatcheries in four districts, viz. North 24-Parganas, Bankura, Burdwan and Hooghly, of West Bengal.

Trend of temperature alteration: Analysis of air temperature data (1986-2005) recorded by Indian Institute of Tropical Meteorology (IIMT, Pune) during the breeding months (March-September) indicate that the mean maximum air temperature has increased by 0.37°C and the mean minimum air temperature by 0.67°C in the 24 Parganas (N) district; in district Bankura the mean minimum air temperature increased by 1.57°C; and in Burdwan district the mean minimum air temperature increased by 0.18 °C and the mean maximum air temperature increased by 0.09°C. Simultaneously the differences of temperature between January-February, February-March and March-April during 1961-2005 indicated a shift towards higher temperature during January-February. Analysis of data at 24-Parganas (N) by taking the frequency of occurrence of (4°C and above) difference of temperature between the three consecutive months as a basis for evaluating the shift of elevated temperature towards cooler months (January-February) showed that the frequency of occurrence of temperature differences was maximum in February-March (average: 55%) and March-April (average: 30%) during previous three decades (1961-90). But, such trend was not evident in the 15 years (1991-2005) where the frequency of occurrence of (4°C and above) difference in minimum temperature shift towards colder months, i.e. January- February (from 14% to 31%); February-March (from 55% to 46%) and March-April (from 32% to 23%) (Fig. 33.4).

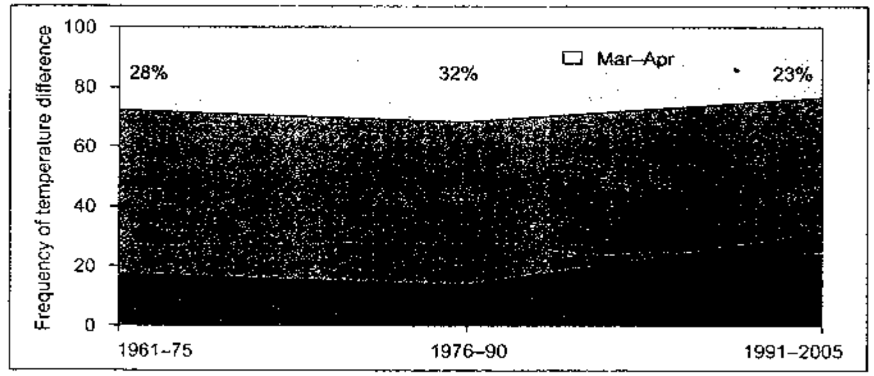


Fig. 33.4. Shift in temperature during 1961-2005 at 24 Parganas (N), West Bengal
Source: Das and Saha (2008).

The analysis of air temperature data showed that both mean maximum and mean minimum air temperature have increased by 0.67°C, and 0.37°C, respectively, during last two decades in the district 24 Parganas (N) during the breeding season (March - September). Putting the recorded air temperature in the worked-out relationship equation $w = 1.1504, a - 3.7305$, $R^2 = 0.9634$ between air and water temperature (where w = water temperature in °C, a = air temperature in °C, and R^2 =correlation coefficient), it has been derived that the mean maximum and minimum water

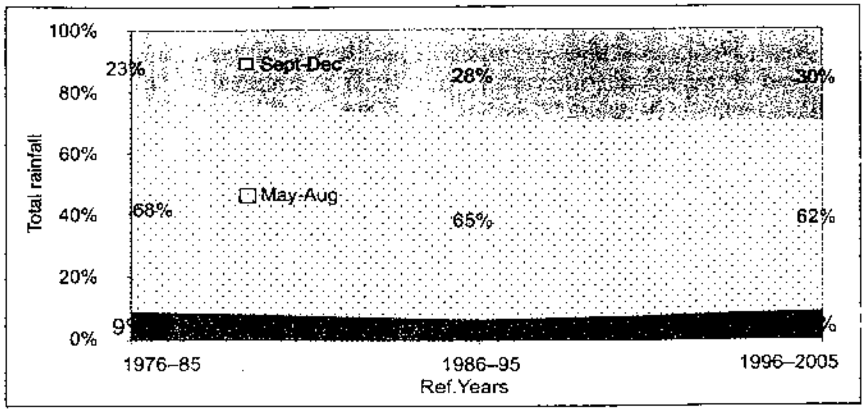


Fig. 33.5. Rainfall pattern at Dum Dum during 1976-2005.

temperature has increased by 0.78°C, and 0.43°C, respectively, in the district during the period.

Trend of shifting pattern of rainfall: Since rainfall is another important criterion that triggers the early maturation of brood fish, the rainfall pattern during the period 1976-2005 of some of the districts of West Bengal were analysed. The analysis of rainfall data collected by the IIMT showed that the proportion of annual total rainfall occurred in monsoon months (May-August, 68% during 1976-85), but this proportion is gradually decreasing over the time (May-August: 65% during 1985-95; 62% during 1996-05) and increasing in post-monsoon months (in September-December, the proportion was 30% whereas only 23% during 1976-1985) at Dum Dum (Fig. 33.5) during 1976-2005. Similar pattern in rainfall distribution was observed at Kolkata and Bankura districts of West Bengal during 1976-2005.

Advancement of breeding period: Interaction with fishers and operators of 50 fish hatcheries indicated temperature rise as the main reason for advancement of the

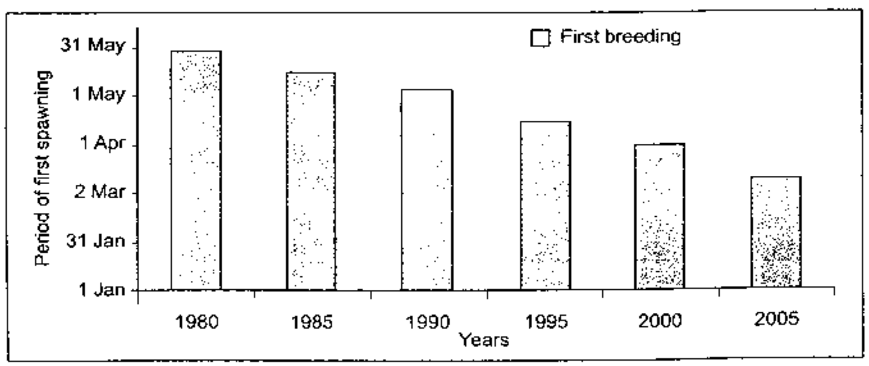


Fig. 33.6. Advanced breeding period of Indian major carps at different hatcheries of 24-Parganas.

breeding season of IMC, with 90-95% reasoning to demand and high sell price of seed. The increase in income is attributed to more quantity of spawn by 90-95% response. The study also observed that the breeding period of the major carps has advanced in all the districts by 1 to 2 months in the last 20 years (Fig.33.6).

Price and income: The price per measure *bati* (100 ml) of IMC varied during the season. During 1980-85 each bati was priced ₹ 250-300 in June-July, which reduced to ₹150-200 in August-September. During 2000-05 initial price per *bati* was ₹ 500-600 during the advanced months of breeding, March-April coming down to ₹ 180-200 in August-September. In spite of the enhanced cost of production in the last two decades, the high price of the IMC spawn initially with extended season of sale has raised the income of the fish seed hatcheries and fishers. Thus the alteration in climate had a positive impact on the breeding of IMCs hatcheries unlike in rivers where there was a negative effect.

Impact on reproductive integrity

All the stages of reproduction in fish, viz. gametogenesis and gamete maturation, ovulation/spermiation, spawning and early development stages, are affected by temperature. Imbalance or rapid change in temperature are stressful to fish and may also be linked with other stressors. The primary effect of stress is activation of sympathetico-chromaffin tissue and hypothalamic-pituitary pathways resulting in the release of respective catcholamines and corticosteroid hormones in the blood streams. These will increase the metabolic processes to reduce the stress response in fish. If stress is maintained the effects start manifesting by the inhibition of reproductive function, cessation of ovulation, depression of reproductive hormones in blood and ovarian failure. Temperature change modulates the hormone action at all levels of reproductive endocrine cascade.

Fish are obligate poikilotherms some of which can perceive temperature changes of less than 0.5°C. Investigation was conducted on *Cyprinus carpio* subjected to enhanced temperature. The optimum range of the fish is 15-32°C and its upper critical range is 30-41°C. It spawns optimally in the range of 12-30°C.

In another investigation conducted by scientists at the CIFRI under the ICAR Network project on Impact of Climate Change on Inland Fisheries, the mature female *C. carpio* were subjected to an enhanced temperature of 34°C to study the effect on the reproductive integrity of the fish. Observation on the levels of cholesterol in the ovary and liver, hormone estradiol in serum, and gonadosomatic and hepatosomatic indices for 21 days indicated a decrease in the gonadosomatic index and serum estradiol levels. The cholesterol levels in ovary and liver increased. Histology of the ovary of *C. carpio* exhibited impaired vitellogenesis in oocytes.

Functional homeostasis of steroid hormones is important in the life cycle of fish as they are seasonal breeders. Any change in the steroid hormones leads to disruption of the reproductive efficiency of the fish and depletion of the population in the long run. During sexual maturation, synthesis of gonadotropin and steroid hormones are high. There has been an accumulation of liver and ovarian cholesterol (a precursor of steroid hormones), and as a result, the hormone estradiol is depleted. Estradiol stimulates liver to produce vitellogenin. Failure of incorporation of vitellogenin due to increased temperature (which is mainly responsible for increase in gonadal weight) has resulted in lower GSI and estradiol level in serum.

Impact on fish physiology and health

Fluctuating temperature: Fluctuating temperature often disturbs the homeostasis of fish and subjects them to physiological stress and shift in habitat or mortality. In the climate warming scenario fishes will be subjected to the hazard of rapid temperature changes. It is more so in the tropical waters where daily variations in water temperature and thermocline in deep water bodies will assume significance. These effects would often become additive or synergistic with those of other adverse effects (e.g. low *p*H, algae, oxygen shortage). It is essential to understand that these temperature changes, though sublethal, can place a stress of considerable magnitude on the homeostatic mechanism of fishes at the primary, secondary and tertiary level.

High temperature: Investigations were conducted at the CIFRI on the alteration occurring in the levels of various stress sensitive blood and tissue parameters of the fish *Labeo rohita* and *Rita rita* acclimatized at 29°C and subjected to a rapid sublethal rise to 35°C. The results indicated that the homeostatic mechanism of the fish is stressed. The changes evident are hypercholesterolemia indicating impaired sterol mechanism, hyperglycemia and decreased blood sugar regulatory mechanism. Pituitary activation as evidenced by inter-renal ascorbic acid depletion and cortisol elevation is pronounced. Oxygen consumption in both the fishes increased as judged by increased hemoglobin. It was also observed that compensatory responses initiated within 72 hr. Obviously adaptation to the stress of elevated temperature occurs. But if the stress of enhanced temperature is of chronic nature, as in a climate warming scenario, then the tolerance limits would be exceeded.

Low temperature: To assess the physiological effect of low temperature on fish, low temperature shock at 5°C was given to juveniles for 5 min and subsequently transferred to aquarium water of 28°C for recovery. A significant decrease occurred in anterior kidney ascorbic acid level. There was a rise in plasma cortisol within 20 min after the shock. Plasma chloride levels decreased significantly, but subsequently recovered. Plasma glucose level increased due to glycogenolysis in muscle and liver. Plasma lactic acid level increased and persisted up to 24 hr of recovery.In another study, *L. rohita* juveniles were subjected to gradual lowering of the ambient temperature from 28°C to 13°C (critical temperature for *L. rohita*). The result indicated significant rise in plasma cortisol with hyperglycemia. There was a cessation of feeding and sudden burst of activity followed by a state of total cessation of activity. But there was no mortality and fishes recovered when placed in higher temperature.

Fish disease: Information regarding the impact of climate warming on freshwater fish parasites or diseases are not available. In a climate warming scenario temperature changes can place a stress of considerable magnitude on the homeostatic mechanism of fishes leading to infection by parasites. In India the only freshwater fish disease, which had been very menacing and virulent, was the epizootic ulcerative syndrome (EUS). Transcending the confines of culture ponds, the EUS has plagued the natural fish population of open water-bodies. Environmental factors play a key role in the initiation and spread of this disease. Disease outbreak occurs at the time of waning of rainfall and onset of gradual stagnation and fall in water temperature. The intense disease outbreak occurred throughout India during 1990s, which also coincides with one of the warmest decades of the century.

Growth of fish under simulated temperature regime: In another study conducted by scientists of CIFRI under the ICAR Network Project on Impact of Climate Change on Inland Fisheries, advance fry of *Labeo rohita* (1.39 ± 0.013 g) acclimatized in laboratory conditions and adapted to formulated pelletised artificial feed were subjected to unit rise of water temperature within the range of 29°C-35°C simulating climate warming scenarios. It indicated that fishes reared at 34°C grew significantly faster (18.38 cg in a day) than those at 29°C, 30°C, 31°C, 32°C, 33°C and 35°C. It would take an average of 77 days for a carp to double its weight at 30°C to 33°C and 35°C, but at 34 °C it would take only 35-36 days.

Osmoregulation of anadromous fishes: The anadromous species such as the Indian shad *Tenualosa ilisha* have a characteristic of early development in freshwater followed by seaward movement and again migration to freshwater for spawning. The seaward migration is highly seasonal and is restricted to spring or fall, at the time of temperature change. Hence temperature may be a controlling factor in determining the timing of development and migration. In the American shad, high salinity tolerance develops at the time of larval-juvenile metamorphosis (July), several months before peak downstream migration (October). At the end of the migratory period ion losses occur in laboratory-reared and wild fish, coinciding with increased gill Na^+, K^+-ATPase activity. Ion losses are delayed in fish maintained at elevated temperature (summer), indicating that higher temperature will permit a longer period of freshwater residence for shad. Less is known about the impact of global warming on the osmoregulatory function of anadromous fishes. More research is needed on the salinity tolerance and physiological changes that occur during migrations.

Adaptation options in inland fisheries

Enhanced water temperature

Changes in culture system

- Reduction in dissolved oxygen, water quality deterioration
- Enhanced primary productivity
- Increased growth and food conversion
- Increased disease incidence
- Enhanced breeding period in hatcheries
- Exotic species introduction
- Changes in level of production from ponds and hatcheries
- Enhanced operating cost
- Increase in capital costs due to creating deeper ponds with aeration facilities

Changes in rivers

- Geographic shift of fishes
- Habitat loss or gain
- Fish breeding alteration/ changes
- Decrease in fish and related biota species richness, alteration in species composition
- Exotic species invasion

Adaptation options

- Making changes in feed formulations and feeding regimes of fishes
- Exploring substitution by alternate species of fish
- Providing monetary input to the changes in operational costs in ponds and hatcheries

Floods

Changes in culture system

- Salinity changes
- Escape of fish stock
- Structural damage
- Introduction of disease /predators
- Loss of fish stock
- Damage to aquaculture facilities
- Higher capital costs for flood resistance like construction of embankments, etc.
- Higher insurance costs

Changes in rivers

- Geographic shift of fishes
- Habitat loss or gain
- Fish breeding failure
- Decrease in fish and related biota species richness

Adaptation options

- Embankments for frequent and shallow flood protection
- Harvesting fish at smaller size
- Giving importance to fish species that require short culture period and minimum expense in terms of input
- Continuous supply of seed from hatcheries or in other words raising production of seed from hatcheries

Drought

Changes in culture system

- Salinity change

- Water quality deterioration
- Limited water volume
- Loss of fish stock
- Limited fish production

Adaptation options

- Smaller ponds that retain water for 2-4 months can be used for fish production with appropriate species (catfish, tilapia etc.) and management practices.

Storms (coastal region)

Changes in culture system

- Inundation and flooding
- Salinity changes
- Escape of fish/prawn stock
- Introduction of disease and predators
- Loss of prawn/ fish stock
- Damage to facilities
- Higher insurance costs

Adaptation options

- Early detections systems of extreme weather events
- Communication of early warning system
- Accept certain degree of loss
- Development and implementation of alternative strategies to overcome these periods
- Maximizing production and profits during successful harvest
- Suitable site selection and risk assessment work through GIS modeling

Alteration in rainfall and water availability

Changes in culture system

- Deterioration in water quality
- Increased diseases
- Reduced pond level
- Altered and reduced freshwater supply
- Cost of maintaining pond level artificially
- Conflict with other water users
- Loss of fish stock
- Reduced production capacity
- Change of culture species

Changes in rivers

- Geographic shift of fishes
- Species richness decrease

- Breeding failure
- Habitat loss/gain

Adaptation options

- Extending coverage of freshwater aquaculture areas
- Multiple use. reuse and integration of aquaculture with other farming systems
- Intensification of aquaculture practices in resources of wastewater and degraded water such as ground saline water
- Small ponds (50-200 m^2) of seasonal nature (1-3 months) can be used for rearing/ culture of appropriate species of fish/prawn
- Increasing infrastructure sophistication of hatcheries for assured seed production of 34,000 million carp fry, 8,000 and 10,000 million scampi and shrimp PL respectively

Human adaptation to changes in climate

Negative impacts on aquatic ecosystems and fisheries may be aggravated by human adaptation to changes in climate. For adaptation to increased demand for water for irrigation the option aims at increasing supply. Increasing the water source for irrigation is expensive and has the potential environmental impacts. The demand side options aim at reducing demand. These include increasing irrigation efficiency through improved technology and higher prices for water, and changes in cropping pattern by switching to crops that require less or no irrigation. For flood management, supply side options include increasing flood protection with levees and reservoir; these are expensive and have potential environmental impacts. Demand side options include improvement in flood warning systems and information and to curb floodplain development. Thus a variety of options are available and influences on fish and fisheries depend on the details of such choices. The demand side options, in most cases, would appear to be better choices for those interested in fish and fisheries.

Development of a unified strategy

A common framework should be created at the country level that can be used towards implementing the integrated watershed management strategy starting from Gram Panchayat (village council) to the river-basin level in a unified manner. Integrated watershed management does not merely imply amalgamation of different activities to be undertaken within a hydrological unit. It also requires collection of relevant information, so as to evaluate the cause and effect of all the proposed actions. This framework will need regular maintenance and updating to fully reflect the most accurate ground truth data. Local planning and management strategies have to be evolved and validated through the proposed framework, so as to generate and evaluate various options suitable for local conditions. This would greatly help inland fisheries development in future.

Marine fisheries

In marine fisheries, being open access to a large extent, there is intense competition

among the stakeholders with varied interests to share the limited resources in the coastal waters. It has been realized that the scope for increasing fish catch from the coastal waters is limited. Climate change is projected to exacerbate this situation and act as a depensatory factor on fish populations. Warming of water has potential impact on fish diversity, distribution, abundance and phenology, which will have, in turn, effects on the ecosystem structure and function. Acidification of water will have effects on calciferous animals. Increased incidence of extreme events such as storms, floods and drought will affect the safety and efficiency of fishing operations, flow of rivers, area covered by wetlands and water availability, and will have severe impacts on fisheries. Sea level rise will have effects on the coastal profile and livelihoods of communities. The potential outcome for fisheries may decrease in production and value of fisheries, and decline in the economic returns from fishing operations.

Impact of climate change on climatic and oceanographic parameters

The world's oceans are affected by changes in precipitation, wind and currents, themselves the result of geographical differences in temperature and humidity of the atmosphere. Thus, important oceanic weather systems such as the El Niño Southern Oscillation (ENSO) and the Indian Ocean monsoon will be affected by global warming. Changes in ocean circulation can alter the climate. For example, changes in ocean currents that occur during El Niño can affect the climate for a year or two.

It has been found that the sea surface temperature (SST) has increased in the Indian sea by 0.2°C along the northwest (NW), southwest (SW) and northeast (NE) coasts, and by 0.3°C along the southeast (SE) coast during the 45-year period from 1961 to 2005. For instance, the annual average SST, which ranged between 27.7°G and 28.0°C during 1961-1976 increased to 28.7°C-29.0°C during 1997-2005 between 9°N, 76°E and 11°N, 77°E (southwest coast). The warmer surface waters (29.0°C-29.2°C) expanded to a very large coastal area (between 8°N, 72°E and 14°N, 75.5°E) in the 45 year period. The cooler waters (25.2°C-25.5°C) in 23°N, 68°E (off Saurashtra in the northwest coast) during 1961-76 disappeared completely in the later years (Fig. 33.7). It has been found that the SST showed peaks at an interval of about ten years (1969-70, 1980, 1987-88, 1997-98, 2007) during 1961-2007, and the decadal number of SST anomalous (+ 1 or − 1 deviation from the 47-year mean) months increased. For example, only 16% of the months were SST anomalous during 1961-70, but 44% during 2001-07. It has been predicted that the annual average sea surface temperature in the Indian seas would increase by 2.0°C to 3.5°C by 2099.

The impact of global warming on the Arabian Sea is the disruption of the natural decadal cycle in the SST after 1995, followed by a secular increase in temperature. This increase in temperature is associated with a 5-fold increase in the development of most intense cyclones (> 100 kmph) in the Arabian Sea (May-June) after 1995 (1995-2007), compared to the previous 25 years (1970-94). Concurrent with these events, there are progressively warmer winters, decreased monsoon rainfall, both occurring over India and an increase in the phytoplankton biomass in the Arabian Sea during fall and winter, all of which are linked. It has been found that

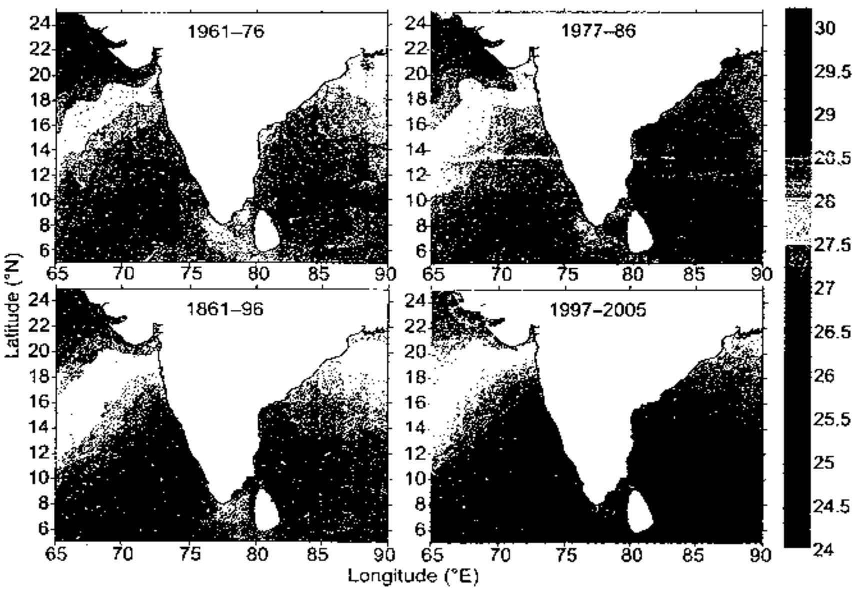


Fig. 33.7. Plot of sea surface temperature showing warming of sea surface along the Indian coast during 1961-2005.
(Data source: ICOADS and AVHRR data from NOAA/NASA; the values near the vertical bar indicate SST (°C))
(Satellite image, hence island ecosystems are not clearly visible)

warmer winters cause a reduction in the annual wheat yield while decreased rainfall results in the decline of vegetation, increase in aridity and increased occurrence of heat spells over India. The synchronous increase in the phytoplankton biomass to iron-fertilization during fall and winter is due to enhanced dust-delivery from the surrounding landmass under increased aridity. Further, the increased phytoplankton biomass is tightly coupled to the higher fish (oil sardine) catch in the eastern and western Arabian Sea after 1995.

Impact on marine fish

Many tropical fish stocks, for instance, are already exposed to high extremes of temperature tolerance, and hence, some may face regional extinction, and some others may move towards higher latitudes. Coastal habitats and resources are likely to be impacted through sea level rise, warming sea temperatures, extremes of nutrient enrichment (eutrophication) and invasive species. Most fish species have a narrow range of optimum temperatures related to their basic metabolism and availability of food organisms. Being poikilotherms, even a difference of 1°C in seawater may affect their distribution and life processes. At shorter time scales of a few years, increasing temperature may have negative impacts on the physiology of fish because oxygen

transport to tissues will be limited at higher temperatures. This constraint in physiology will result in changes in distributions, recruitment and abundance. Changes in timing of life history events (phenological changes) are expected with climate change. Species with short-life span and rapid turnover of generations such as plankton and small pelagic fishes are most likely to experience such changes. At intermediate time scales of a few years to a decade, the changes in distributions, recruitment and abundance of many species will be acute at the extremes of species' ranges. Changes in abundance will alter the species composition and result in changes in the structure and functions of ecosystems. At long time scales of multi-decades, changes in the net primary production and its transfer to higher trophic levels are possible. Most models show decreasing primary production with changes of phytoplankton composition to smaller forms, although with high regional variability.

The tropical fisheries are characterized by several fast growing (von Bertalanffy's annual growth coefficient: 0.5 to 1.0) and multiple spawning species. Low levels of spawning take place throughout the year for most of the species, however, there are one or two distinct spawning peaks in a year. The eggs of most of the species are pelagic, directly exposed to the higher temperature and currents. As temperatures increase, the development duration of eggs decrease, but the size of emerging larvae decreases. In the warmer years, the adults may grow faster, but there will be a point where growth rates would start to decrease as metabolic costs continue to increase. In some marine organisms, it has been found that the average life-span will decrease as a function of increased growth rate, and the individuals will mature younger at a smaller size. This will in turn reduce the absolute fecundity, as smaller individuals produce lesser number of eggs. The scale of these organism-level changes on the recruitment, biomass and fishery may depend on the environmental variables and food availability in different regions.

Generally, the more mobile species should be able to adjust their ranges over time, but less mobile and sedentary species may not. Depending on the species, the area it occupies may expand, shrink or be relocated. This will induce increases, decreases and shifts in the distribution of marine fish, with some areas benefiting while others lose. From the ICAR Network Project on Impact of Climate Change on Marine Fisheries carried out by Central Marine Fisheries Research Institute, the following responses to climate change by different marine species are discernible in the Indian seas: (*i*) Changes in species composition of phytoplankton at higher temperature; (*ii*) extension of distributional boundary of small pelagics; (*iii*) extension of depth of occurrence; and (*iv*) phenological changes. Some evidences for the responses are given here.

Changes in species composition of phytoplankton and the potential impact at higher trophic levels

Laboratory experiments on seven species of phytoplankton at lower (24°C) and higher (29°C) seawater temperatures showed that at higher temperature, the rate of multiplication was faster and cell density was higher for all the seven species. However, the decay set-in earlier and the cycle was completed earlier at higher temperature. For instance, the maximum cell density of *Chaetoceros calcitrans* was 510×10^3 cells/ml on day 7 after initiation of culture at 24°C, but the maximum cell density was 650×10^3 cells/ml at 29°C on the same day. All the microalgae died on day 12 at 24°C, but on day 10 at 29°C. The species composition within the culture period was different between the two temperatures. For example, on day 9, *Chlorella salina* contributed 22% to the total population at 24°C, but only 12% at 29°C. This study indicated the potential response in the growth rate, species composition and longevity by phytoplankton to higher temperature. Other factors such as light, current and nutrient availability will also affect the amount and composition of phytoplankton. The availability of phytoplankton influences the food availability up through the various trophic levels. The transport and abundance of zooplankton, the main consumers of phytoplankton, must synchronize with the phytoplankton bloom, or the zooplankton cannot survive, thus depriving food for organisms at higher trophic levels. In nature, the phytoplankton blooms, and the occurrence and abundance of zooplankton are always well timed. For instance, along the southwest coast of India, the herbivorous *Temora* spp. have been recognized as opportunistic species following pulses of diatom blooms. Swarms are observed in recently upwelled waters during southwest monsoon. This is followed by abundance of carnivores mainly *Euchaeta* spp. and *Candacia* spp. In the fading phase, the small carnivores such as *Oithona* and *Oncaea* dominate, supplemented by smaller herbivores of the family such as Paracalanidae, and larger Eucalanidae. Any potential mismatch would offset the food web. Synchrony between timing and abundance of peak zooplankton determines the larval recruitment as well as abundance of some adult fishes like the Indian mackerel.

Zooplankton, especially the copepods, are regarded to act as sentinels to the marine biogeochemical cycles. Interannual changes in species assemblages often reflect an integrated response of the ecosystem to hydrometerological forcing. They are considered suitable to indicate the impact of the climate change because (*i*) they are not commercially exploited; (*ii*) since short lived, they do not contain persistent forms of previous years and exhibit imminent coupling between environmental changes and plankton dynamics; (*iii*) being free drifters, they can expand and contract geographical distribution according to their affinity to the environmental properties. During 1998-2005, a decrease in the abundance of copepods was observed during southwest monsoon in the Arabian Sea. Significant changes in the community structure of copepods in active upwelling waters along the southwest coast were also observed.

Extension of distributional boundary of small pelagic

The oil sardine, *Sardinella longiceps* and the Indian mackerel, *Rastrelliger kanagurta* are tropical coastal and small pelagic fish, forming massive fisheries (20% of marine fish catch; catch during 2008: 0.6 million tonnes valued at about 150 million US$) in India. They are governed by the vagaries of ocean climatic conditions, and have high population doubling time in 15 to 24 months. They are cheap source of protein, and form a staple, sustenance and nutritional food for millions of coastal people. These

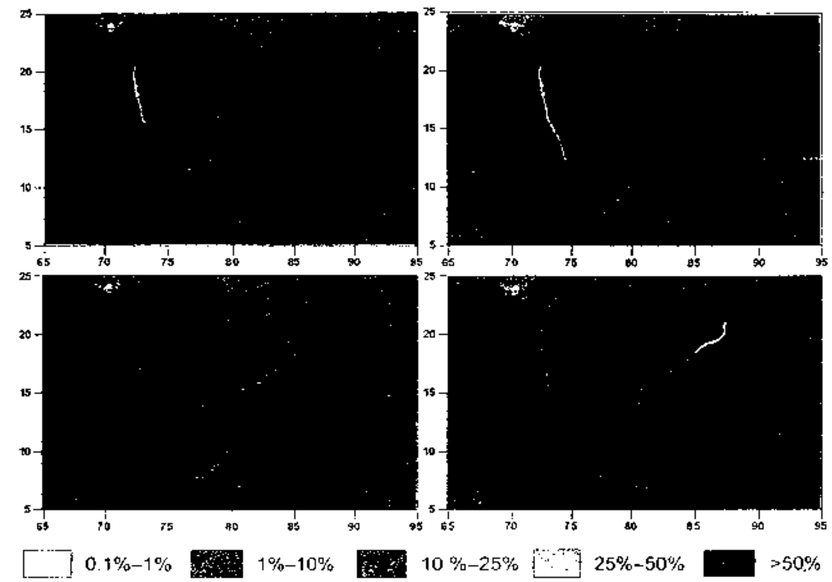


Fig. 33.8. Extension of distribution of oil sardine to the latitudes; the distribution is marked as percentage contribution of the respective coastal area to the all India oil sardine catch. (Satellite image, hence island ecosystems are not clearly visible)

small pelagics, especially the oil sardine, were known for their restricted distribution between latitude 8°N and 14°N and longitude 75°E and 77°E (Malabar upwelling zone along the southwest coast of India) where the annual average sea surface temperature ranges from 27 to 29°C. Until 1985, almost the entire catch of oil sardine was from the Malabar upwelling zone and the catch was either very low or there was no catch from latitudes north of 14°N (Fig. 33.8). The catches from latitude 14°N - 20°N increased, contributing about 15% to the all-India oil sardine catch during 2006-07. The surface waters of the Indian seas are warming by 0.04°C per decade, and the warmer tongue (27-28.5°C) of the surface waters is expanding to latitudes north of 14°N, enabling the oil sardine and Indian mackerel to extend their distributional range to northern latitudes. It is also found that the catches from the Malabar upwelling zone has not decreased indicating the distributional extension and not distributional shift. The Indian mackerel are also found to extend the distribution to the northern latitudes of the Indian seas in a similar way.

Considering the catch as a surrogate of distribution and abundance, it is found that the two most dominant fishes are able to find temperature to their preference especially in the northern latitudes in recent years, thereby establishing fisheries in the extended coastal areas. Assuming further extension of warmer SST tongue in the future, it is expected that the distribution may extend further north of latitude 20°N. However, if the SST in the Malabar upwelling zone increases beyond the physiological optimum of the fish, it is possible that the populations may be driven away from the southern latitudes in the future.

Extension of depth of occurrence of Indian mackerel

The Indian mackerel, *Rastrelliger kanagurta*, in addition to extension of northern boundary, are found to descend to deeper waters in the last two decades. The fish normally occupy surface and subsurface waters. During 1985-89, only 2% of mackerel catch was from bottom trawlers, and the rest of the catch was contributed by pelagic gear such as drift gillnet. During 2003-08, it is estimated that 15% of mackerel catch is contributed by bottom trawlers along the Indian coast. The Indian trawlers operate at a depth ranging from 20 m to 80 m by employing high opening trawlnets. In the last 25 years, the specifications of trawlnet such as mouth opening, headrope length, otter board and mesh size have not been modified, and hence the increase in the contribution of trawlers to the mackerel catch is not gear-related. As the subsurface waters are also warming up, it appears that the mackerel, being a tropical fish, have extended their vertical boundary to the subsurface waters.

Phenological changes in threadfin breams

Fish have strong temperature preferences to spawning. The process of spawning is known to be triggered by pivotal temperatures. The annually recurring life cycle events such as timing of spawning can provide particularly important indicators of climate change. Though sparsely investigated, phenological changes such as seasonal shift in spawning season of fish are now evident in the Indian seas.

The threadfin breams, *Nemipterus japonicus* and *N. mesoprion* are distributed along the entire Indian coast at depths ranging from 10 to 100 m. They are short-lived (longevity: about 3 years), fast growing, highly fecund and medium size fishes (maximum length: 35 cm). Data on the number of female spawners collected every month off Chennai (southeast coast of India) from 1981 to 2004 indicated wide monthly fluctuations. However, a trend in the shifting of spawning season from warmer (April-September; mean SST: 29.0°C-29.5°C) to relatively cooler months (October-March; mean SST: 27.5°C- 28.0°C) was discernible. Whereas 35.3% of the spawners of *N. japonicus* occurred in warm months during 1981-85, the number of spawners gradually reduced and only 5.0% of the spawners occurred in the same season during 2000-04. During 1981-85, it was observed that 64.7% of spawners occurred during October-March, whereas as high as 95.0% of the spawners occurred during the same season in 2000-04. A similar trend was observed in *N. mesoprion* too. The per cent occurrence of spawners of the two species linearly decreased with increasing temperature during April-September, but increased with increasing temperature during October-March over the time scale. It appears that SST between 28° and 29°C may be the optimum condition and when the SST exceeds 29°C, the fish are adapted to shift the spawning activity to seasons when the temperature is around the preferred optima.

These changes in distribution and phenology may have impact on nature and value of fisheries. If small size, low-value fish species with rapid turnover of generations are able to cope up with changing climate, they may replace large size high value species, which are already showing declining trend due to fishing and other non-climatic factors. Such distributional changes would lead to novel mixes of organisms in a region, leaving species to adjust to new prey, predators, parasites, diseases and competitors, and result in considerable changes in ecosystem structure and function.

The effects of changed fish migrations and distribution caused by climate variability and climate change are likely to be most difficult to deal with for highly migratory species, such as tuna. Climate plays a large role in determining short-term, seasonal and multi-year patterns of variability in the location and productivity of these optimal tuna habitat zones. It is not clear whether the spurt in yellowfin tuna fishery in the Bay of Bengal and eastern Arabian Sea since 2004 is due to climate driven changes in the migration route of the fish.

Vulnerability of corals in the Indian seas

Coral reefs are the most diverse marine habitat, which support an estimated one million species globally. They are among the most sensitive of all ecosystems to temperature changes, exhibiting the phenomenon known as coral bleaching when stressed by higher than normal sea temperatures. Reef-building corals are highly dependent on a symbiotic relationship with microscopic algae (type of dinoflagellate known as zooxanthellae), which live within the coral tissues. The corals are dependent on the algae for nutrition and colouration. Bleaching results from the ejection of zooxanthellae by the coral polyps and/or by the loss of chlorophyll by the zooxanthellae themselves. Corals usually recover from bleaching, but die in extreme cases.

In the Indian seas, coral reefs are found in the Gulf of Mannar, Gulf of Kachchh, Palk Bay, Andaman Sea and Lakshadweep Sea. Indian coral reefs have experienced 29 widespread bleaching events since 1989 and intense bleaching occurred in 1998 and 2002 when the SST was higher than the usual summer maxima. By using the relationship between past temperatures and bleaching events, and the predicted SST for another 100 years, it has been predicted that reefs should soon start to decline in terms of coral cover and appearance. The number of decadal low bleaching events was between 0 and 3 during 2000-09, but the number of decadal catastrophic bleaching events will increase from 0 during 2000-09 to 8 during 2080-89.

Given the implication that reefs will not be able to sustain catastrophic events more than three times a decade, reef building corals are likely to disappear as dominant organisms on coral reefs between 2020 and 2040 and the reefs are likely to become remnant between 2030 and 2040 in the Lakshadweep Sea and between 2050 and 2060 in other regions in the Indian seas. These projections on coral reef vulnerability have taken into consideration only the warming of seawater. Other factors such as increasing acidity of seawater would affect formation of exoskeleton of the reefs, and scientists are of the opinion that if the acidification continues as it is now, all the coral reefs would be dead within 50 years. Given their central importance in the marine ecosystem, the loss of coral reefs is likely to have several ramifications. A list of effect

Table 33.3. Climate change and its effect on marine fisheries and aquaculture

Drivers	Effects	Implications
Change in sea surface temperature	Algal blooms increase, less dissolved oxygen, parasites increase, invasion of predators, longer growing seasons, shift in location and size, damage to coral reefs	Infestation of diseases, species composition changes, increased production, migration, loss of species, recruitment decreases
Sea level rise	Loss of land, salt-water infusion, changes to estuary, loss of coastal ecosystem and mangroves	Loss of freshwater species, area reduction for aquaculture, freshwater availability decrease, species shift/composition, distribution changes, reduced recruitment and stock
Increase in frequency of storms	Turbulent water, salinity changes	Loss of stock, catch decreases, risk to fishers, cost of maintenance increase, damages to vessels, nets etc.
El Niño-Southern oscillation	Location and timing of ocean current changes, upwelling alters food supply, coral bleaching	Productivity decrease
Drought	Salinity changes	Loss of stock, fisherfolk migration.

and implications of climate change on marine fisheries and aquaculture is given in Table 33.3.

Options for marine fisheries sector for adaptation

Options for adaptation are limited, but they do exist. The impact of climate change depends on the magnitude of change, and on the sensitivity of particular species or ecosystems.

Develop knowledge base for climate change and marine fisheries: As the ability to sustain fisheries will rest on a mechanistic understanding of the interactions between global change events and localized disturbances, it is important to recognize the regional responses to climate change. Hence, considerable effort should be made for gathering historical climatic and oceanographic data in addition to monitoring these key parameters to suit climate change research. It is also important to recognize the importance of the changes in these parameters as drivers of change in marine communities including fish. Initiating a commitment on long-term environmental and ecological monitoring programmes is important as such data cannot be collected retrospectively. A synergy between the climatic and oceanographic data and fisheries data is required to project the impact of climate change on fish populations. Such projections need to be developed as the first step for future analytical and empirical models, and for planning better management adaptations.

Adopt code of conduct for responsible fisheries: Fish populations are facing the familiar problems of overfishing, pollution and habitat degradation. In India, fisheries still remain, to a large extent, an open access. Seasonal closure of mechanized fishing for 45 to 60 days is perhaps the only regulatory measure that is being followed

effectively at present. Though the fish catch has not reduced conspicuously, it is stagnant for the last one decade and there are indications of decline of several fish stocks. Fishing and climate change are strongly interrelated pressures on fish production and must be addressed jointly. Reducing fishing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal means of reducing the impacts of climate change. Reduction of fishing effort (*i*) maximizes sustainable yields, (*ii*) helps adaptation of fish stocks and marine ecosystems to climate impacts, and (*iii*) reduces greenhouse gas emission by fishing boats. About 1.2% of global oil consumption is used in fisheries, and it is found that fish catching is the main contributor to global warming in the fish production chain. Hence, some of the most effective actions which we can take to tackle climate impacts are to deal with the old familiar problems such as overfishing, and adapt Code of Conduct for Responsible Fisheries and Integrated Ecosystem-based Fisheries Management. In countries like India, the primary mechanisms for managing large-scale commercial fisheries such as total allowable catch (TAC) or total allowable effort (TAE), which are applied through a proportional allocation system, do not exist. Hence, it is relatively difficult for managers to accommodate for changes in stock abundance and it is a challenge to fully comply with the CCRF. The challenge becomes severe considering high level of poverty prevalent in the coastal communities involved in traditional fishing methods, and the lack of suitable alternate income generating options for them. These factors make these communities highly vulnerable to future changes, as their capacity to accommodate changes is very limited. Effort to reduce dependence on fishing by these vulnerable communities is essential.

Increase awareness on the impacts of climate change: Being a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), India has submitted the first National Communication to the UNFCCC in 2004. The second National Communication is under preparation for submission in 2011. National climate change response strategies are under preparation on a sectoral basis. Specific policy document with reference to the implications of climate change for fisheries needs to be developed for India. This document should take into account all relevant social, economic and environmental policies and actions including education, training and public awareness related to climate change. Effort is also required in respect of raising awareness of the impact, vulnerability, adaptation and mitigation related to climate change among the decision makers, managers, fishermen and other stakeholders in the fishing sector.

Strategies for evolving adaptive mechanisms

In the context of climate change, the primary challenge to fisheries and aquaculture sector will be to ensure food supply, enhance nutritional security, improve livelihood and economic output, and ensure ecosystem safety. These objectives call for identifying and addressing the concerns arising out of climate change; evolve adaptive mechanisms and implement action across all stakeholders at national, regional and international levels. In response to shifting fish population and species, the industry may have to respond with the right types of craft and gear combinations, on-board processing equipments etc. Governments should consider establishing Weather Watch Groups (WWG) and decision support systems on a regional basis. Allocating research funds to analyze the impacts and establishing institutional mechanisms to enable the sector are also important. The relevance of active regional and international participation and collaboration to exchange information and ideas is being felt now as never before. For this, action plans at regional level need to be taken by (*a*) strengthening regional organizations and place climate change agenda as a priority; (*b*) addressing transboundary resource use; and (*c*) evolving common platforms and sharing the best practices. Action plan at international level also need to be taken by (*a*) linking with mitigation activities; (*b*) enhancing co-operation and partnerships; and (*c*) applying international fishery agreements.

In addition to the above, the following theme plan to adapt to and mitigate climate change is suggested:

- Impact assessment of climate change on distribution and species diversity of fisheries resources;
- Assessment on production and economic value of commercially important fish in the changed scenario;
- Identify adaptive fishing and post-harvest practices to sustain production and quality;
- Evaluate sensitive biological processes such as growth, maturity and spawning and the adaptive capacity of important fish groups with reference to climate change;
- Identify genes for thermal tolerance for aquaculture purpose;
- Identify new land use system for aquaculture;
- Identify new candidate species and develop breeding and grow-out techniques;
- Assess the changes in seed availability and feed requirements for changed aquaculture practices;
- Investigations on potential fish diseases in the natural and farming systems;
- Investigations on diversity and dynamics of microbes in the water-bodies;
- Assess demand-supply scenario for fisheries in the changing scenario;
- Develop regional contingency plans for weather-related risks to the fishing communities;
- Reduce GHG emissions by fisheries sector;
- Quantify the carbon sequestration potential of freshwater, brackishwater and marine ecosystems;
- Identify cost-effective opportunities for reducing GHG emission from fisheries sector;
- Establish Weather Watch Groups for fisheries sector;
- Evolve decision support systems;
- Develop a compendium on indigenous traditional knowledge in the fisheries sector and explore opportunities for its utilization;

- Intensify efforts to increase climate literacy among the stakeholders in fisheries sector.

For the fisheries and aquaculture sector, climate change notwithstanding, there are several issues to be addressed. Strategies to promote sustainability and improve the supplies should be in place before the threat of climate change assumes greater proportion. While the fisheries sector mav strive to mitigate climate change by reducing CO_2 emission especially by fishing boats, it could contribute to reduce the impact by following effective adaptation measures by providing fiscal incentives for reducing the sector's carbon footprint, and for following other mitigation and adaptation options.

34. Aquatic Pollution

There is no life without water and water makes the Earth different from all other planets. Without water, human beings, animals and plants will perish. Aquatic environments are known as the homes for a diverse assemblage of organisms. Only about 3% of the water available on the Earth is fresh and most of it is stored as ice and snow at the poles or is located deep under the surface. However, there is about 4,300,000 km^3 of freshwater to be shared among the different inhabitants of the planet Earth. Whether water is clean enough for use or too polluted to harm the users depends on how we deal with it, as every habitat has limits on its ability to absorb negative impacts like pollution.

The term pollution is derived from a Latin word (*pollu'ere*) that means to soil or to fertile. The terms pollution, contamination and degradation (of water) have been used synonymously to describe the faulty conditions of water. Pollution is the addition of something to water which changes its natural qualities so that the riparian owner does not get the natural water of the stream transmitted to him. The most accepted definition in the 1970s was unreasonable interference of water quality with the beneficial uses of the resources. Generally, it is the presence of a substance in the environment that because of its chemical composition or quantity prevents the functioning of natural processes, and produces undesirable environmental and health effects. Under the Clean Water Act of the United States of America (USA), the term has been defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water and other media.

All waters in the world are affected in one way or the other by pollution. Acid rain could affect the highest mountains; pollutants are added from the starting points in the mountains and spread throughout the watershed to areas where the rivers flow into the sea. Lakes, groundwater and wetlands are all affected by either point or non-point source pollution. Litter left behind or carelessly tossed away chemicals such as pesticides and fertilizers, and oil-based products seeping into the watersheds from industry and pleasure vehicles all affect marine and aquatic environments. Run-off from highways, parking lots, city streets, bridges and heavily populated coastal areas enters nearby watersheds and adds its detrimental effects to the ecosystem.

Till about half a century ago, pollution was not seen in our oceans. However, oceans at present have become the world's largest and most efficient septic tank. The intensity of pollution has been largely increasing as many of the manufacturing objects used today, are made of plastics, which are non-biodegradable. The time required for biodegradation of different litters varied greatly, i.e. indefinite for polystyrene foam, 600 years for monofilament line, 450 years for disposable diapers and plastic bottles, 400+ years for plastic rings, 200 years for aluminium cans, 50 years for tin cans, 13 years for painted wood, 1 year for wool, 1 to 5 months for cotton, 2 months for

cardboard, 6 weeks for newspaper, 2 to 4 weeks for paper towel. Pollution does not occur only when a body of water is adversely affected due to the addition of large amounts of materials but, the acts such as cutting-down trees along rivers, straightening of channels and channel linings, hydraulic modifications and reducing low flows below tolerable levels by excessive withdrawals also leads to pollution as per the Clean Water Act of USA.

The effects of water pollution are not only devastating to people but also to animals, fishes and birds. Polluted water is unfit for drinking, recreation, agriculture and industry. It diminishes the aesthetic quality of lakes and rivers. More seriously, contaminated water destroys aquatic life and reduces its reproductive ability. Ultimately, it becomes a hazard to human health. Waste disposal has an environmental cost and a financial cost. The financial costs involved cannot be ignored, though the interest would be in reducing the environmental costs as the financial costs can easily double for a trivial improvement in environmental quality. Though the individual and the community can help minimize water pollution, nobody can escape from its effects. So, quite often, we talk of pollution management than prevention of pollution.

Causes of pollution

Degradable wastes are organic material that can undergo decomposition through bacterial attack. The inputs that can be included under this category are urban sewage, agricultural waste, food-processing waste, distillery waste, paper-pulp mill waste, organic discharges from the chemical industry and oil spillages. In addition, inputs like leaves and grass clippings, run-off from livestock feedlots and pastures also contribute to this. When natural bacteria and other microorganisms in the water breakdown organic material, they use up the oxygen dissolved in the water. Most of the fishes and bottom-dwelling animals cannot survive when levels of dissolved oxygen drop too low. When this occurs, it kills aquatic organisms in large numbers, which leads to disruptions in the foodchain.

Fertilizers containing nutrients such as nitrates and phosphates could have effects similar to those of organic wastes. In excess levels, nutrients over-stimulate the growth of aquatic plants and algae. Excessive growth of these types of organisms consequently clogs waterways, uses up dissolved oxygen as the organisms decompose and block light to deeper waters. The depletion of oxygen, in turn, proves very harmful to aquatic organisms, as it affects the respiration of fish and other organisms that derive oxygen from water.

Heat, acids and alkalis, and some chemicals such as cyanides can be considered as dissipating wastes as they lose the damaging effects soon after they enter the water-body. Particulates like dredging spoil, fly ash, China clay waste, colliery waste and a variety of man-made material like plastics are inert, but they may clog the feeding and respiratory structures of animals, may reduce photosynthesis by reducing light penetration or may smother the benthos. Conservative wastes like heavy metals, halogenated hydrocarbons and radioactive material are not subject to microbial attack and therefore exist over a long duration, and cause harmful effects in plants and animals.

Pathogens are another type of pollution that proves very harmful. They can cause many illnesses that range from typhoid and dysentery to minor respiratory and skin diseases. Pathogens include such organisms as bacteria, viruses and protozoans. These pollutants enter waterways through untreated sewage, storm drains, septic tanks, run-off from farms, etc. There is also threat from carcasses and other animal material infecting water supplies following inadequate disposal. Though microscopic, these pollutants have a tremendous effect evidenced by their ability to cause diseases.

Pollution source

The sources of water pollution are categorized as point and non-point. Point sources of pollution occur when the polluting substance is emitted directly into the waterway. A pipe spewing toxic chemicals directly into a river is an example. A non-point source occurs when there is run-off of pollutants into a waterway, for instance when fertilizer from agricultural field is carried into a stream by surface run-off.

The common point sources of pollution are municipal and industrial wastewater effluents; run-off and leachate from solid waste disposal sites; run-off from industrial sites; storm sewer outfalls from urban centres; run-off and drainage from industrial sites, mines and oil fields; discharge from vessels, storage tanks and piles of chemicals; run-off from construction sites; bypasses from sewers and sanitary pipes. The non-point source includes flow from agricultural fields and orchards, run-off from logging operations, urban run-off from unsewered areas and septic tank leachates, atmospheric deposition, run-off from roads, etc.

When toxic substances enter lakes, streams, rivers, oceans and other water-bodies, these get dissolved, lie suspended in water or get deposited on the bed. This results in the pollution of water whereby the quality of the water deteriorates, affecting aquatic ecosystems. Pollutants can also seep down and affect the groundwater deposits. The most important sources of pollution are the city sewage and industrial waste discharged into the rivers by virtue of the quantities in which these are discharged. The facilities to treat wastewater are inadequate in Indian cities. Presently, only about 10% of the wastewater generated is treated allowing about 90% of it to directly enter the receiving waters. Due to this, pollutants enter groundwater, rivers and other water- bodies, and may even harbour pathogens. Agricultural run-off or the water from the fields that drains into rivers is another major source of water pollution, as it could be rich in the major nutrients–nitrogen and phosphorus–as also in pesticides.

Domestic sewage: Domestic sewage refers to the wastewater that is discarded from households. It is large by volume and contains dissolved and suspended impurities such as organic materials and plant nutrients that tend to rot. The main organic materials are food and vegetable waste, plant nutrients from chemical soaps and washing powders and detergents. Most detergents and washing powders contain phosphates and the addition of this nutrient leads to eutrophication, especially in freshwater ecosystems where phosphorus is often a limiting nutrient.

Domestic sewage is also very likely to contain disease-causing microbes (Table 34.1). Huge quantities of sewage are generated in the urban areas in India.

Mumbai city alone with a population density of 25,000 people per km^3 generates 2.2 $\times 10^6$ m^3 of domestic wastewater in a day, out of which about 2×10^6 m^3, at the most is partially treated. This sewage treated water enters marine areas (largely creeks and bays), transferring 5.6×10^5, 7×10^4, 1.2×10^4, 160, 200, 4,600 and 100 kg/day of biochemical oxygen demand, nitrogen, phosphorus, nickel, copper, zinc and lead apart from pathogens and viruses to the receiving water.

Table 34.1. Diseases associated with pathogenic microorganisms found in domestic sewage

Type	Disease or syndrome caused
Bacteria	
Aeromonas hydrophila	Enteritis
Campylobacter enteritis	Enteritis, diarrhoea
Clostridium perfringens	Enteritis
Escherichia coli	Enteritis, diarrhoea
Francisella tularensis	Tularemia
Leptospira interrogans	Jaundice, meningitis
Listeria monocytogenes	Listeriosis
Mycobacterium tuberculosis	Tuberculosis
Pseudomonas aeruginosa	Skin, ear infections
Salmonella (1,700 types)	Enteritis, typhoid
Shigella (4 species)	Enteritis, diarrhoea
Staphylococcus aureus	Skin infections
Vibrio cholerae and *V. parahemolyticus*	Cholera, skin infections
Yersinia enterocolitica and *Y. pseudotuberculosis*	Enteritis
Helminths	
Ascaris lumbricoides	Ascariasis
Ancylostoma duodenale	Hookworm infections
Trichuris trichiura	Trichiuriasis
Taenia spp.	Taeniasis
Toxocara canis	Abdominal pains
Strongyloides stercoralis	Abdominal pains
Protozoans	
Entamoeba histolytica and *Escherichia coli*	Enteritis, chronic diarrhoea, dysentery, liver abscess
Giardia lamblia	Giardiasis, enteritis
Cryptosporidium parvium	Enteritis, diarrhoea
Balantidium coli	Enteritis, diarrhoea
Naegleria fowleri	Meningoencephalitis
Acanthamoeba spp.	Meningoencephalitis
Viruses	
Polioviruses (3 types)	Paralysis, meningitis
Echoviruses (34 types)	Meningitis, diarrhoea
Coxsackieviruses A and B (30 types)	Meningitis, conjunctivitis, chronic fatigue syndrome, myocardia, diabetes
Hepatitis A and E viruses	Epidemic hepatitis
Enteroviruses 68-71	Meningitis, conjunctivitis
Rotaviruses (4 types)	Enteritis
Reoviruses (3 types)	Enteritis, respiratory infections
Adenoviruses (40 types)	Enteritis, eye and respiratory infections
Norwalk and like viruses	Gastroenteritis
Caliciviruses and Astroviruses	Enteritis
Coronaviruses	Enteritis
Parvoviruses (2 types)	Enteritis, respiratory infections in children

Farming: Agriculture, including commercial livestock and poultry farming, leads to the addition of many organic and inorganic pollutants to water. Fertilizers used in the farms can increase the amounts of nitrates and phosphates in water leading to eutrophication. Animal wastes are high in oxygen-demanding substances and nutrients, and may often harbour pathogens. Wastes contained and disposed of on land could also reach a water-body through run-off and leaching.

Farms often use large quantities of herbicides and pesticides, which are toxic pollutants. These substances are particularly dangerous to life in rivers, streams and lakes, where toxic substances can build up over a period of time through the processes known as bioaccumulation and biomagnifications. Intensive cultivation of crops causes chemicals and pesticides to leach into groundwater. Indiscriminate usage of fertilizers and pesticides for agriculture is undoubtedly one of the significant sources of water pollution.

Industrial effluents: Industrial wastewater usually contains both biodegradable and persistent pollutants depending upon the source of the discharge and the material manufactured. A large portion of the industrial effluents comes from the processing industry and the food products industry. Most of the major industries in India have treatment facilities for their effluents. However, there are many, which do not have. Most of these defaulting industries are sugar mills, distilleries, leather-processing industries and thermal power stations.

Acid rain: Rainwater is slightly acidic to neutral liquid. During precipitation, it dissolves gases such as carbon dioxide and oxygen in the atmosphere. The acidifying gases such as oxides of sulphur and carbon monoxide, released into the atmosphere mostly by industries, also dissolve in rainwater. This results in lowering the *p*H of precipitation. It may fall to a value below 4.

Pollution types

Nutrient pollution: A type of organic pollution can occur when inorganic pollutants such as nitrogenous compounds and phosphates accumulate in aquatic ecosystems. The major sources of nutrients to streams and groundwater are precipitation, dissolution of natural minerals from soil or geologic formations, fertilizer application and effluent from sewage-treatment plants. The first three of these are non-point sources, and treatment-plant effluent is a point source. The cooling water used in electricity-generating plants may reduce levels of ammonia and organic nitrogen and increase levels of nitrate.

The atmosphere of Earth consists of 78% nitrogen and it is about three-fourths of the nitrogen available in the environment. Most of this nitrogen is in the form of elemental nitrogen, though some compounds of nitrogen and oxygen produced by chemical reactions also exist. Nitrogenous compounds in the atmosphere undergo transformations that eventually convert nitrogen into nitrate. Nitrate can dissolve in rainwater or snow and can reach streams or groundwater in run-off or seepage. This process also contributes to the formation of 'acid rain'.

The case of phosphorus is different. The largest reservoir of phosphorus in the

environment is the minerals in rocks, sediment and soil as phosphorus has an imperfect cycle, wherein a sedimentation process exists. Where natural deposits of phosphatic minerals are mined, the run-off and seepage may be a source of phosphorus to streams. In general, phosphatic compounds are much less soluble than nitrogenous compounds and do not readily move in run-off or seepage.

A major human influence on nitrogen and phosphorus in the environment is the use of fertilizers in agriculture. High levels of these nutrients cause an overgrowth of plants and algae. As the plants and algae die, they become organic materials in the water and release nutrients on decomposition. The enormous decay of this plant matter, in turn, lowers the oxygen level. The process of rapid plant growth followed by increased activity by decomposers and a depletion of the oxygen level is called eutrophication.

Organic pollution: It is the most common form of pollution and occurs when an excess of organic matter such as manure or sewage enters the water. When organic matter increases in an ecosystem, the number of decomposers will increase. These decomposers grow rapidly and use the dissolved oxygen at a greater rate than it can be replenished causing oxygen depletion. Lack of oxygen can kill aquatic organisms. As these die, decomposers break them down leading to further depletion of oxygen. Organic effluents also frequently contain large quantities of suspended solids, which reduce the light available for photosynthesis. Toxic ammonia may also be present.

Organic pollutants originate from domestic sewage, urban run-off, industrial effluents and farm wastes. These consist of proteins, carbohydrates, fats and nucleic acids in a variety of combinations. Raw sewage is 99.9% water and 0.1% solids. Sewage effluents are the greatest source of organic material discharged into water-bodies. The BOD gives a simple measure of the biologically oxidizable matter, which is the quantity of oxygen required to oxidize the organic matter by microorganisms.

Industrial effluents also contribute to organic pollution. Some of the sources of pollution contributing substantially are food-processing and brewing industries, dairies, abattoirs and tanneries, textile and paper-making industries. Fish farms may also result in the deterioration of water quality. It has been suggested that the effluent from a trout farm producing 200-250 tonnes of fish per year is equivalent to the untreated sewage from 1,400-5,000 persons.

Oil pollution: Oil pollution is a growing problem, particularly devastating to coastal wildlife. As oil is lighter than water, it spreads rapidly to form deadly oil slicks. Tanker spills are an increasing environmental problem as it is virtually impossible to completely remove or contain the oil once it is spilled. This is mainly due to the reason that a significant proportion of the world's oil production is transported by sea. About an 80% of the oil transported by tankers is crude and the remainder refined products. It is estimated that about 0.0001% of all the oil transported through waterways end up in polluting the water as spillage. Oil spill in the sea may finally reach the shore and contaminate broad expanses of shoreline. Attempts to chemically treat or sink the oil may further disrupt marine and beach ecosystems. Birds are the worst affected in the case of an oil slick as oil sticks to the feathers of birds, reducing the capacities of insulation and flight, which ultimately may lead to the sinking of birds due to the loss of water-repellant property. The gills of fish become clogged with oil leading to suffocation. Bodies of mammals become coated with oil adversely affecting the maintenance of body temperature. Oil-coated marine plants cannot obtain energy from the Sun for photosynthesis, though it may result in luxuriant growth later due to the added nutrients. Oil may also get trapped in the soft substrata for many years, as the low oxygen concentration reduces the decomposition rate rendering the possibility of its getting re-suspended in storms or on dredging.

Besides the oil tankers, offshore-drilling operations also contribute immensely to oil pollution. Large quantities of production wastes of low toxicity are produced during exploration and production. These can broadly be grouped into two classes, wastes related to drilling and well completion and wastes related to oil production. The first class includes drilling mud, drill cuttings and chemical additives, whereas the second class consists primarily of produced water. The volume of produced water far exceeds the volume of drilling wastes. The waste from refineries is smaller but considerably more toxic.

There are natural oil inputs into the aquatic medium as well. It is presently known that there are almost 200 significant marine oil seeps, most of its near continental coastlines. Given the probable range of seepage loss between 0.02 and 2.0 mt/year, the present underground deposits are only a small fraction of the quantity of oil that was formed underground over geologic time. Most of it has evidently seeped to the surface and been broken down by chemical and biological processes. Erosion of continental rocks is another process that inputs petroleum into the marine environment. Accidents at offshore production facilities are another source of inputs. The blowout of Ixtoc 1 oil well in 1979 for 290 days is estimated to have released about 0.48 mt crude oil into the Gulf of Mexico, almost 10 times the estimated annual average for the entire world.

Crude oil consists of thousands of different organic molecules, the majority of them hydrocarbons between 4 and 26 atoms per molecule. There are also some sulphur and nitrogen compounds, and metals such as vanadium. There are three different types of hydrocarbons, namely alkanes, cyclohexanes and aromatics. Oils from different sources may have different compositions. Though organic in nature, the heavier fractions of oil are resistant to degradation and end up as water-in-oil emulsions (chocolate mousse) and tar balls. The process is further restricted as oil does not contain oxygen, making it resistant to decomposition under anaerobic conditions.

Toxic pollution: With increasing industrialization chemical wastes have increased to dangerously high levels in some areas around the globe. The oceans can neutralize some chemical wastes because of their vastness. As the quantity of chemicals ending up in the oceans increases, toxic materials begin to accumulate. Chemical pollution originates mostly in factories, farms and almost all the activities of human beings. Chemical pollutants, especially nutrients, can cause an increase in productivity through algal photosynthesis, which in turn, may reduce the availability of oxygen resulting in death of organisms that need oxygen to breathe. Many of the bloom-forming algae

produce toxins and the organisms with poor detoxifying mechanisms accumulate and concentrate them. These toxins are further concentrated in the organisms at higher trophic levels resulting in adverse effects and a possible decline in populations. This is true with almost all non-degradable wastes including metals. There appear to be no consistent correlations between environmental levels of metals other than mercury, and the concentrations in invertebrates and fish. As the bivalve mollusks feed by filtering water, they can accumulate naturally occurring toxins from the surrounding waters, as is the case with the microscopic organisms responsible for red tides. Bivalves can also store chemical contaminants such as metals and organochloride chloride compounds, and bacteriological pollutants such as sewage-related bacteria and viruses. Some of the toxins may kill the organisms that come in contact with them.

A toxic substance is a chemical pollutant that is not a natural substance in aquatic ecosystems. The greatest contributors to toxic pollution are organic compounds like herbicides, organochlorine pesticides, polychlorinated biphenyls, chlorinated aliphatic hydrocarbons, solvents, straight-chain surfactants, petroleum hydrocarbons, polynuclear aromatics, chlorinated dibenzodioxins, organometallic compounds, phenols and formaldehyde; metals such as lead, nickel, cadmium, zinc, copper and mercury; gases such as chlorine, ammonia and methane; anions such as cyanides, fluorides, sulphides and sulphites; and acids and alkalies.

Among these, heavy metals cause severe damage to the living systems at various levels. The prominent sources of heavy metal contamination are urban industrial aerosols created by combustion of fuels, metal ore refining and other industrial processes, liquid and solid wastes generated from animals and humans, mining activities, and industrial and agricultural chemicals. Heavy metals also enter the water-body by industrial and consumer waste or even from acid rain breaking down soils and rocks, and releasing heavy metals into streams, lakes and groundwater. These are also released into the aquatic environment through natural processes like volcanic activity and weathering of rocks. Human-induced releases of tin, lead and mercury are 110.0, 13.0 and 2.3 times greater than geological mineralization. The most important feature that distinguishes heavy metals from other toxic pollutants is their non-biodegradability. The toxicity due to metal ions is due to their ability to bind with protein molecules, which prevents the replication of DNA and subsequent cell division.

The two general categories of toxic effects distinguished are acute (a large dose of short duration) and chronic (a low dose over a long time) toxicities. Lethal toxicity refers to that causes death by direct action, whereas sublethal refers to the level that is below the one that directly causes death. Lethal concentration is the quantity of the toxicant required to cause the death of a certain percentage of organisms (LC_{50}, LC_{75}, etc.) killed on exposure over a period of time (48 hr, 96 hr, etc.) and expressed as 48h LC_{50}, 96h LC_{50}, etc. The term effective concentration is used when an effect other than death is being studied. Incipient lethal level is the concentration at which acute toxicity ceases, usually the concentration at which 50% of the test population can live for an indefinite period. Safe concentration is the maximum concentration of a toxic substance that has got no observable effect on a species after long-term exposure over one or more generations. Maximum acceptable concentration is the concentration of a toxic material that may be present in a receiving water without having any adverse effect.

Thermal pollution: Heat is a pollutant as increased temperatures result in the death of many aquatic organisms. There are four major causes of thermal pollution of water, namely use of water as a cooling agent, soil erosion, deforestation of shorelines and run-off from hot-paved surfaces. However, the foremost cause is the use of water as a cooling agent in power plants, factories and industrial facilities where freshwater is used as a coolant and then is returned to the aquatic environment at a higher temperature than the original. An increase in temperature alters the physical environment by a reduction in the density of water and its oxygen content. Nevertheless, the oxygen concentration below a cooling water discharge could be substantially higher than that at the intake because of the turbulence and agitation within the cooling tower. Thermal pollution can lead to a decrease in the dissolved oxygen level in water while increasing the biological demand of aquatic organisms for oxygen.

Soil erosion makes the water muddy increasing the absorption of light, thus increasing the water temperature. Deforestation of shorelines contributes to the problem in two ways–firstly, plant roots hold soils together so deforestation enhances soil erosion; secondly, with the vegetation gone, the quantity of light at the water surface is increased, thereby raising the water temperature. Run-off from paved surfaces is also hotter and raises the temperature of the water into which it flows.

The water used as a coolant is released from industrial plants and heated water spreads over the cool water systems, as a result, the temperature of the streams increases. This may disrupt the ecological relationship between the water system and aquatic life. Even a rise in temperature of only a few degrees may be lethal to a variety of aquatic life. The death of certain species can remove the food supply of the species that prey on them forcing them to move downstream or face extinction. As most of the aquatic animals have a limited threshold on temperature changes, the abrupt temperature change may cause thermal shock to the species. Since the organisms cannot adapt to the sudden temperature change, this may force them to either go into extinction or migrate to a more suitable environment. In addition, the water at a higher temperature causes a decrease in the dissolved oxygen level. Warmer temperature also increases the metabolism of fish, thereby increasing their need for oxygen. Increase in the metabolic rate in fish will increase the consumption of aquatic insects by them, resulting in an increase in fish population and depletion of aquatic insects. This results in an imbalance in the food web of the ecosystem. Mosquito fish (*Gambusia holbrooki*) from a population exposed over many years to heated discharge bred throughout the year, whereas those from natural populations bred only for six months in a year. Moreover, the exposed population had larger clutch sizes, but produced smaller offspring. Changes in temperature may also cause fish to migrate to regions where the water is at the optimum temperature and can kill any species, which cannot move away.

With the increase in temperature and decrease in oxygen, all chemical and biological activities increase. This may result in the destruction of the ecosystem, as the capacity for self-purification will be substantially reduced. An increase in temperature increases

photosynthesis and aquatic plant growth, which may crowd out zooplankton. Excess plant growth and eutrophication lead to an increase in dead plants and organic matter. Dead organic matter is decomposed by bacteria using up the oxygen in water and is influenced to a high degree by the oxygen content. Higher temperatures can cause enzymes to speed up metabolism.

There is also an argument that heated water may be used for beneficial purposes, calling it thermal enrichment. Warm water from power plants may be used for irrigation to extend plant growing season in frost-prone areas, speed the growth of fish and shellfish for commercial production, melt snow on sidewalks, desalinate ocean water, etc. It may also be used to hasten the conversion of organic nitrogenous compounds to ammonia and nitrites to nitrates. However, the harmful effects of thermal pollution seem to outweigh the beneficial effects.

Radioactive pollution: Atoms of the same chemical element may vary in the number of neutrons they have and are known as isotopes. Some isotopes are unstable and seek stability by giving off particles or electromagnetic rays. These isotopes are known as radioisotopes or radionuclides. There are four major types of radiation, namely Alpha particles – consisting of two protons and two neutrons; Beta particles – negatively charged electrons or positively charged positrons; Gamma rays – short-wave electromagnetic radiation having neither mass nor charge; and Neutron radiation – free neutrons as a result of spontaneous fission of heavy, unstable elements with large excess of neutrons.

Radioactive substances are produced in the form of waste from nuclear power plants, and from the industrial, medical and scientific use of radioactive materials. These are also produced through uranium and thorium mining and refining. The environment is also naturally radioactive. Radiation comes from outer space, from the Earth, from the atoms within the body and from the activities such as burning fuel and cultivating soil. The best-known examples of natural radioactivity are at Chavara in Kollam district of Kerala, and the provinces of Espirito Santo and Rio de Janiero in Brazil. Each radionuclide has its characteristic half-life, which may be a fraction of a second, hours, days, months or millions of years. The half-life of ^{226}Ra is 1,602 years. Radioactivity is inversely related to the half-life and therefore, a substance with a long half-life has low radioactivity. Some of the radionuclides of special biological concern are given in Table 34.2.

Table 34.2. Radionuclides of biological concern

Radionuclide	Half-life	Impact
^{3}H	12.4 years	Assimilated by body in water
^{14}C	5,730 years	Passed up food chain
^{32}P	14.3 days	Concentrated in bones
^{40}K	1.3×10^9 years	Found throughout body
^{90}Sr	28.9 years	Concentrated in bones
^{131}I	8.1 days	Concentrated in thyroid
^{137}Cs	30.2 years	Found throughout body
^{226}Ra	1,622 years	Concentrated in bones
^{238}U	4.5×10^9 years	Concentrated in lungs and kidneys

Ecological pollution: Ecological pollution takes place when chemical, organic, thermal or any other type of pollution is caused by a natural event rather than by human activity. An example of ecological pollution would be an increased rate of siltation of a waterway resulting from a landslide. Another example would be a large animal drowning in a flood resulting in the addition of a large amount of organic material. Major geological events such as a volcano eruption, seismic activities like tsunami in India (2006) and more recently in Japan (2011) might also be sources of ecological pollution.

Environmental effects

Biological oxygen demand: BOD is the quantity of oxygen required by microorganisms to decompose the organic substances in a water-body. BOD levels of industrial effluents may be much more than that of domestic sewage. Animal slurries have been estimated to have BOD values of about 20,000 mg/litre compared with an average of 350 mg/litre for untreated human sewage. When organic matter enters a lake or stream, microorganisms begin to decompose the material. Oxygen is consumed as microorganisms use it in their metabolism. This can quickly deplete the available oxygen in water. When the dissolved oxygen levels drop too low, many aquatic species die. When the oxygen level drops to zero, the water becomes septic. When organic compounds decompose without oxygen, it gives rise to the undesirable odours usually associated with putrid conditions.

Prolonged exposure to low-dissolved oxygen levels may not directly kill an organism, but will increase its susceptibility to other environmental stresses. Exposure to < 30% saturation (< 2 mg/litre oxygen) for one to four days may kill most of the biota in a system. If oxygen-requiring organisms perish, the remaining organisms will be air-breathing insects and anaerobic bacteria.

Eutrophication: Eutrophication of surface and coastal waters is one of the prime examples of global diffuse pollution problems strongly affecting the developed as well as developing nations. The increase in the use of fertilizers and intensive animal husbandry has resulted in increase in nutrient inputs. The discharge of waste from industries, agriculture and urban communities into water-bodies generally stretches the biological capacities of aquatic systems. Chemical run-off from fields also adds nutrients to water. Excess nutrients cause the water-body to become choked with organic substances and organisms. An area is considered to be 'hypernutrified' if the winter nutrient concentrations exceed 12 mmol DAIN (dissolved available inorganic nitrogen) per m^3 in at least 0.2 mmol DAIP (dissolved available inorganic phosphorus) per m^3. Over time, water-bodies become eutrophic and the main causative factors for this are nitrate and phosphate. Due to the enrichment the algal growth increases, preventing light penetration and the aerobic bacteria decomposing the organic matter become more active. These bacteria deplete oxygen levels, so that only anaerobic bacteria can be active. Anaerobic organisms then attack the organic wastes, releasing gases such as methane and hydrogen sulphide, which are harmful to the aerobic forms of life. Eutrophication can cause problems such as bad tastes and odours as well as green scum algae. Also, the growth of rooted plants increases, which decreases the amount of oxygen in the deepest waters of the lake. Sometimes, it leads to the death of all forms of life in the water-bodies. It is also reported that eutrophication increases the growth and age structure of fish populations.

Chemical pollutants: Chemical pollutants which are discharged into the water systems by the industrial plants may adversely affect the organisms that inhabit the ecosystem. Most of the chemical pollutants that industrial plants discharge are heavy metals, particularly cadmium, zinc and some organic metal-containing compounds that cause serious threats to public health and environment. The effluents may contain chlorinated hydrocarbons and other toxic organic compounds, and can cause chronic environmental health hazards. Most of the effluents are directly discharged into the water systems such as rivers, lakes and oceans as point-source pollution. The death of organisms occurs due to the chemical pollutants containing a high concentration of phosphates, nitrates and potassium. Other chemical pollutants such as metals may disrupt the stabilization process by killing the necessary microflora for a healthy water system.

Ammonia: The maximum ammonia concentrations in surface water based on danger to aquatic organisms such as fish may vary with acidity and water temperature, which affect, both, the toxicity of ammonia and the form in which it occurs. In most natural surface waters, total ammonia concentrations greater than about 2 mg per litre exceed chronic exposure for fish. In alkaline water at high temperature the criteria can be exceeded by total ammonia concentrations less than 0.1 mg/litre. The natural conversion of ammonia to nitrate in streams removes oxygen from water and therefore, can also adversely affect fish. Temperature plays a major role in this process as nitrification essentially ceases below 10°C and above 45°C. Ammonia loads systematically decrease downstream from the non-tidal to tidal reaches, indicating the uptake by adsorption to sediments, nitrification or biological uptake.

Nitrate: Nitrogen is lost from the soil primarily by erosion, crop harvesting and nitrate leaching and may finally reach the water-bodies. Rainfall is also recognized as a significant source of nitrogen though farming is the main source of nitrate in river and groundwater. There is a considerable variation in nitrogen flux, depending on input distribution, hydrological flushing and seasonal patterns of temperature. It also depends on the type of fertilizer applied. High nitrate content caused by fertilizer applications and or septic tank effluents may not be remediated because of the diffused nature.

Phosphorus: Phosphorus is an essential element for all life forms. It is a mineral nutrient and orthophosphate is the only form of phosphorus that autotrophs can assimilate. Extracellular enzymes hydrolyze organic forms of phosphorus to phosphate. This release of phosphates reinforces eutrophication. Excessive concentration of phosphates is the most common cause of eutrophication in freshwater lakes, reservoirs, streams and in the headwaters of estuarine systems. Phosphorus is often the nutrient responsible for accelerated eutrophication as it is normally the limiting nutrient.

Acidification: The decline of salmonid and other fish stocks in Norwegian acid-sensitive rivers were linked to the acidification of freshwaters about 60 years ago. Subsequently, it has been shown that many aquatic plants and animals are affected by acidification. This has led to major changes in the nature of the flora and fauna of many streams and lakes. The decline in recruitment has also been demonstrated in the case of percids.

It was assumed that these changes were a response to the direct effects of acidity. Later on, it was shown to be an indirect effect due to an increase in aluminium concentration of this element, one of the commonest in the Earth's crust is normally not soluble and is bound to silica at *p*H 7.0. As the acidity of the water increases, aluminium becomes more soluble and is released from the soil. The main toxic effect of aluminium is due to the soluble form, which predominates in the *p*H range of 5.0-5.5. However, this toxicity is lessened in the presence of organic compounds such as humic acids and when the calcium levels exceed 1.0 mg/litre. Dissolved aluminium concentrations as low as 0.05 mg/litre can kill fish and macro invertebrates, while its lower levels may have non-lethal effects such as respiratory difficulty, impaired growth and reduced reproductive ability.

Acidification of surface waters by air pollution is a recent phenomenon and has been found threatening aquatic life in many areas of the world.

Effects on wetlands: Wetlands are nurseries for many terrestrial animals and fish species. Destruction of ecosystem due to heavy pollution has been posing threat for several endangered species. In a healthy wetland or estuary, there are algae that are an essential part of the food chain. When nutrients, particularly phosphorus, are added to the system, more algae grow. When the algae die and decompose, the oxygen level in the water gets reduced, resulting in the death of fish and other aquatic organisms. The algae also reduce the amount of light that is able to penetrate the water, which can affect the growth of other aquatic plants. It has been observed that some of the opportunistic algal species like *Ulva lactuca* and *Enteromorpha linza* become luxuriant in the untreated sewage discharge areas.

Impacts of sewage on fish

Sewage pollution adversely affects fish and other aquatic life by degrading and destroying the aquatic habitat. The accumulation of excessive organic matter contributes to a reduction of plant growth and productivity leading to shortage of food material. Excess organic matter can also reduce the dissolved oxygen content, adding stress to the system resulting sometimes, in the death of aquatic organisms. Fish mortality is the most obvious indication of the adverse effects of sewage. In fact, death is too extreme a criterion for determining whether a substance is harmful to aquatic biota or not. A much more appropriate way to assess the health of aquatic life is to look at the many sub-lethal effects that pollutants cause without necessarily resulting in the death of individual organisms.

The sub-lethal effects of water pollution on fish have been documented worldwide for a great many species. They can take many forms – physiological,

biochemical, pathological and behavioural. Physiological abnormalities include reduction or inhibition of reproductive capacity, growth retardation and reduced resistance to infection from pathogens. Biochemical disturbances cause alterations in metabolism, body fluids and enzyme activities leading to subtle organ impairments and physical abnormalities in developing youngones. Some common pathological disturbances include fin erosion, ulcerations, liver tumours and skeletal anomalies caused by damaged genetic material. By altering external surfaces, pollutants can facilitate invasion by pathogens. Behavioural changes such as altered feeding and migrating patterns may result from the chemical damage to fish-sensory equipment and the altered abilities to react to the changes in the water composition. In the long run, sub-lethal effects on fish can adversely affect the community structure, population dynamics, and ecosystem structure and function.

Studies on the sub-lethal effects of pollution on fish are few. Sewage-treatment plants are the largest single source of fecal coliforms, suspended solids, nutrients, and other chemicals in aquatic ecosystems. The effect is compounded in the estuaries by the pooling of effluents, particularly during low river flow conditions, when dilution factors can be extremely low. As tides reverse, water flows in the river causing effluents to pool and spread across the river. Under such conditions, the toxic effluent can remain in the river for six hours or more. Young migrating fish as also the resident and migratory fish may be exposed to such conditions. Long-term toxicity can also lead to the loss of individual species and stocks. Water disturbances created by outfalls, heat inputs and some chemical pollutants also naturally attract fish, despite the presence of sub-optimal conditions that may very well cause fish to become unhealthy. Hence, the mere presence of fish is not an indicator of a good fish habitat.

The performance of all the organisms decreases when they confront severe pollution. For example, to reduce the irritation that some chemicals cause to their gills, fish reverse the water flow over their gills, a phenomenon referred to as coughing. It has been observed that pulp-mill effluent and other contaminants increase fish coughing, which can adversely affect fish health and survival by severely limiting energy expenditure for migration or feeding, thus reducing spawning and the production of progeny. It may also affect growth rates as well as make the fish more susceptible to bird predation and diseases.

Chlorine in chlorinated wastewater effluents may 'burn' fish tissues, especially gill structures. Chlorine also reduces the biochemical ability of fish to absorb oxygen. To protect itself from the irritation, the fish secretes mucus that rapidly builds up and clogs its respiratory surface. Eventually, the fish dies of asphyxiation. At high doses, chlorinated effluents result in immediate fish kills. Severe burning has also been observed to cause convulsions in fish, which die of a broken back. Exposure to residual chlorine also increases gill permeability, which leads to increased accumulation. Chlorine is also found to affect the nervous system of fish.

Health hazards

In industrialized countries, bacterial contamination of surface water caused serious health problems in major cities throughout the mid-1800's. By the turn of the century, cities in Europe and North America began building sewer networks to route domestic wastes downstream of water intakes. Development of these sewage networks and waste-treatment facilities in urban areas expanded tremendously in later years. However, the rapid growth of the urban population (especially in Asia and Latin America) has outpaced the ability of the governments to expand sewage and water infrastructure. While water-borne diseases have been eliminated in the developed world, outbreaks of cholera and other similar diseases still occur with alarming frequency in the developing countries.

The molluscan shellfish industry is important to the economy of many rural coastal communities. When waters are polluted by sewage, sewage-related bacteria and viruses are concentrated in the shellfish tissue to very high levels. Since in many countries, consumers prefer shellfish that are partially cooked or raw, there is a possibility of ingesting contaminated tissue and of contracting diseases such as cholera and typhoid. In addition to posing a serious public health threat, biologically contaminated shellfish grounds cause significant economic losses.

The presence of excessive nitrate can result in restriction of oxygen transport in the bloodstream. Infants are particularly susceptible to nitrate poisoning because fetal haemoglobin is more readily oxidized to methaemoglobin (fatalities from methaemoglobinemia occur infrequently and are most common in rural areas). Illness and death caused by methaemoglobinemia are not always recognized and therefore, its occurrence might be under-reported.

Just as raw sewage poses an obvious risk to the public health, so does poorly or partially treated sewage. The health hazards associated with the effluent originate from both the toxic substances and the organic matter present in that effluent. The ability of persistent toxic chemicals to cross the placenta, to bioaccumulate and to persist in the environment for long periods poses a health threat to a wide range of species including fish, birds, reptiles and mammals. Subtle effects have been observed at extremely low concentrations. Interference with endocrine system, which regulates hormonal activity in humans and wild life, is the effect most frequently associated with the synthetic organic contaminants found in many industrial and agricultural chemicals. By interfering with cell-to-cell communication, mimicking natural hormones, and triggering wrong biological responses, synthetic compounds disrupt normal hormonal functions and cause potentially life-threatening and irreversible neuro-behavioural or developmental damage. Documented effects on wildlife include immune and thyroid system disorders, disrupted sexual development, decreased fertility and birth defects (Table 34.3).

In addition to the toxic materials frequently found in treated effluents, the pathogenic microorganisms also flourish. Bacteria, parasites and viruses found in human and animal stools, i.e. in wastewater, cause many serious diseases such as hepatitis, myocardia and meningitis, and are implicated in infections such as chronic fatigue syndrome and diabetes. Less serious illnesses such as diarrhoea, and skin and ear infections also ensue. Because of their relatively low-grade symptomatology and self-curing nature, most of these infections are not reported to public health authorities.

Table 34.3. Potential health and environmental effects of toxins found in sewage treatment plant effluents

Toxin	Potential health and environmental effects
	Heavy metal
Cadmium	Neurotoxin, teratogen
Chromium	Carcinogen
Lead	Neurotoxin, teratogen, affects female fertility, bioaccumulative
Mercury	Neurotoxin, teratogen, affects female fertility, bioaccumulative
Zinc	Excessive ingestion uncommon, can cause gastrointestinal distress and diarrhoea
	Agricultural chemical
2,4-D	Teratogen
Lindane	Carcinogen, teratogen, immunotoxic
Methoxychlor	Reduces fertility, bioaccumulative
DDD and DDE	Neurotoxin, affects fertility, immunotoxic, carcinogen
	Industrial chemical
PCBs	Neurotoxin, carcinogen, immune suppressor; causes skin disorders, liver damage, depression and internal bleeding; affects fertility
Chloroform	Carcinogen, affects female reproductive capacity
Xylene	Affects male reproductive capacity
Tetrachlorethylene	Affects respiratory system, very persistent in the environment
Trichloroethylene	Poisonous by ingestion or absorption through skin, skin irritant
Cresol, Phenol	Poisonous by ingestion or absorption through skin
PAHs	Carcinogens, biotransformable
LABs	Persistent in the environment, effects not yet known

Remedies

The sewage-treatment process only partially eliminates disease-causing microorganisms. The percentage removed depends on the microbial type, the type of treatment applied, the length of the treatment and especially the operational conditions. Primary treatment is extremely inefficient at removing pathogens. They either settle in the sludge becoming a disposal problem or simply flow straight into the receiving waters. Secondary treatment removes some bacterial pathogens, but is usually inefficient at inactivating parasites and viruses. Non-disinfected secondary effluent poses an extreme health risk if the waters are to be used for recreational activities, shellfish raising or the irrigation of crops that will be eaten raw. Only at the tertiary level there is enough of the organic load and turbidity removed to allow for an optimum disinfection process. Tertiary treatment can inactivate 99.5-99.9% of microorganisms. Unfortunately, few municipalities are equipped with tertiary wastewater-treatment facilities.

Sewage may be treated to convert the constituents to suitable end-products, so that it may be satisfactorily discharged into receiving waters. Normally, there are four stages in the treatment process, but all of them may not be necessary, depending on

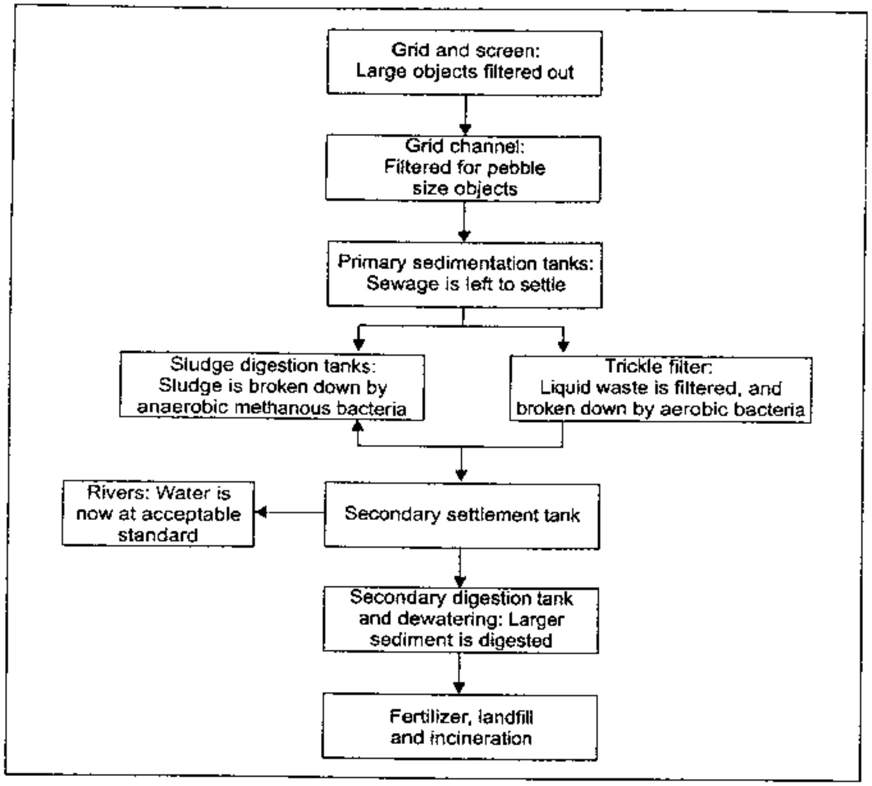


Fig 34.1. Sewage treatment

the quality of the effluent, and the nature and use of the receiving water-body (Fig. 34.1). Preliminary treatment involves screening of large particles, maceration and removal of grit during primary treatment (sedimentation), suspended solids are removed as sludge; dissolved and colloidal organics are oxidized by microorganisms in the secondary (biological) treatment. The tertiary treatment is used for the further removal of BOD, bacteria, suspended solids, specific compounds and nutrients, when a very high-quality effluent is needed.

Control and abatement

The high cost of treatment has been the major concern for wastewater management. There is considerable agreement, nonetheless, on the need for revised technology to diminish industrial and automotive emissions, to produce degradable wastes and to dispose of all wastes in ways, less damaging to the environment – for example, by returning sewage to the farm as fertilizer, and by recycling glass and metal materials. Finally, improvement is required in techniques for preventing pollution by especially hazardous wastes.

Remedial actions

Enough resources have already been spent on documenting the ills caused by municipal wastewater pollution. Although each city, town or community has its own specific environmental and socio-economic conditions, the available research points to a common conclusion: Sewage pollution is harming the environment, and it is affecting our health and economy. Conjointly, governments should empower everybody affected by pollution to sue polluters. Facing both the threat of private lawsuits and government sanctions, private entrepreneurs would find ways to eliminate sewage pollution. Technological innovation would spring up, education campaigns would become good investments, financial incentives not to discard harmful substances into sewers would become common, and comprehensive commercial and industrial source control and monitoring programmes would be set up in order to exercise tight control over the substances discharged into the sewerage system.

Bioremediation

The emergence of biotechnology as a tool has overruled the chemical technologies used for pollution abatement, which are costly, non-ecofriendly and generate more secondary wastes, which impair the ecosystem functioning. Most of these engineering technologies have failed in effluent clean-up process. As alternatives, though slowly, biological tools are being substituted in pollution abatement programmes. Bioremediation has been recognized as an inexpensive, effective and environment-friendly, safe technology that offers new and innovative ways to clean up hazardous wastes. However, the use of the technology is limited by an incomplete understanding of the biodegradation process. This is a tool that can be used for the abatement of pollution resulting from a variety of compounds, biodegradable as well as recalcitrant. There is evidence that microbes in anaerobic sediments can dechlorinate even the polychlorinated biphenyls, which are otherwise resistant. Genetic engineering holds great potential in this area.

Though bacteria and other microbes are natural sources of bioremediation tools, the most applicable one could be phytoremediation, especially with reference to aquatic pollution abatement. The use of specially selected (or engineered) and pollutant-accumulating plants for environmental clean-up is an emerging area in pollution abatement. Phytoremediation works best at sites with low to medium amount of pollution, and at sites contaminated with metals and nutrients. Plants are used either to stabilize or to remove metals from the soil and contaminated water through the five mechanisms, namely Phytoextraction –Plants are used to remove toxic or heavy metals from soil; Rhizofiltration –The use of plant roots to remove toxic or heavy metals from polluted water; Phytostabilization –The elimination of the bioavailability of toxic or heavy metals from soils using plants; Phytotransformation –Degradation of contaminants through plant metabolism, which is applicable to both soil and water; Phytostimulation – It is plant-assisted biodegradation, used for both soil and water, involving the stimulation of microbial biodegradation through the activities in plant rhizosphere.

Once absorbed by the plants, toxic or heavy metals can be stored in the roots, stems or leaves; converted into less harmful substances within the plant; or changed into gaseous forms and released into the atmosphere through transpiration.

Legislation

Waste management is simply, minimization, destruction, treatment and disposal of waste in an efficient way. In the simplest way, pollution prevention has two components: prevention of pollutants being generated and preventing the pollutants from being introduced into the environment. In pollution prevention, the government machinery and regulatory agencies have to play a major role, though many of the pollution prevention initiatives are voluntary efforts rather than requirements imposed by a regulatory agency.

Pollution is a global problem and does not respect national boundaries. The first major international conference on environmental issues was held in Stockholm (Sweden) in 1972 and was sponsored by the United Nations (UN). The most important outcome of the conference was the creation of the United Nations Environmental Programme (UNEP). The UNEP became the first UN agency to be headquartered in a developing country with offices in Nairobi, Kenya. Major focus for the UNEP has been the study of ways to encourage sustainable development while increasing standards of living without destroying environment. In 1973, the International Maritime Organization, an agency within the UN, developed an agreement known as MARPOL (Marine Pollution). This agreement regulates the disposal of trash, sewage and hazardous chemicals through ships along sea.

The United Nations Convention on the Law of the Sea entered into force on 16 November 1994, establishing a legal regime for the protection and conservation of the world's oceans. It provided a guideline for governing the oceans. In Part V, Article 73 (Enforcement of Laws and Regulations of the Coastal State) states, "The coastal state may, in the exercise of its sovereign rights to explore, exploit, conserve and manage the living resources in the exclusive economic zone, take such measures, including boarding, inspection, arrest and judicial proceedings, as may be necessary to ensure compliance with the laws and regulations adopted by it in conformity with this convention."

Part XII provides for general obligations of control of marine pollution, jurisdiction of states, responsibilities and liabilities, and also states the need for cooperation and global and regional levels for combating pollution.

Pollution is probably the major source of habitat destruction of species within the oceans. It can destroy and seep into every aspect of the ocean, killing and displacing thousands of species at the same time. Displacing and destroying marine mammal and fish habitats alike, can cause such stress to species that they simply cannot carry on the survival or reproduction of their species any longer. The Convention of the Law on the Sea (Part V) also addresses the conservation of marine living resources including mammals.

The International Standards Organization has formulated the environmental

management system standards under ISO 14000. Each nation is free to adopt these standards as appropriate to fit each county's political and resource considerations. The ISO 14000 Environmental Standards include several standards that can be applied in the management of the environment programme of any company and each company is free to develop its own environment management system.

In 1972, the US Congress passed the Clean Water Act that prevents toxins from being released directly into the water. In 1990, the Environmental Protection Agency (of USA) established the National Pollutant Discharge Elimination System (NPES). This act requires industry and municipalities to obtain permits to discharge pollutants directly from point sources into surface waters. Direct discharging includes industrial and commercial wastewater and industrial storm water.

The Government of India has also enacted many rules and regulations in the area of aquatic pollution prevention. The Water (Prevention and Control of Pollution) Act, 1974 and Rules, 1975 was enacted to provide for the prevention and control of water pollution, the maintenance or restoration of the wholesomeness of water, and for the establishment of boards for the prevention and control of water pollution. The Water (Prevention and Control of Pollution) Cess Act, 1977 and Rules 1978 has been enacted for the levy and collection of a cess on water consumed by persons carrying on certain industries and by local authorities, with a view to augment the resources of the central and state boards for the prevention and control of water pollution. The Environment (Protection) Act, 1986 and Rules, 1986 meant to provide for the protection and improvement of environment and for matters connected therewith and The Environmental Impact Assessment Notification, 1994, is aimed at imposing restrictions and prohibitions on the expansion and modernisation of any activity or new projects being undertaken in any part of India unless environmental clearance has been accorded by the Central Government or the state government concerned.

A comprehensive pollution prevention programme should include redesigning or reformulation of products, substitution of raw materials or alternative chemicals that introduce smaller quantities of hazardous substances into agricultural and industrial production processes, improved process technology and equipment to alter the primary source of waste generation, improved plant operations (housekeeping), and recycling of polluted substances at the site of their generation (closed loop recycling).

Pollution prevention programmes should include a comprehensive toxin reduction programme with defined goals for reducing the loading of toxic pollutants over time, identification of areas where pollution-prevention techniques should be implemented, and monitoring and reporting of success in meeting these goals.

Creation of awareness among the users of water and environmental education are the two most important ways to curb water pollution. Politicians must think of sustainable development rather than economic expansion, and developed countries should work in conjunction with the developing countries towards achieving the aim of pollution prevention. A successful corporate pollution prevention programme can improve global competitiveness, enhance consumer acceptance of products, reduce environmental impacts, improve working conditions and enhance community relations.

It is generally agreed that the key to the resolution of water problems is controlled by—water-quality management and planning, the enforcement of standards, the licensing and policing of discharges, following approved procedures in agriculture, and by good environmental awareness on the part of the public. It is unrealistic to prohibit all discharges to our water-bodies. Instead, the careful, diligent control of discharges to rivers and lakes will go a long way towards restoring and preserving the good quality of many waters.

35. Fish as Health Food

Overall health is achieved through a combination of physical, mental, emotional, and social well-being, which, together is commonly referred to as the health triangle. One of the principal determinants of maintaining good physical health is to have nutritionally balanced food or nutrients. Seven major classes of nutrients are carbohydrates, fats, proteins, minerals, vitamins, fiber and water. Nutrients may be classified as macronutrients or micronutrients depending upon the quantity needed in the routine diet; those nutrients needed in relatively large quantities are called macronutrients (or bulk or basic nutrients) and those needed in relatively small quantities are called micronutrients (Table 35.1). An ideal combination of the basic nutrients is made up of 50-60 % carbohydrates, 30 % fat and 10-15 % proteins; although the other nutrients, vitamins and minerals, do not supply energy, they are essential for many physiological functions vital for the preservation of health.

Macronutrients are the nutrients humans consume in the largest quantities and they provide bulk energy, such as carbohydrates, proteins and fats. Water and atmospheric oxygen, although consumed in large quantities, are not usually considered as food or nutrients. Calcium, sodium, chloride, magnesium and potassium along with phosphorus and sulphur are sometimes added to the list of macronutrients as they are required in large quantities compared to other vitamins and minerals. They are also referred to as the macrominerals. The macronutrients (excluding fiber and water) provide energy. Carbohydrates and proteins provide 17 kJ (4 kcal) of energy/g, while fats provide 37 kJ (9 kcal)/g.

Carbohydrates range from simple sugars (monosaccharides) like glucose, fructose, galactose to complex polysaccharides like starch and glycogen. Fats are triglycerides, made of various fatty acids bound to glycerol. Some of the fatty acids are essential in the diet as they cannot be synthesized in the body. The building blocks of proteins are the amino acids and some of them are essential amino acids. An essential amino acid can be defined as an amino acid that human body is not capable of synthesizing, therefore should get directly from diet. Most foods contain a mix of some or all of the nutrient classes. Some nutrients are required regularly, while others are needed only occasionally. Poor health can be caused by an imbalance of nutrients, whether in excess or a deficiency.

Micronutrients are nutrients needed throughout life in small quantities. The micronutrients are minerals and vitamins. They include dietary minerals needed by the human body in very small quantities (generally less than 100 microgram/day) as opposed to macrominerals which are required in larger quantities. The microminerals or trace elements include iron, cobalt, chromium, copper, iodine, manganese, selenium, zinc and molybdenum.

Vitamins are organic substances participating in very small amounts in the

Table 35.1. Nutrients required in human diet

Energy sources	Folic acid
Carbohydrates	Cyanocobalamine (vit B_{12})
Fats	Vitamin C (Ascorbic acid)
Proteins	Vitamins A, D, E and K
Essential amino acids	**Mineral elements**
Arginine (in adults)	Calcium
Valine	Chlorine
Histidine	Chromium
Isoleucine	Cobalt
Leucine	Copper
Lysine	Fluorine
Methionine	Iodine
Phenylalanine	Iron
Threonine	Magnesium
Tryptophan	Manganese
Essential fatty acids	Nickel
Linoleic acid	Molybdenum
Linolenic acid	Phosphorus
Vitamins	Potassium
Thiamine (vitamin B_1)	Selenium
Riboflavin (vitamin B_2)	Sodium
Nicotinamide	Zinc
Pantothenic acid	
Pyridoxine (vitamin B_6)	
Biotin	

normal function of the cells. They do not provide calories and are only required in relatively small amounts; however, they are essential to the body so one can not survive long without any of them. The body needs 13 different vitamins, which some organisms are unable to synthesize and must obtain from exogenous sources or diet (Table 35.1).

Antioxidants are molecules (Table 35.2) capable of slowing or preventing the oxidation of other molecules. Oxidation reactions can produce free radicals, which start chain reactions that damage the cells. Antioxidants terminate these chain reactions by removing free radical intermediates, and inhibit other oxidation reactions by being themselves oxidized. As a result, antioxidants are often reducing agents such as the thiols, ascorbic acid (vitamin C) or polyphenols like tannins, lignins and flavonoids. Although oxidation reactions are crucial for life, they can also be damaging; hence, the living organisms maintain complex systems of multiple types of antioxidants and antioxidant enzymes like catalase, superoxide dismutase (SOD) and peroxidases. Low levels of antioxidants or inhibitors of the antioxidant enzymes, cause oxidative stress and may damage or kill cells.

Table 35.2. Some antioxidant metabolites

Ascorbic acid (vitamin C)
Glutathione
Lipoic acid
Uric acid
Carotenes
α-tocopherol (vitamin E)
Ubiquinol (coenzyme Q)

Fish as Health food

Health food refers to specific foods claimed to be especially beneficial to health. In contrast to a regular healthy diet, proponents of health foods claim that particular foods have specific favorable effects on health. Examples of health foods include alfalfa sprouts, wheat and yogurt. Natural foods and organic food are related categories. The term is often used for foods that are low in fat and/or sugar, since over consumption of fatty and sugary foods is seen as contributing to the obesity epidemic. This is health-food concept in the affluent society and developed countries. However, the concept of a health-food or a healthy, balanced diet is different for the vast majority of world population, especially for the developing world. There is a big gap between the rate of population growth and the rate of food production and the gap is ever increasing. Undernutrition, malnutrition and starvation and resultant mortality are major problems in developing and underdeveloped countries. Two forms of child undernutrition Marasmus (chronic deficiency of calories) and Kwashiorkar (chronic protein deficiency), often occuring together, are world health problems. In this context, fish, being one of the cheapest sources of animal proteins, is playing a big role and can still play a bigger role in preventing the protein-calorie malnutrition.

Fish as a food is consumed by many animal species, including humans. Three quarters of the Earth are covered by water, so fish has been an important part of the diet of humans in almost all countries in the world since the dawn of time. Animal proteins are generally superior to plant proteins and fish is one of the cheapest sources of animal proteins and availability and affordability is better for fish in comparison to other animal protein sources. Fish serves as a health-food for the affluent world owing to the fish oils which are rich in polyunsaturated fatty acids (PUFAs), specifically ω-3 PUFAS and at the same time, it is a health-food for the people in the other extreme of the nutrition scale owing to its proteins, oils, vitamins and minerals and the benefits associated with the consumption of small indigenous fishes.

Nutrient profiling of fishes show that fishes are superior nutrients and umpteen number of health benefits are believed to be associated with routine fish consumption. Fish, especially saltwater fish, is high in omega-3 fatty acids, which are heart-friendly, and a regular diet of fish is highly recommended by nutritionists. This is conjectured to be one of the major causes of reduced risk for cardiovascular diseases in Eskimos. It has been suggested that the longer lifespan of Japanese and Nordic populations may be partially due to their higher consumption of fish and seafood. The Mediterranean diet likewise is based on a rich intake of fish. Fish are also great for the skin. Nutritionists recommend that fish be eaten at least 2-3 times a week. Oily fish is claimed to help prevent a range of other health problems from mental illness to blindness. The health benefits of eating fish are being increasingly understood now. The largest ever study into the health benefits of eating fish is about to be launched; this $20-million US Government-sponsored probe will examine whether fish oil and vitamin D can help prevent heart disease, cancer and a range of other illnesses. Similarly, there are Government of India-sponsored projects running which aim at nutrient profiling of important food-fishes from the Indian waters and also to study the health benefits of eating fish regularly.

Nutrient profile of fish

Fish is an important component of human diet. More than 50% of Indian population is fish eating and in some states like Asom and other North-Eastern states, West Bengal, Odisha, Goa and Kerala, more than 90% of the population consume fish. Fish contains proteins and other nitrogenous compounds, lipids, minerals and vitamins and very low level of carbohydrates (Table 35.3). Protein content of fish varies from 15 to 20% of the live body weight. Fish proteins contain the essential amino acids in the required proportion and thus, improve the overall protein quality of a mixed diet. The superior nutritional quality of fish lipids (oils) is well known. Fish lipids differ greatly from mammalian lipids in that they include up to 40% of long-chain fatty acids (C_{14} - C_{22}) that are highly unsaturated and contain 5 or 6 double bonds; on the other hand, mammalian fats generally contain not more than 2 double bonds per fatty acid molecule. Fish is generally a good source of vitamin B complex and the species with good amount of liver oils are good source of fat soluble vitamins A and D. Fish is particularly a good source of minerals like calcium, phosphorus, iron, copper and trace elements like selenium and zinc. Besides, saltwater fish contains high levels of iodine also. In fact, fish is a good source of all nutrients (Tables 35.4-35.6) except carbohydrates and vitamin C. Some inland fish species like singhi (*Heteropnestus fossilis*), magur (*Clarias batrachus*), murrels (*Channa* sp.) and koi (*Anabas testudineus*) have therapeutic properties.

Table 35.3. Biochemical composition of fish

Moisture	65-80%
Protein	15-20%
Fat	5-20%
Ash	0.5-2%

Table 35.4. Proximate composition of some Indian food fish and shellfish (All values given are g/100 g edible portion)

Common name	Scientific name	Moisture	Protein	Fat	Ash	Remarks
Rohu	*Labeo rohita*	76.90	19.10	0.20	0.90	Freshwater
Catla	*Catla catla*	76.30	19.60	1.30	0.90	Freshwater
Mrigal	*Cirrhinus mrigala*	77.10	19.00	0.10	1.40	Freshwater
Common carp	*Cyprinus carpio*	74.84	20.84	3.15	1.17	Freshwater
Mola	*Amblypharyngodon mola*	75.25	15.72	5.76	3.4	Freshwater
Magur	*Clarias batrachus*	78.70	18.20	1.42	0.97	Catfish
Channa	*Channa punctatus*	75.80	19.84	3.15	1.00	Murrel
Hilsa	*Hilsa ilisha*	69.93	19.96	9.27	1.85	Migratory
Grey mullet	*Mugil cephalus*	74.90	20.80	5.10	0.60	Brackishwater
Mullet	*Rhinomugil corsula*	75.77	20.22	2.45	1.62	Brackishwater
Pearl spot	*Etroplus suratensis*	75.30	22.50	2.40	0.90	Brackishwater
Anchovy	*Stolephorus* spp.	79.40	15.10	1.30	2.60	Marine
Bombay duck	*Harpodon nehereus*	88.50	7.50	2.00	1.50	Marine
Oil sardine	*Sardinella longiceps*	67.01	19.38	11.7	1.73	Marine
Freshwater prawn	*Macrobrachium rosenbergii*	78.29	21.17	0.27	0.37	Shellfish
Tiger shrimp	*Penaeus monodon*	71.23	24.89	1.25	1.98	Shellfish
Crab	*Scylla serrata*	79.23	17.50	0.21	1.39	Shellfish
Mussel	*Perna viridis*	76.69	12.55	2.57	2.06	Shellfish

Source: *Biochemical Composition of Indian Food Fish*. Gopakumar K (Ed.), CIFT (ICAR), Kochi and Data generated under ICAR Outreach Activity, Consortium #3: Nutrient Profiling of Fish.

Table 35.5. Amino acid content of some Indian food fish and shellfish

Amino acids (g/100 g)	*L. rohita* (Rohu)	*C. mrigala* (Mrigal)	*C. striatus* (Murrel)	*H. fossilis* (Singhi)	*M. cephalus* (Mullet)	*L. lineolatus* (Silver belly)	*P. monodon* (Tiger prawn)	*P. viridis* (Mussel)
Asp	9.32	10.24	10.74	6 33	12.91	11.78	17.07	9.56
Thr	4.76	3.99	4.24	4.29	4.69	4.28	5 46	4.00
Ser	3.27	3.75	3.60	2.41	4.78	2.68	5.50	3.63
Glu	12.98	14.11	21.60	10.79	18.09	17.03	11.84	14.96
Pro	4.13	2.63	4.00	3.86	1.45	3.99	4.55	4.31
Gly	3.84	3.72	3.75	4.74	5.68	4.92	8.66	9.32
Ala	6.49	5.87	5.49	4.47	6.20	6.46	7.07	5.10
Val	4.24	4.87	5.54	4.07	6.01	5.89	4.28	4.74
Cys	2.06	1.24	2.40	0.50	3.51	1.35	1.46	2.43
Met	2.05	2.42	2.47	1.34	2.79	2.48	2.05	1.75
Ile	5.66	4.18	4.50	4.56	4.99	4.90	4.86	5.88
Leu	8.25	7.97	8.76	6.92	10.65	7.51	10.45	7.94
Tyr	3.22	3.07	1.90	1.84	2.92	1.63	1.68	4.15
Phe	3.70	3.78	2.91	3.84	4.46	5.36	4.28	4.67
His	6.17	3.78	3.16	4.86	5.94	2.51	2.49	4.46
Lys	12.22	13.12	13.26	10.98	10.58	12.25	9.97	10.46
Arg	3.60	5.46	4.87	2.78	7.36	6.49	6.43	7.26
Try	1.28	-	-	1.38	-	1.02	-	-

Source: *Biochemical Composition of Indian Food Fish*. Gopakumar K (Ed.), CIFT (ICAR), Kochi and Data generated under ICAR Outreach Activity, Consortium #3: Nutrient Profiling of Fish.

Fish and macronutrients

Proteins: Proteins play three major roles in nutrition. They provide both essential and nonessential amino acids which are building blocks for protein biosynthesis. Protein biosynthesis is necessary both for growth of infants and children and also for the constant replacement and turnover of body proteins in adults. Secondly, amino acids are precursors of hormones (e.g. adrenaline, nor-adrenaline), porphyrins, many other biomolecules and secondary metabolites. Thirdly, the amino acids contribute a minor but significant fraction of the total daily energy requirement of the body via oxidation of its carbon skeletons. Thus, proteins are important for growth and development of the body, maintenance and repairing of worn out tissues and for production of enzymes and hormones required for many body processes.

The importance of fish in providing easily digested protein of high biological value is well documented. In comparison to the other sources of dietary proteins of animal origin, such as chicken, mutton, pork, beef etc. the unit cost of production of fish is much cheaper. Fish also come in a wide range of prices making it affordable to the poor. A common man can afford to meet the family's dietary requirement of animal proteins because he has the option to choose from a fairly large number of fish species available. A portion of fish provides with one-third to one-half of one's daily protein requirement. This explains how fish plays an important role in meeting the nutritional food security, especially in preventing the protein-calorie malnutrition. In the past this has served as a justification for promoting fisheries and aquaculture activities in several countries. On a fresh-weight basis, fish contains a good quantity of protein, about 18-20%, and contains all the eight essential amino acids including the sulphur-containing lysine, methionine, and cysteine.

Fatty acids (fish oils): There are mainly three types of fatty acids: (*i*) saturated fatty acids (SFAs), (*ii*) monounsaturated fatty acids (MUFAs), and (*iii*) polyunsaturated fatty acids (PUFAs). The first two are synthesized endogenously, but the third one cannot be synthesized by the humans from other components by any known biochemical pathways, and therefore must be obtained from the diet. Fatty acids (FAs) are highly complex biomolecules and it is important to know their nomenclature to understand them.

Nomenclature n-3/n-6 (ω-3/ω-6) fatty acids : n-3 fatty acids, popularly referred to as ω (omega) -3 fatty acids, are a family of polyunsaturated fatty acids (PUFAs) that have in common a final carbon-carbon double bond in the n-3 position; that is, the third bond from the methyl end of the fatty acid (Fig 35.1). ω-3 18:4 (stearidonic acid) or 18:4 ω-3 or 18:4 n-3 indicates an 18-carbon chain with 4 double bonds, and with the first double bond in the third position from the CH_3 end. So in free fatty acid form, the chemical structure of stearidonic acid is as shown below.

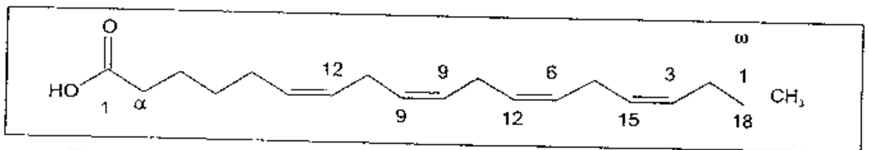


Fig. 35.1. Chemical structure of stearidonic acid showing numbering conventions.

n-3 fatty acids which are important in human nutrition are: α-linolenic acid (18:3, *n*-3; ALA), eicosapentaenoic acid (20:5, *n*-3; EPA), and docosahexaenoic acid (22:6, *n*-3; DHA). These three PUFAs have either 3, 5 or 6 double bonds in a carbon chain of 18, 20 or 22 carbon atoms respectively. All double bonds are in the *cis*-configuration,

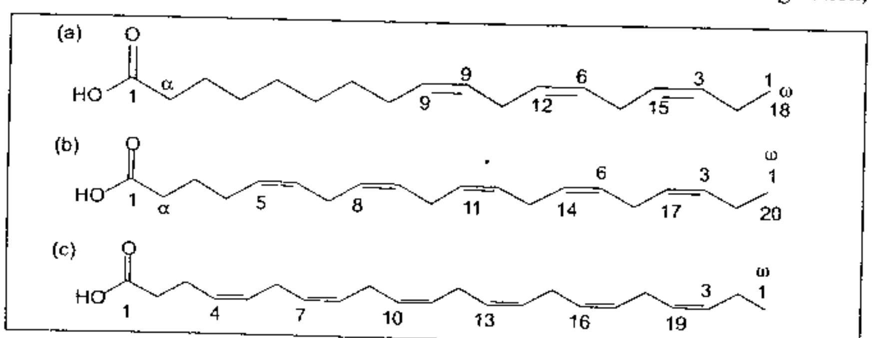


Fig. 35.2. Chemical structure of some PUFAs—(a) alpha (a)-linolenic acid (ALA), an essential *n*-3 fatty acid, (b) eicosapentaenoic acid (EPA), (c) docosahexaenoic acid (DHA).

i.e. the two hydrogen atoms are on the same side of the double bond (Fig 35.2). Most naturally-produced fatty acids (created or transformed in animalia or plant cells with an even number of carbon in chains) are in *cis*-configuration where they are more easily transformable. *n*-3 compounds are more fragile than *n*-6 because the last double bond is geometrically and electrically more exposed, notably in the natural *cis*-configuration.

The human body cannot synthesize *n*-3 fatty acids *de novo*, but it can form 20-carbon unsaturated *n*-3 fatty acids (like EPA) and 22-carbon unsaturated *n*-3 fatty acids (like DHA) from the eighteen-carbon *n*-3 fatty acid α-linolenic acid. These conversions occur competitively with *n*-6 fatty acids, which are essential closely related chemical analogues that are derived from linoleic acid (LA). Both the *n*-3 α-linolenic acid and *n*-6 linoleic acid are essential nutrients which must be obtained from food. Synthesis of the longer *n*-3 fatty acids from linolenic acid within the body is competitively slowed by the *n*-6 analogues. Thus accumulation of long-chain *n*-3 fatty acids in tissues is more effective when they are obtained directly from food or when competing amounts of *n*-6 analogs do not greatly exceed the amounts of *n*-3.

In the body, essential fatty acids serve multiple functions. In each of these, the balance between dietary ω-3 and ω-6 strongly affects function. They are modified to make: (*i*) the classic eicosanoids (affecting inflammation and many other cellular functions), (*ii*) the endocannabinoids (affecting mood, behaviour and inflammation), (*iii*) the lipoxins from ω-6 EFAs and resolvins from ω-3 (in the presence of aspirin, down regulating inflammation), (*iv*) the isofurans, neurofurans, isoprostanes, hepoxilins, epoxyeicosatrienoic acids (EETs) and neuroprotectin D, (*v*) they form lipid rafts (affecting cellular signaling), (*vi*) they act on DNA (activating or inhibiting transcription factors such as NFκB, which is linked to pro-inflammatory cytokine production).

Importance of omega-3 fatty acids in diet: The long chain PUFA (LC-PUFA) (i.e. C20 and C22) that belong to the omega (ω)-3 family, have a number of neutraceutical and pharmaceutical applications. Eicosapentaenic acid (EPA, 20:5 ω3) and docosahexaenoic acid (DHA, 22:6 ω3) are the important ω3 PUFA. EPA and DHA are important in treatment of arthrosclerosis, cancer, rheumatoid arthritis, psoriasis and diseases of old age such as Alzheimer's and age-related macular degeneration (AMD).

Omega-3 fatty acids are considered a boon to human beings. Body functions are improved by their intake. Brain is a vital organ that keeps the body functions in proper control. These fatty acids increase the volume of grey matter associated with mood and regulation of emotions. The risk of dementia and Alzheimer's disease is also checked. They also boost the cognitive functions in elderly people, and there is improvement in osteoarthritis by prevention of loss of cartilage that acts as a cushion in the joints and checks inflammation. They protect against prostrate and breast cancer by stimulating the death of tumor cells. These fatty acids increase HDL cholesterol and reduce triglycerides, a condition that is favorable for the heart. These keep the blood in fluid state by decreasing platelet aggregation.

Omega-3 fatty acids are found in flax seeds, walnuts and soybeans, besides fatty fishes like salmon. Although omega-3 fatty acids have been known as essential to normal growth and health since the 1930s, awareness of their health benefits has dramatically increased in the past few years. The heart-health benefits of the long-chain omega-3 fatty acids - DHA and EPA omega-3 - are the best known. These benefits were discovered in the 1970s by researchers studying the Greenland Eskimos. The Greenland Eskimos consumed large amounts of fat from seafood, but displayed virtually no cardiovascular disease. The high level of omega-3 fatty acids consumed by the Eskimos reduced triglycerides, heart rate, blood pressure, and atherosclerosis. As the importance of omega-3 fatty acids to health has received increasing awareness, the number of food products enriched in omega-3 fatty acids has increased. Many manufacturers add fish oil or flax oil into their final product to enrich it in omega-3 fatty acids. Some animal products, such as milk and eggs, can be naturally enriched for omega-3 fatty acids by feeding the animals a diet that is rich in omega-3 fatty acids. Some countries have recognized the importance of DHA omega-3 and permit the following biological role claim for DHA: DHA, an omega-3 fatty acid, supports the normal development of the brain, eyes and nerves.

Fish oils are the major source of PUFA, and considerable evidence has indicated that ω3 PUFA in fish oil are actually derived via the marine food chain zooplankton consuming ω-3 PUFA-synthesizing micro algae. LA and ALA are predominant in green vegetables and some plant oils. Although some research has derived qualitatively that humans can convert the parent ALA to EPA and then to DHA, the most recent consensus is the degree of conversion is unreliable and unrestricted.

The most widely available source of EPA and DHA is coldwater oily fish such as salmon, herring, mackerel, anchovies and sardines. Oils from these fish have a profile

Table 35.6. Fatty acid composition of the lipids of major Indian food fish and shellfish (All values are expressed as % by weight of total fatty acids.)

Common name	Scientific name	SFA	MUFA	PUFA	Others
Stinging catfish	*Heteropneustes fossilis*	39.2	35.2	22.9	2.8
Spiny eel	*Mastacembelus armatus*	41.3	33.5	25.3	0.0
Milk fish	*Chanos chanos*	38.0	34.4	27.6	0.0
Grey mullet	*Mugil cephalus*	43.1	36.9	19.4	0.0
Freshwater shark	*Wallago attu*	39.3	33.5	25.4	2.0
Pearl spot	*Etroplus suratensis*	36.0	30.6	33.0	0.0
Anchovy	*Stolephorus spp.*	43.3	16.4	37.2	2.7
Bombay duck	*Harpodon nehereus*	30.2	20.0	46.7	3.1
Oil sardine	*Sardinella longiceps*	42.9	20.7	31.3	5.3
Yellowfin tuna	*Thunnus albacares*	39.1	20.5	37.1	3.2
Skipjack tuna	*Katsuwonus pelamis*	30.3	19.3	47.7	3.2
Tuna	*Thunnus obesus*	31.3	15.0	53.6	0.5
Tuna	*Euthynnus affinis*	23.2	12.3	63.3	1.0
Freshwater prawn	*Macrobrachium rosenbergii*	31.3	34.2	34.3	-
Prawn	*Penaeus indicus*	42.6	22.7	34.7	-
Green mussel	*Perna viridis*	31.1	22.4	46.8	-

Source: Biochemical Composition of Indian Food Fish. Gopakumar K (Ed.), CIFT (ICAR), Kochi and Data generated under ICAR Outreach Activity, Consortium #3: Nutrient Profiling of Fish.

of around seven times as much *n*-3 as *n*-6. Other oily fish such as tuna also contain *n* 3 in somewhat lesser amounts. Although fish is a dietary source of *n*-3 fatty acids, fish do not synthesize them; they obtain them from the algae or plankton in their diet. Fatty acid composition of the lipids of major Indian food fish and shellfish are presented (Table 35.6).

***n*-6 Fatty acids:** Like *n-3* fatty acids, *n-6* fatty acids (such as ©-linolenic acid and arachidonic acid) play a similar role in normal growth (Table 35.7). *n-6* is better at supporting dermal integrity, renal function, and parturition. These preliminary findings led researchers to concentrate their studies on *n-6*, and it was only in recent decades that *n-3* has become of interest.

Table 35.7. List of common *n*-3 and n-6 fatty acids found in nature

Common name	Lipid name	Chemical name	Abbreviation
Common n-3 (ω-3) fatty acids			
α-Linolenic acid	18:3 (*n*-3)	*all-cis*-9,12,15-octadecatrienoic acid	ALA
Stearidonic acid	18:4 (*n*-3)	*all-cis*-6,9,12,15-octadecatetraenoic acid	STD
Eicosapentaenoic acid	20:5 (*n*-3)	*all-cis*-5,8,11,14,17-eicosapentaenoic acid	EPA
Docosapentaenoic acid	22:5 (*n*-3)	*all-cis*-7,10,13,16,19-docosapentaenoic acid	DPA
Docosahexaenoic acid	22:6 (*n*-3)	*all-cis*-4,7,10,13,16,19-docosahexaenoic acid	DHA
Common n-6 (ω-6) fatty acids			
Linoleic acid	18:2 (*n*-6)	9,12-octadecadienoic acid	LA
Arachidonic acid	20:4 (*n*-6)	5,8,11,14-eicosatetraenoic acid	AA
Docosadienoic acid	22:2 (*n*-6)	13,16-docosadienoic acid	DDA
Docosapentaenoic acid	22:5 (*n*-6)	4,7,10,13,16-docosapentaenoic acid	DPA

The biological effects of the *n-6* fatty acids are largely mediated by their conversion to *n-6* eicosanoids that bind to diverse receptors found in every tissue of the body. The conversion of tissue arachidonic acid (20:4n-6) to n-6 prostaglandin and n-6 leukotriene hormones provides many targets for pharmaceutical drug development and treatment to diminish excessive n-6 actions in atherosclerosis, asthma, arthritis, vascular disease, thrombosis, immune-inflammatory processes and tumor proliferation. Competitive interactions with the *n-3* fatty acids affect the relative storage, mobilization, conversion and action of the n-3 and n-6 eicosanoid precursors. This competition was recognized as important when it was found that thromboxane is a factor in the clumping of platelets, which leads to thrombosis. The leukotrienes were similarly found to be important in immune/inflammatory-system response, and therefore relevant to arthritis, lupus, and asthma. These discoveries led to greater interest in finding ways to control the synthesis of *n-6* eicosanoids. The simplest way would be by consuming more *n*-3 and fewer *n*-6 fatty acids.

Some medical research indicates that excessive levels of *n*-6 fatty acids, relative to *n*-3 fatty acids, may increase the probability of a number of diseases and depression. Modern Western diets typically have ratios of *n*-6 to *n*-3 in excess of 10 to 1, some as high as 30 to 1. The optimal ratio is thought to be 4 to 1 or lower. Excess *n*-6 fats interfere with the health benefits of *n*-3 fats; in part because they compete for the same rate-limiting enzymes. A high proportion of *n*-6 to *n*-3 fat in the diet shifts the physiological state in the tissues toward the pathogenesis of many diseases: prothrombotic, proinflammatory and proconstrictive. Chronic excessive production of *n*-6 eicosanoids is associated with heart attacks, thrombotic stroke, arrhythmia, arthritis, osteoporosis, inflammation, mood disorders and cancer.

Many of the medications used to treat and manage these conditions work by blocking the effects of the potent *n*-6 fat, arachidonic acid. Many steps in formation and action of n-6 hormones from n-6 arachidonic acid proceed more vigorously than the corresponding competitive steps in formation and action of n-3 hormones from n-3 eicosapentaenoic acid. The cyclooxygenase (COX)-1 and COX-2 inhibitor medications, used to treat inflammation and pain, work by preventing the COX enzymes from turning arachidonic acid into inflammatory compounds. Many of the anti-mania medications used to treat bipolar disorder work by targeting the arachidonic acid cascade in the brain. Linoleic acid (18:2, *n*-6), the shortest-chained *n*-6 fatty acid, is an essential fatty acid. Arachidonic acid (20:4) is a physiologically significant *n*-6 fatty acid and is the precursor for prostaglandins and other physiologically active molecules.

Nutritional significance of fish oils and PUFAs for human health – Some clinical correlations

1. Omega-3 fatty acids have been shown in epidemiological and clinical trials to reduce the incidence of coronary heart disease (CHD). Studies have indicated decreases in total mortality and cardiovascular incidents (i.e. myocardial infarctions) associated with the regular consumption of fish and fish oil supplements. Similar to those who follow a Mediterranean diet, Arctic-population, who consume high amounts of *n*-3 fatty acids from fatty fish also tend to have higher proportions of *n*-3, increased HDL cholesterol and decreased triglycerides (fatty material that circulates in the blood) and less heart disease. Administration of purified EPA from fish oil improves the thickness of carotid arteries along with improving blood flow in patients with unhealthy blood sugar levels. Non-fatal coronary events are also significantly reduced in the people fed with EPA and they have superior cardiovascular function. Thus, EPA is a promising treatment for prevention of major coronary events, especially non-fatal coronary events. Recommendations made by American Heart Association (AHA) Dietary Guidelines include at least two servings of fish per week (particularly fatty fish) (*Source:* Circulation, 106, 2747-2757, 2002).
2. Lack of essential fatty acids causes behavioural problem in the pediatric population which is known as attention-deficit hyperactivity disorder (ADHD). Children suffering from ADHD are inattentive, impulsive and hyperactive. Studies have reported that children with ADHD had significantly lower levels of arachidonic (AA), eicosapentaenoic (EPA) and decosahexaenoic acids (DHA) in their blood and these hyperactive children suffered more from symptoms associated with essential fatty acid deficiency (thirst, frequent urination, and dry hair and skin) and were more likely to have asthma (*Source: American Journal of Clinical Nutrition* , **62**, 761-68).

Recent research has shown associations between attention-deficit/hyperactivity disorder (ADHD) and erythrocyte long-chain n-3 PUFA (LC n-3 PUFA) levels, with limited evidence for dietary LC n-3 PUFA intake and ADHD. This is the most common developmental disorder in childhood. The main symptoms include poor impulse control, hyperactivity and inattention. Children with ADHD often experience co-morbidity with other behavioural disorders including anxiety, conduct, oppositional and/or mood disorders and antisocial personality. The prevalence rates are estimated at 4–15%; boys are more commonly diagnosed with ADHD than girls. It is now clear that problems associated with ADHD also persist into adulthood. The aetiology of ADHD appears to be multifactorial with genetic and environmental influences. Focus has also been placed on diet, including emerging evidence that ADHD may be associated with low levels of dietary and erythrocyte long-chain n-3 PUFA (LC n-3 PUFA). The LC n-3 PUFA, including EPA (20: 5n-3) and DHA (22: 6n-3), can be converted from α-linolenic acid (18: 3n-3) by endogenous desaturation and elongation (12); however, only negligible amounts are converted. LC PUFA are critical in normal brain and nervous system development and function. 22: 6n-3 is highly concentrated in brain and retina, while LC n-6 arachidonic acid (20: 4n-6) together with 22: 6n-3 plays a major structural role in neuronal membranes. Therefore, there has been growing interest in the role of n-3 PUFA in psychiatric illness across the lifespan. It has been well established that 22: 6n-3 is critical for infant brain development, and 22: 6n-3 may be associated with enhanced cognitive performance in childhood. A number of studies have found lower blood n-3 levels in children with ADHD compared with control groups and there is evidence for alleviation of ADHD symptoms with n-3 PUFA supplementation. Results of trials have been conflicting; although placebo-controlled studies have reported improvement in ADHD symptoms in children following supplementation with 732 mg/d of LC n-3 PUFA and 60 mg/d of g-linolenic acid (18: 3n-6) over 24–30 weeks. Given the overall current evidence for the role of LC n-3 PUFA in ADHD symptoms and the lower consumption of foods rich in LC n-3 PUFA, children with ADHD are encouraged to consume more LC n-3 PUFA containing foods for mental health benefits. (*Source: British Journal of Nutrition* 2009, 1-7. doi: 10.1017/S0007114509990821.)

3. Children who consume fresh, oily fish have significantly lower risk of developing asthma (airway hyper responsiveness). Omega-3 fatty acids, EPA and DHA, especially EPA is reported to prevent development of asthma or reduce its severity. Studies have suggested long-term fish oil supplementation may reduce asthma severity. Major dietary sources of DHA are fish and fish oils. (*Source: Medical Journal of Australia*, **164**, 137-40, 1996; *American Journal of Clinical Nutrition*, **65**, 1011-1017, 1997.)
4. Low dietary intakes and plasma concentration of n-3 fatty acids are associated with dementia (memory loss), cognitive decline and age-related macular degeneration (AMD) risk. These are some of the major cause of disability in the elderly population. AMD is a disease associated with aging that gradually destroys sharp, central vision. Central vision is needed for seeing objects clearly and for common daily tasks such as reading and driving. AMD affects the macula (located

in the center of the retina, the light-sensitive tissue at the back of the eye), the part of the eye enables to see fine detail. AMD causes no pain. In some cases, AMD advances so slowly that people notice little change in their vision. In others, the disease progresses faster and may lead to a loss of vision in both eyes.

The AMD occurs in two forms: wet and dry. 'Wet AMD' occurs when abnormal blood vessels behind the retina start to grow under the macula. These new blood vessels tend to be very fragile and often leak blood and fluid. The blood and fluid raise the macula from its normal place at the back of the eye. Damage to the macula occurs rapidly. With wet AMD, loss of central vision can occur quickly. Wet AMD is also known as advanced AMD. It does not have stages like dry AMD. An early symptom of wet AMD is that straight lines appear wavy. 'Dry AMD' occurs when the light-sensitive cells in the macula slowly breakdown, gradually blurring central vision in the affected eye. As dry AMD gets worse, you may see a blurred spot in the center of your vision. Over time, as less of the macula functions, central vision is gradually lost in the affected eye. The most common symptom of dry AMD is slightly blurred vision. There may be difficulty in recognizing faces and more light is needed for reading and other tasks. Dry AMD generally affects both eyes, but vision can be lost in one eye while the other eye seems unaffected.

AMD is a leading cause of vision loss in people over 60 years of age. It has been reported that n-3 fatty acids, particularly DHA delay the progression of dementia and AMD (*Source: American Journal of Clinical Nutrition*, **83** (suppl), 1494 S-1498 S, 2006). Major dietary sources of DHA are fish and fish oils.

5. In a study of nearly 9,000 pregnant women, researchers found women who ate fish once a week during their first trimester had 3.6 times less risk of low birth weight (LBW) and premature birth than those who ate no fish. Low consumption of fish was a strong risk factor for preterm delivery and low birth weight. However, attempts by other groups to reverse this increased risk by encouraging increased pre-natal consumption of fish were unsuccessful.
6. *n*-3 fatty acids are known to have membrane-enhancing capabilities in brain cells. One medical explanation is that *n*-3 fatty acids play a role in the fortification of the myelin sheaths. A benefit of *n*-3 fatty acids is helping the brain to repair damage by promoting neuronal growth. In the prefrontal cortex (PFC) of the brain, low brain *n*-3 fatty acids are thought to lower the dopaminergic neurotransmission in this brain area, possibly contributing to the negative and neurocognitive symptoms in schizophrenia. This reduction in dopamine (a neurotransmitter) system function in the PFC may lead to an over activity in dopaminergic function in the limbic system of the brain, which is suppressively controlled by the PFC dopamine system, causing the positive symptoms of schizophrenia (a psychiatric diagnosis that describes a mental disorder characterized by abnormalities in the perception or expression of reality). This is called the *n*-3 polyunsaturated fatty acid/dopamine hypothesis of schizophrenia. This mechanism may explain why *n*-3 supplementation shows effects against both positive, negative and neurocognitive symptoms in schizophrenia (*Source: Progress in Neuropsychopharmacol and Biol Psychiat* **31**, 469–474, 2007.)

7. Several epidemiological studies suggest covariation between seafood consumption and rates of mood disorders (where a disturbance in the person's mood is hypothesized to be the main underlying feature). Long term disturbances of mood such as depression and bipolar disorder are considered mood disorders. Biological marker studies indicate deficits in omega-3 fatty acids in people with depressive disorders, while several treatment studies indicate therapeutic benefits from omega-3 supplementation. A similar contribution of omega-3 fatty acids to coronary artery disease may explain the well-described links between coronary artery disease and depression.

Fish and micronutrients

Vitamins: Fish is a rich source of vitamins, particularly vitamins A, D and E from fatty species, as well as thiamin, riboflavin and niacin (vitamins B_1, B_2 and B_3). Vitamin A from fish is more readily available to the body than from plant foods. Among all the fish species, fatty fish contains more vitamin A than lean species. Studies have shown that mortality is reduced for children under five with a good vitamin A status. Vitamin A is also required for normal vision and for bone growth. As sun drying destroys most of the available vitamin A better processing methods are required to preserve this vitamin. The small indigenous fish *Amblypharyngodon mola* is a very rich source of vitamin A as compared to many other species (Fig.35.3).

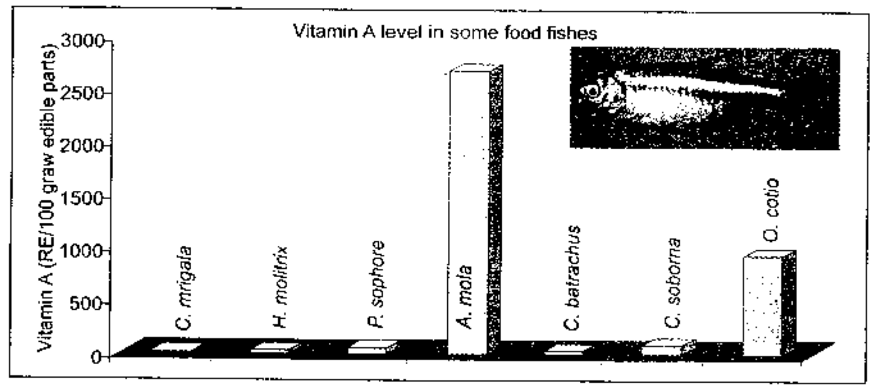


Fig 35.3. Vitamin A content in some food fishes. Mola (*Amblypharyngodon mola*, Cyprinidae) is a very rich source of vitamin A.

Vitamin D present in fish liver and oils is crucial for bone growth since it is essential for the absorption and metabolism of calcium. It also plays a role in immune function and may offer protection against cancer. Oily fish is the best food source of unfortified vitamin D. Vitamin D is not found in many foods and tends to be a vitamin that many vulnerable groups go short of, such as teenage girls and the elderly. Fish is also a good source of the B vitamins and can provide a useful contribution to the diet for this group of vitamins, as does red meat. The B group of vitamins is responsible for converting food to energy in the cells of the body and they help with the function of nerve tissue. If eaten fresh, fish also contains a little vitamin C which is important for proper healing of wounds, normal health of body tissues and aids in the absorption of iron in the human body.

Minerals: The minerals present in fish include iron, calcium, zinc, phosphorus, selenium and fluorine in general and iodine in particular in marine fish (Table 35.8). These minerals are highly bioavailable meaning that they are easily absorbed by the body. The nutritional significance of these minerals and their bio-availability is discussed below.

Table 35.8. Mineral content of some Indian food fish and shellfish (All values given are mg/100 g edible portion)

Common name	Scientific name	Na	K	Ca	Fe	P
Rohu	*Labeo rohita*	112.16	132.18	86.28	1.40	128.66
Catla	*Catla catla*	58.00	161.70	495.20	1.00	245.00
Mrigal	*Cirrhinus mrigala*	69.50	170.50	352.10	1.10	283.20
Common carp	*Cyprinus carpio*	34.36	121.28	30.32	2.55	268.20
Calbasu	*Labeo calbasu*	103.20	310.10	318.50	0.90	395.00
Singhi	*Heteropnevstes fossilis*	44.86	153.80	82.20	1.88	198.28
Channa	*Channa striatus*					
Grey mullet	*Mugil cephalus*	136.40	252.80	136.90	4.40	175.00
Mullet	*Rhinomugil corsula*	116.16	204.09	31.57	1.33	168.17
Pearl spot	*Etroplus suratensis*	126.90	296.70	315.30	1.80	251.00
Anchovy	*Stolephorus* spp.	170.12	243.00	48.00	0.86	165.09
Bombay duck	*Harpodon nehereus*	-	-	1390.00	19.00	235.00
White bait	*Anchoviella spp.*	-	-	679.00	3.50	475.00
Tuna	*Euthynnus affinis*	156.80	1,290.30	590.00	10.10	349.00
Oil sardine	*Sardinella longiceps*	88.12	196.22	68.28	1.24	118.12

Source: Biochemical Composition of Indian Food Fish. Gopakumar K (Ed.), CIFT (ICAR), Kochi and Data generated under ICAR Outreach Activity, Consortium #3: Nutrient Profiling of Fish.

Iron is important in the synthesis of hemoglobin in red blood cells which is important for transporting oxygen to all parts of the body. Iron deficiency is associated with anemia, impaired brain function and in infants is associated with poor learning ability and poor behavior. Due to its role in the immune system, its deficiency may also be associated with increased risk of infection. Compared to other animal sources, although fish contain less iron than the amount found in red meat, iron in white fish is well absorbed and so is a useful source of iron. However, on a weight for weight basis, shellfish contains as much iron as lean meat.

Calcium is required for strong bones (formation and mineralization) and for the normal functioning of muscles and the nervous system. It is also important in the blood clotting process. The intake of calcium, phosphorus and fluorine is higher when small fish are eaten with their bones rather than when the fish bones are discarded. Deficiency of calcium may be associated with rickets in young children and osteomalacia (softening of bones) in adults and older people. Fluorine is also important for strong bones and teeth.

Zinc is required for most body processes as it occurs together with proteins in essential enzymes required for metabolism. Zinc plays an important role in growth and development as well as in the proper functioning of the immune system and for a healthy skin. It also has a role in cell division, cell growth, wound healing and the breakdown of carbohydrates and is needed for the senses of smell and taste. Zinc deficiency is associated with poor growth, skin problems and loss of hair among other problems. High-protein foods like meat and fish contain the highest amount of zinc, and it is easily absorbed from these sources. Oysters provide more zinc than any other food. Other types of oily fish and seafood such as skate, anchovies, herring, sardines, crab, prawns, shrimps, mussels, and winkles also provide a significant amount of zinc.

Iodine, present in seafood, is important for hormones that regulate body metabolism and in children it is required for growth and normal mental development. A deficiency of iodine may lead to goiter (enlarged thyroid gland) and mental retardation in children (cretinism). Fish is one of the few reliable sources of iodine. The UK recommended intake of iodine for adults is 140 mcg a day and a 100g portion of some fish can provide all the requirement of iodine for the day.

For selenium, fish is a particularly good source. In UK, the recommended intake for selenium is 75 mcg a day for men and 60 mcg a day for women and a 100g portion of baked cod could provide 34 mcg of selenium, which is roughly half the daily recommended intake. Selenium is a component of some of the enzymes which protect the body against damage due to oxidation (free radical damage). It is also necessary for the use of iodine in thyroid hormone production and for immune system function. Low levels of selenium intake may be associated with the increased risk of some cancers. It is evident that fish contribute more to people's diets than just the high quality protein they are so well known for. Fish should therefore be an integral component of the diet, preventing malnutrition by making these macro- and micro-nutrients readily available to the body.

Nutritional status and growth pattern of urban infants in relation to birth weight

Malnutrition continues to be a serious public health problem throughout the developing world, particularly in sub-Saharan Africa and southern Asia, including India. It has been well documented that the survival of infants and their postnatal growth and development are largely dependent on birth weight. Since underweight is considered as a composite indicator to reflect both acute and chronic under-nutrition, it has been suggested that under-nutrition is a function of both deprivation and disease, which are in turn the consequence of poverty.

The prevalence of low birth weight in children is still unacceptably high for India. The nutritional status of infants is closely related to the maternal nutritional status during pregnancy and infancy. In India 30% of all the infants born are low birth weight babies (weight less than 2,500 g). An ICMR study reported that the average birth weight ranged between 2.5 and 2 kg and the prevalence of low birth weight ranged between 26 and 57% in the urban slums and 35 to 41 % in the rural communities. This is a matter of concern since 90 % of the deaths occur among infants with birth weight below 2,000 g. Low birth weight was found to be connected with several factors such as age of the mother, maternal weight, weight gain during pregnancy, interpregnancy interval, hemoglobin (< 8 g), illiteracy.

There are immediate and delayed consequences of low birth weight. These include: (*a*) high morbidity and infant mortality- prenatal mortality (still birth and death within the first week of birth) is 6-10 times higher in infants born with low birth weight; (*b*) slower growth rate- stunting. The functional consequences of stunting are not fully understood, but persistent malnutrition can result in impaired physical and mental performance. Fetal care and maternal health are linked and therefore, specialists in maternal-fetal medicine (MFM) always give emphasis on maternal health and nutrition to prevent LBW and other complications.

Fetal origin of adult diseases: Low birth weight (LBW) has been consistently shown to be associated with coronary heart disease (CHD) and its biological risk factors. The effects of low birth weight are increased by slow infant growth and rapid weight gain in childhood. The combination of small size at birth and during infancy, followed by accelerated weight gain from age 3 to 11 years, predicts large differences in the cumulative incidence of CHD, type II diabetes and hypertension. Studies indicate that CHD and type II diabetes may originate through two widespread biological phenomena–developmental plasticity and compensatory growth. Epidemiological surveys conducted in fishermen communities have shown that professional fishermen in coastal areas do not face LBW problem and are bestowed with the health benefit owing to consumption of marine fishes and other low value, trash fishes as leftover of catch.

Existing dietary guidelines: Human resource is one of the vital strengths of any stronger nation and nutrition plays a very important role in its development. A healthy population can lead the nation better in all the frontiers like education, economics, agriculture, defence, medical and such other developmental activities. Therefore, in all the countries depending on the nutritional status of the population and the availability of foods, *'Dietary Guidelines'* are formulated. The diet of an individual is what it eats, and is largely determined by the perceived palatability of foods. Actually a healthy diet is based on many other considerations like the calorific value of the diet and the actual calorific need of the individuals. Dietitians, the health professionals who specialize in human nutrition, meal planning, economics, preparation, are trained to provide safe, evidence-based dietary advice and management to individuals (in health and disease), as well as to institutions. The dietary guidelines enable the population to choose a healthy diet and lead a healthy life. A poor diet can have an injurious impact on health, causing deficiency diseases such as scurvy, beriberi, and kwashiorkor; health-threatening conditions like obesity and metabolic syndrome, and such common chronic systemic diseases as cardiovascular disease, diabetes, and osteoporosis. Many common health problems can be prevented or alleviated with a healthy diet.

Against this backdrop, the National Institute of Nutrition (NIN), working under the aegis of Indian Council of Medical Research (ICMR), had constituted a committee in 1998 and after thorough deliberations 14 dietary guidelines were formulated (http://www.ninindia.org/dietary%20guidelines_final.doc).

The Dietary Guidelines that was made available about a decade ago appears to be more generalized and do not specify any nutrients. There is no specific mention of any proteins, either plant or animal proteins, and among animal-proteins source of proteins and preference of animal proteins from different sources. Similarly, for fats and oils, there is no specific instruction for PUFAs and ω-3 and ω-6 PUFAs, their source and ratio in which they should be taken. Similarly, no specific guidelines have been mentioned for people with specific needs like cardiac care. As the present day public is more aware of health and diet and need specific health advisory, there is need to be more specific while formulating 'dietary guidelines' for different clienteles or consumer groups. The USDA Nutrient Data Laboratory provided guidelines for consumers on Fish consumption and cardio-vascular disease (CVD) (Table 35.9). It specifically advises on the amounts of EPA + DHA in fish and fish oils and the amount of fish consumption required to provide ~1g of EPA + DHA per day so that individuals with CVD and healthy subjects desirous of preventing this problem can select the fish in their diet. Therefore, there is the need to develop revised 'Dietary Guidelines' keeping the availability of food materials and specific need of different clientele groups in view.

Formulating a fish-based diet: The geographical location, seasons, ecosystems, management practices etc. are important factors that influence the growth, body composition and nutritive value of fish. Consumers have wide choice owing to

Table 35.9. Amounts of EPA + DHA in fish and fish oils and the amount of fish consumption required to provide ~1g of EPA + DHA / day

Fish	EPA + DHA content, g/3-oz* serving fish (edible portion) or g/g oil	Amount required to provide ~1 g of EPA + DHA per day, oz* (fish) or g (oil)
Tuna	0.26	12
Sardines	0.98-1.70	2-3
Mackerel	0.34-1.57	2-8.5
Herring	1.81	1.5
Salmon	1.48	2
Rainbow trout	0.98	3
Cod	0.24	12.5
Haddock	0.2	15
Catfish	0.15	20
Oyster	1.17	2.5
Lobster	0.07-0.41	7.5-42.5
Shrimp	0.27	11
Clam	0.24	12.5
Scallop	0.17	17.5
Crab	0.35	8.5
Capsules		
Cod liver oil	0.19	5
Standard fish body oil	0.30	3
Omega-3 fatty acid concentrate	0.50	2

Sources: Data from USDA Nutrient Data Laboratory, Kris-Etherton *et al.* Fish consumption and CVD. Circulation 2002 **106**: 2747-2757 1;*oz (ounce) = 28.35 g.

availability of many fish species from different habitats and culture systems and thus presumed to vary in their nutrient composition. However, the detailed nutrient profiles of many of the fish species available in India are scanty and scattered. Therefore, there is a need to generate and document information on proximate composition, detailed account of fatty acid and amino acid profile in majority of fishes, with respect to such variations. It is also necessary to find out the varieties of fishes consumed and their consumption rate by different sections of fish eating population. Such scientific information should be compiled to develop database which would help the scientists, scientific managers, dieticians, food manufacturing companies, policy makers to take decision on manufacturing and valuation of fish food products and also for consumer guidance. The information generated would help in formulating dietary guidelines for consumers.

This assumes significance in the context of availability of vast and varied fishery resources in the country, both marine and inland, and also the increasing health consciousness of public. This will also help in prioritization of species for commercial exploitation which would in turn provide information useful for effective marketing of fish, enabling proper prices for the fisherman, fish farmers and aquaculture industry people.

Fish is soft, easy to cook and more easily digested than meat so even young children can be fed with fish, contributing to improved nutrient intake. Fish can also be used as complementary foods especially in paste or powder form. Young children can benefit tremendously from the small fish which are excellent source of calcium and fluorine-elements crucial for the development of strong bones and teeth in the young. However, the challenge is to develop acceptable fishery products to use as complementary foods for young children.

India, like many other developing countries has not yet eliminated problems of under nutrition, especially among children of its poor communities. Low birth weight (LBW) is indicative of intra-uterine growth retardation and studies carried out in India and abroad suggest that children who suffer from such problems show substandard growth and development and are susceptible to obesity in adulthood. Studies carried out in India have shown that there are incidences of low birth weight (<2,500 g) deliveries among the poor. Combating low birth weight would be a valuable contribution towards reducing incidence of obesity and type II Diabetes mellitus in our population. Studies have shown that apart from correction of anemia, supplementation with foods rich in n-3 fatty acids could significantly reduce the low birth weight incidence. Studies carried out in Kerala have shown that 90% of the population of this state is fish eating; their consumption rate has been quite good, five times a week, 35 g each time on an average. The incidence of low birth weight in Kerala is less than half of that reported from rest of the country and child health in Kerala is far superior to that in the rest of the country. The role of n-3 fatty acids from marine fish on child health has long been reported. More such studies in different states across the country are necessary to strengthen the results from the Kerala-based study on child health, low birth weight and their correlations with fish consumption. It is also necessary to find out the fish availability, fish consumption rate and pattern in different sections of the society, especially in fisherman communities and coastal population to correlate the fish intake and low birth weight. Similarly, a survey on effect of fish consumption on human health like birth weight at different ages till three years and their blood picture especially hemoglobin content in pediatric population is necessary. Since low birth weight is a manifestation of mother's malnutrition status, pregnant mother's health is also required to be studied. This information generated will help the planners to devise strategies to combat some of the major child health problems, especially low birth weight, childhood asthma by dietary interventions through the government's major child health programs like: ICDS. Dietary guidelines can be made available to the public and nutritional superiority of fish as a health food can be reinforced scientifically so that more people opt for fish-based diet to defer the early onset or prevent nutritionally controllable diseases of the pediatric, adult and elderly population. This will also ensure that the fisheries sector can contribute to Millennium Development Goals (Goal 4- Reducing child mortality by two-thirds by 2015, and Goal 5- Improved maternal health) since high malnutrition levels are associated with increased child mortality rates (The Millennium Development Goals (MDG), United Nations, 2009).

36. Fish Harvest Technology

Fish harvest technology encompasses various processes of catching aquatic organisms. Use of fishing methods varies, depending on the types of fisheries, and can range from simple techniques such as gathering of aquatic organisms by hand picking to highly sophisticated fish harvesting systems such as aimed midwater trawling or purse seining conducted from large fishing vessels. The targets of capture fisheries can range from small invertebrates to large tunas and whales.

The large diversity in capture fisheries and the wide distribution of targeted species necessitate a variety of fishing gears and methods for efficient harvest. These technologies have been developed around the world according to local traditions and have been influenced by technological advances in textile materials and various disciplines such as vessel design, hydrodynamics, acoustics and electronics. Filtering the water, luring and outwitting the prey and hunting are the basis for most of the fishing gears and methods used even today. Harvest technologies, as they are practiced today generally fall into three main groups: (*i*) catching fish singly or in schools by use of nets or spears, (*ii*) trapping fish in stationary gear such as fish traps or set nets, and (*iii*) attracting fish to get caught on hooks by use of bait, artificial lures or other means such as light. Half of the world's seafood is caught or otherwise collected by small-scale fishermen operating millions of fishing craft. Over the years, traditional fishing gears have been upgraded and newer more efficient fishing systems have been introduced. Most important among them are fish harvesting systems like trawls, seines, lines, gill nets and entangling nets and traps.

The last 50 years have seen rapid and major changes in the development of the fishing industry. The improvement and modernization of boats and fishing equipment have increased productivity and efficiency influencing the working conditions and lives of fishermen. Most significant among the technological developments which supported the evolution of fish harvest technology are (*i*) developments in craft technology and mechanization of propulsion, gear and catch handling; (*ii*) introduction of synthetic gear materials; (*iii*) developments in acoustic fish detection and satellite based remote sensing techniques; (*iv*) advances in electronic navigation and position fixing equipment; and (*v*) awareness of the need for responsible fishing to ensure sustainability of the resources, protection of the biodiversity and environmental safety and energy efficiency.

Many fishing vessels process the catch onboard and are equipped with fish finding equipment and sophisticated navigational aids. Small-scale fishing, especially in developed countries, has also undergone technological improvements in boat design and propulsion, navigation aids, fishing gear and methods and onboard preservation of the catch. Sophistication and availability of communication and safety equipment have improved considerably. Advances in satellite-based technologies such as global

positioning system (GPS) have positively influenced the precision in fishing, and Global Maritime Distress Safety System (GMDSS) based rescue systems have facilitated safety of fishermen, who undertake one of the most dangerous occupations in the world. The mechanization of gear handling has vastly expanded the scale on which fishing operations can take place.

Indian fishing industry

India has a long coastline of 8,118 km and an exclusive economic zone of 2.02 million km^2. Marine fish production of India which was only 0.5×10^6 tonnes in 1950, increased to 2.83×10^6 tonnes in 2009. Marine fishery potential of the Indian exclusive economic zone (EEZ) is estimated at about 3.934×10^6 tonnes. About 58 % of the resources is available at a depth of 0-50 m, 35% at 50-200 m and 7 % from beyond 200 m depth. The present catch of 2.8×10^6 tonnes forms about 72% of the estimated fishery potential and is largely derived from the intensively fished coastal zone up to 120 m. About 280,491 fishing crafts of various sizes and classes are under operation to exploit this resource, consisting of 53,684 mechanized boats, 44,578 motorised crafts, 181,284 non-mechanized crafts. Mechanized fishing sector produces 64 % of the marine landings, followed by motorized sector (26%) and artisanal sector (9 %).

Synthetic gear materials

Major advances in fibre technology, along with the introduction of modern gear materials, have directly influenced and brought about important changes in the design, dimensions and method of handling fishing gears. Introduction of synthetic fibres during the 1920s opened a new era in the field of fishing gear development. The vegetable fibres which were till then extensively used, consisted mainly of cellulose and were attacked by cellulose consuming bacteria during immersion in water hence were prone to decay and deterioration. The disadvantage with vegetable fibres is their short useful lifetime. This was overcome by the introduction of synthetics, which are practically rot-proof. In recent times, synthetic fibres have by and large replaced natural fibres in the fishing industry. Synthetic fibres are known by the type of polymer.

i. Polyamide (PA) fibres are manufactured in two different types, PA 66 and PA 6. In India only PA 6 is produced for fishing net purposes in the trade name Nylon.
ii. Polyester fibres are manufactured from polycondensation of terephthalic acid and the alcohol, ethylene glycol compounds. The trade name is Terylene.
iii. Polyethylene is an additive polymer of the monomer ethylene, which is normally obtained by cracking petroleum.
iv. Polypropylene is the additive polymer of propylene obtained in the same way.

Not all synthetics are represented in the Indian fishing industry. PA is available as multifilament yarns and twisted netting yarns of different sizes and also as single yarn monofilaments of different sizes. Polyethylene is available as twisted monofilament and braided monofilaments of different sizes. Polypropylene as multifilament twisted netting yarns of sizes equivalent to nylon are also available. The latest introductions of high performance synthetic twines such as Dynema which has very high breaking strength, and high modulus and Olivene MK3 and Sapphire which have better breaking strength, high knot strength, high abrasion resistance, less mud penetration and round and compact construction, could be used especially in trawl nets for drag reduction.

Fish harvesting systems

Fish harvesting system include the components of fishing vessel and fishing gear. The term fishery vessel is used to denote the mobile floating objects of any kind and size operating in fresh, brackish and marine water areas, used for catching, transporting, landing, preserving and processing of fish, shellfish and other aquatic animals. There are vessels performing other functions related to fisheries such as supply vessels and research vessels, these are termed as non-fishing vessel. The basic criterion used for the classification of fishery vessels is the gear used for catching fish or other aquatic organisms. The characteristics used to distinguish the various types and classes of fishing vessels are the general arrangement and deck layout, position of the bridge or wheelhouse, the fishing equipment used and the method of fish preservation and processing used in the vessel. The vast majority of the world's fishing vessels are under 25 Gross Registered Tonnage (GRT).

Classification of fish harvesting system

Fishing gears are either passive or active; active fishing systems are generally energy intensive and more productive than passive gears. Based on the degree of selectivity, the fishing gears are more selective like gill nets, hook and line and traps or less selective like trawls, seines and entangling nets.

Depending on the sector in which they are used, there are small-scale or artisanal fishing gears covering a wide variety of traditional low energy systems of fish capture, and large-scale industrial mechanized fishing systems including purse seining, trawling and automated long lining. Based on the water-bodies in which they are used there are inland fishing gears, including riverine, estuarine and reservoir gears, and marine fishing gears. Based on the area of operation, there are coastal, offshore and deep-sea fishing gears and depending on the fishing position in the water column, there are pelagic, midwater and demersal or bottom fishing gears. Classification of fishing gear is mostly based on the principles of fish capture, historical development and structural differences. In the International Standard Statistical System of Classification adopted by FAO for fishery statistics (FAO.1982. Food and Agriculture Organization, Rome), fishing gears are grouped into 14 categories according to principles of capture, and sub-grouped according to structure of the fishing gear, leaving scope for further additions in future, as below:

i. Surrounding nets
ii. Seine nets
iii. Trawls
iv. Dredges
v. Lift nets
vi. Falling gear

vii. Gill nets and entangling nets
viii. Traps
ix. Hooks and lines
x. Grappling and wounding gears
xi. Harvesting machines
xii. Miscellaneous gear
xiii. Recreational gear
xiv. Gear not known or not specified.

Trawling

Trawlers use trawls as fishing gear and are provided with engines of sufficient power to tow the net at the appropriate trawling speed. These are fitted with trawl winches and equipment necessary to haul the net onboard and lift the cod end over the deck. Depending on the area of operation and the trawl used trawlers range in size from traditional canoes fitted with inboard motors (mini-trawlers) up to large freezer trawlers and factory trawlers. Trawling may be conducted by a single boat or by using two boats (pair trawling or bull trawling).

Side trawlers: In side-trawling, the trawl is set on the side of the vessel and the warps pass through blocks hanging from two gallows, one forward and one aft. Usually the superstructure and wheelhouse are placed aft, the fish hold is situated amidships and the trawl winch transversally at the front of the superstructure. When the vessel is not trawling, the otter boards are stored between the gallows and the bulwark. With the advent of stern trawling, side trawling has gone into obsolescence.

Stern trawlers: In stern trawling, warps are led from the trawl winch through various lead blocks to the after deck and over the stern. The wheelhouse or bridge is usually situated in the forward part of the vessel. Medium sized and large stern trawlers are often fitted with a stern ramp, on which the trawl is hauled on to the deck. In small vessels a stern roller is used to reduce friction when shooting and hauling up the trawl. The trawl winch is placed transversely usually behind the wheelhouse. The fish hold is situated amidships in small trawlers and in the forward part in medium sized and large stern trawlers. The majority of small trawlers and some medium sized trawlers are not equipped with refrigeration facilities but many of them have insulated fish holds and carry ice-top reserve fish. Otter boards are used by the trawlers for facilitating the mouth opening of the trawl nets, during single boat trawling.

Freezer trawlers: Freezer trawlers have facilities for on-board freezing and preservation of the catch.

Factory trawlers: These are generally large stern trawlers equipped with processing plants with freezing facilities and fish oil, fish meal plants and sometimes canning plants. Separate holds are provided for each of the products.

Trawls: A trawl is a bag-shaped net that is dragged behind a boat. It has a big mouth at the front and tapers back to a narrow cod end. Different types of trawl nets are used to fish in the mid-water (mid-water trawling) and along the sea floor (bottom trawling). Trawling though a very efficient gear system, suffers from poor selectivity.

Table 36.1. Trawl designs developed by the CIFT

Long wing trawl

Specially designed trawl for shrimp trawling with low vertical opening and extra long wings on either side to facilitate sweeping of wider horizontal area along the sea bed. Shrimp catches increases by 45%, compared to conventional shrimp trawls. Designs: 17.0 m and 32.0 m long wing trawls.

Bulged belly trawl

It has relatively high vertical opening compared to conventional shrimp trawl, to improve the catch of finfishes by about 30% without compromising on shrimp catching abilities. Designs: 17.0 m, 20.0 m, 25.0 m, 32.0 m bulged belly trawls.

High opening trawl

In vertical opening of the trawl is increased by innovative design improvements, facilitating capture of demersal as well as off-bottom resources. Designs: 17.0 m, 25.0 m and 32.0 m six seam and 25.0 m eight panel high opening trawls.

Large mesh trawl

Relatively large meshes are incorporated in the front trawl resulting in significant reduction in trawl resistance, making use of the herding effect of large meshes on fin fishes. The reduced drag permits greater trawling speed and/or operation of a larger trawl with the available installed engine power. Designs: 25.0 m, 32.0 and 40.0 m large mesh trawls.

Rope trawl

In rope trawl, the front trawl sections are replaced by ropes which as in the case of large mesh demersal trawl, results in reduction of trawl resistance. Fin fishes are retained due to the herding effect of ropes. The reduced drag permits greater trawling speed and/or operation of a larger trawl with the available installed engine power. Designs: 35.0 m rope trawl.

Semi-pelagic trawls

These facilitate trawling for off bottom resources; can be used from both small and medium class trawlers.

Midwater trawls

It is mainly used to harvest the column dwelling fishes and squids. This harvesting system has potential for harvesting shoaling pelagic fish, but is still to be developed on commercial scale in India.

Trawls for deep sea operations

High speed demersal trawl (HSDT)

Deep sea trawls developed for commercial harvesting of fast swimming, low density demersal resources in the depth range of 50 - 500 m depth, in the Indian EEZ. Designs: 41.0 m HSDT-I, 38.0 m HSDT-II and 38.25 m HSDT-III.

Bobbin trawl

Two-panel deep sea demersal trawl suitable for operation in the rough bottom conditions, in Indian EEZ. Design: 32.0 m Bobbin trawl.

Hybrid trawl

Multi-purpose hybrid trawl for demersal cephalopod and finfish resources. Design: 38.0 m multi-purpose hybrid trawl.

High opening trawl

Two-panel trawl with high vertical opening suitable for harvesting demersal and off bottom resources. Design: 50.0 m high opening trawl.

Low-drag, energy saving trawls for semi-pelagic resources

Large mesh semi-pelagic trawls

Trawls incorporating large meshes for reducing drag and fuel consumption, for harvesting semi-pelagic resources. Design: 33.7 m large mesh semi-pelagic trawl.

Mini-trawl for traditional motorized crafts

A mini-trawl for operation from traditional crafts powered by outboard motors of 8-15 HP, for shallow water shrimp trawling. Design: 12.8 m mini-trawl.

Bottom trawls are the most popularly used trawl nets which target prawns, cephalopods and demersal finfish resources. A variety of shrimp trawl nets are used all over the country and the mesh size of the trawl nets generally ranges from 50 mm in the forepart of the net to 18-20 mm in the codend. A multi-day trawler may carry about 10 numbers of nets on board for one cruise. Small trawlers undertake daily fishing while larger trawlers undertake multi-day fishing. The Central Institute of Fisheries Technology (CIFT) has introduced several trawl designs, over the years for demersal, semi-pelagic and midwater trawling (Table 36.1).

Purse-seining

A purse-seine is a surrounding net having a line at the bottom passing through rings attached to the net, which can be drawn or pursed. The two-boat system is the oldest system of purse-seining and was first developed on the east coast of the USA. In this system, two small boats are carried in davits on a large vessel and on reaching the ground these are lowered. Each boat carries half of the purse-seine net. The boats move in opposite direction, encircle the shoal and again come together. The net is then hauled and the catch is brailed or pumped in.

In the one-boat system net is carried onboard the bigger vessel. A small auxiliary boat called the skiff is released with one end of the net on sighting the shoal. The seiner then quickly surrounds the shoal and as it reaches the skiff purses the net and hauls it sufficiently enough to brail the fish. The size of a purse seiner, depends on the distance to the fishery ground, expected catch, availability of a vessel for transportation of catch etc. Based on the deck arrangements, two main types of one boat purse-seiners can be distinguished, viz. (*i*) North American type and (*ii*) European type. The North American types of seiner have the bridge and accommodation placed forward. The power block is slung from a derrick attached to the mast behind the wheelhouse. The winch is usually fitted to the parallel drums and is situated opposite the pursing gallows. The net is carried at the stern of the vessel. In the European type purse seiners, the bridge and accommodation are located aft. The fish hold is situated amidships. The net is carried on the upper deck and power block is fitted to the side of the bridge. The pursing winch is normally situated forward with the drums facing the pursing davit.

The equipment on board a purse-seiner are power block, hydraulic system for hoisting the boats, fish pumps, etc. Usually purse seiners have on board equipment for fish detection and large fish holds. A brailer attached to a derrick is provided for removing fish collected in the purse. Sometimes a pump is lowered into the pursed seine and the fish is pumped through a hose and a water separator on deck into the hold. To assist in fish school detection crow's nest is fitted on masts.

Small purse-seiners operated in traditional fisheries of India are known as ring seiners.

Tuna purse seiners: The tuna purse seiners generally have the North American type deck layout and are equipped to handle very large and heavily constructed tuna purse-seines. They are equipped with a skiff and the deck equipment consists of a three-drum purse seine winch. A crow's nest is placed at the top of the mast. In large tuna purse-seiners, the search for tuna schools is often carried out by a helicopter, for which a landing platform would be provided.

Seine netters: In seine netting, the fishing area is surrounded by a net attached to very long ropes and the net is towed or dragged over the bottom. Seines, which are operated from the boat, are called boat seines. Boat seines are similar to light high opening bottom trawl but they use long length of seine rope spread out on the sea bed on each side of the net. Danish seine is a well-known boat seine, is operated on the bottom from a single boat, and consists of a bag and wings attached to long ropes set in water so as to cover a large area in order to herd the fishes therein into the net mouth. In Danish seining, an anchor which is buoyed is used to winch the first rope, at the beginning of the operation. In Scottish seining, an anchor is not used, instead a combination of winch and propeller is used to simultaneously pull and close the gear. Seines operated from the shore are called shore seines or beach seines. An example is *Rampani* net operated in Karnataka coast of India.

Purse-seines: Purse-seines are used for catching pelagic shoaling fishes such as anchovies, sardines, mackerel, herring, Pollock, pilchard and capelin and tuna. These are the predominant types of surrounding nets, in which the bottom of the net is closed after encircling the fish school, by a purse line which prevent fish from escaping downwards by diving. The last part of the net to come aboard is called the bunt, and this is where the fish is concentrated prior to transfer to the vessel. Purse-seining is done either with one or two vessels. Based on the target species there are anchovy purse-seine, sardine purse-seine, mackerel purse-seine, cod purse-seine and tuna purse-seine. Based on the scale of operations there are small, medium and large purse-seines. Mini-purse seines or ring seines are small purse-seines operated from traditional canoes (*thangu vallom*) or similar crafts powered by outboard or inboard motors and are used in coastal waters of south-west cost of India for efficient harvesting of pelagic shoaling fishes such as anchovies, sardines, mackerels and inshore tunas. Medium size purse-seines are also operated in the small-scale mechanized purse seiners, along the west coast.

Gill netting

Gill nets are simple gears operated from boats and canoes in inland and inshore waters, from decked small vessels in coastal waters and from medium size vessels in offshore and deep waters. Small gill-netters have their wheelhouse either aft or forward. In medium size vessels the bridge is usually located aft. In small gillnetters, setting and hauling operations are done by hand, while in larger vessels, hydraulic net haulers or net drums are used.

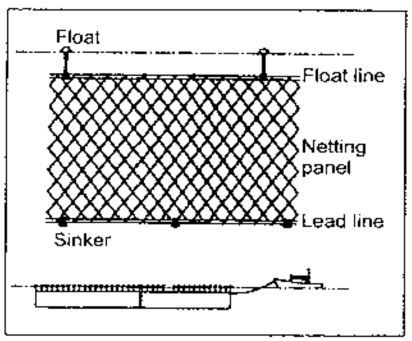


Fig. 36.1. Gill net.

Gill nets are long walls of netting that are kept erect by means of floats and sinkers and positioned in the swimming layer of the target fish (Fig. 36.1). Gillnets appear almost invisible underwater. The gill nets are designed so that the mesh size are just big enough for the head of the fish, so that when the fish startle and try to backout their gills become trapped in the net. Depending on method of operation gill nets are classified into drift gill nets, set gill nets and encircling gill nets. Drift gill nets are operated in the surface layers and drifted with the current either separately or with the boat. Set gill nets or anchored gill nets are fixed to the bottom or at a distance above bottom by means of anchors or ballast. Fixed gill nets operated in the shallow coastal waters are fixed by means of stakes and the catch is collected during low tide. Encircling gill nets are operated in the surface layers in coastal areas. After encircling the fish, noise and other vibrations are used to drive the fish towards the net so that they are either gilled or entangled. Entangling nets are loosely hung single or multi-walled netting of small mesh size, which catch fish entangling rather than enmeshing

Based on the structure, there are simple gill nets with a single wall of netting, trammel nets with two or three walls of netting and combination nets which has simple gill net in the upper portion and multi-walled trammel net in the lower part. Triple-walled trammel net has a loosely hung small-meshed panel between two large meshed panels, which are relatively tightly hung. The inner wall when it intercepts a fish passing through the large mesh on the outer wall forms a pouch in which the fish is trapped and retained. Nylon multifilament was popular material for gill nets both in inland and marine sector, which is now replaced by nylon monofilament gill nets. Central Institute of Fisheries Technology has developed gill nets optimized for catching marine fishes such as sardine, mackerel, Spanish mackerel, pomfret and hilsa, and for freshwater fishes, in terms of material and mesh size.

Trap fishing

Trap setters: Trap setters are used for serial operation of pots for catching lobsters, crabs, crayfish and other similar species. Trap setters range from open boats or large decked vessels. In open or partly open vessels the wheelhouse is placed forward. In small-decked pot vessels the wheelhouse is located either forward or aft and fish hold amidship. Larger pot vessels are equipped with derricks, cranes or darts for setting and hauling of pots. On smaller vessels mechanized pot haulers are fitted. Inshore pot vessels are often designed for relatively high speed because better prices are obtained for fresh catch. In India, mechanized vessels equipped with pot haulers are not prevalent.

Traps are passive fishing gears with enclosures to which the fish are lured or guided and from which escape is made difficult by means of labyrinths or retarding devices like funnels or constrictions (Fig. 36.2). A wide range of traditional fishing gears is grouped here. Traps or pots are basically baited cages dropped down to the sea floor. The traps are baited to attract the catch and then left to soak. For commercial fishing these are usually set on the bottom singly or in series connected by ropes and position marked by buoys. Traps are usually used for fishing bottom dwelling species like crab, shrimp, lobsters and fishes like perch. Pots are made from materials like wood,

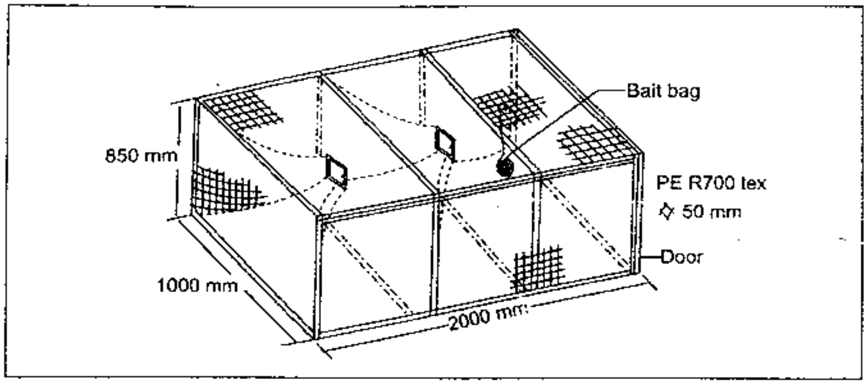


Fig. 36.2 A trap for perches.

wicker, metal rods, wire netting or reinforced plastic, designed to catch fish, crustaceans or cephalopods by enticing them with baits or shelter spaces. These are provided with one or more entrances of appropriate gape

Stationary uncovered pound net: Stationary uncovered pound net called set nets in Japan, are large nets, anchored or fixed on stakes. A leader net is kept at an appropriate angle to the swimming direction of migrating fish schools so as to guide them to enclosures with retarding devices and closed at the bottom by netting.

Fyke nets and stow nets: Fyke nets are used in shallow waters consists of a cone-shaped bag of netting with ring shaped rigid structures to maintain cylindrical shape of the net body and is provided with wings to lead the fishes into the bag. The fyke nets are fixed to the bottom by stakes or ballast and are operated separately or in series. Stow net are conical bag net operated in shallow waters and estuaries where tidal currents are strong. The mouth of the net is kept open against the current by means of stakes driven to the bottom or by means of floats and ballast.

Barriers, fences, weirs and corrals: Barriers, fences, weirs and corrals are trapping enclosures made of indigenous materials and operated in tidal waters.

Aerial traps: Aerial traps are systems in which fish like mullets, which jump out of water on disturbance and flying fishes, attracted by light are caught in floating enclosures or rafts. Verandah net and boat operated aerial traps are examples in this category.

Improved and durable lobster trap and crab pot: The Central Institute of Fisheries Technology (CIFT) Kochi, has developed and improved a durable lobster traps as substitute for traditional traps of short life span and low efficiency, for harvesting of spiny lobster of 700 mm × 550 mm × 400 mm size. It has mild steel rod frame mounted with 25 mm square welded mesh with plastic coating for corrosion protection. Crab pots have been developed for catching crabs in live and undamaged condition.

Lining

Lines are passive fishing gear widely used in both traditional and modern fishing. In its simplest form, line fishing basically consists of a line and a hook. They are operated either singly or in large numbers. Fishes are enticed by edible bait or lure and are finally held by the hook concealed in the bait or lure.

Important types of hook and lines are hand lines operated in the small-scale and recreational fishing and long lines where a large number of hooks are attached to the mainline by means of branch lines. Long lines when set in surface and midwater with freedom to drift with the current are called drifting long lines; when set close to the bottom are called bottom-set long lines; when set vertically, they are called vertical long lines; when combining the properties of bottom and vertical long lines they are called bottom vertical long lines.

Handliners: Hand lining is one of the oldest and most basic forms of fishing. At its simplest, the technique consists of just a line, weight, and baited hook or lure. They are operated from boats, canoes and other small vessels. Hand lines can be set and hauled either manually or by mechanized reel fastened to the gunwale. This is one of the most mobile and compact of all means of fishing, due to the minimal amount of equipment needed. It is particularly suitable for fishing grounds with rocky bottom.

Longliners: Long lines (Fig. 36.3) can be operated from vessels of any size. In a typical arrangement the lines are set over the stern and hauled from the bow or from the side with a mechanical or hydraulic line hauler. The wheelhouse can be situated either aft or forward, but on larger vessels the bridge is generally placed aft. Automatic and semi-automatic systems are used in bigger boats to bait the hooks and to set and haul the lines.

Tuna long lines are usually operated from medium sized vessels. The line hauler is placed on the starboard side. A conveyor, to the aft deck ready for baiting and setting, then carries the long lines and the buoys. A baiting table and chute are located on the stern from where the lines are set. Typical equipment of a tuna longliner includes brine freezing tanks for preserving the catch.

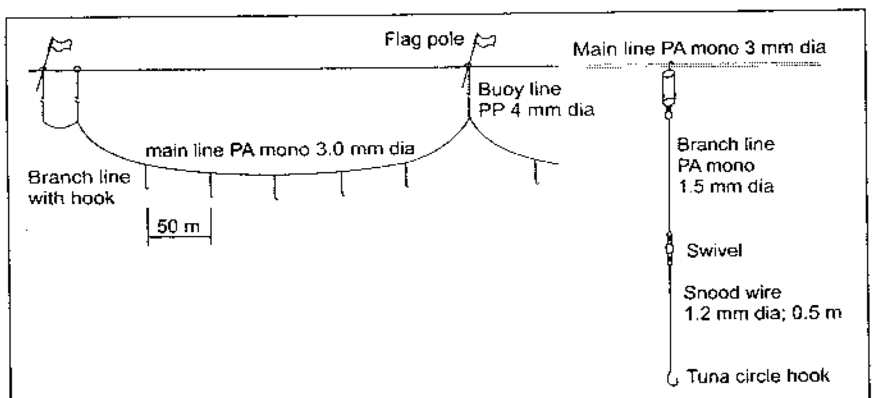


Fig. 36.3.Tuna long line.

Long lines for sharks and tuna using indigenous and imported hooks are very popular in India. Central Institute of Fisheries Technology has developed improved long lines for shark fishing.

Pole and line vessels: These vessels are used for catching skipjack and other tuna. Tanks with live bait and a water spray system for fish attraction are typical features of these vessels. Therefore this type of fishing is also called live bait fishing. In Japanese type pole and line vessels the fishermen stand at the railing on the forward part of the vessel and bridge is accommodated aft. The holds are placed in the middle part of the vessel. In American type of pole and line vessels, the platform for fishermen are located around the stern of the vessel with bait tanks on the deck aft and wheelhouse situated forward. Pole and line fishing is extensively practiced in Lakshadweep Islands for tuna fishing.

Troll lines: In trolling, baited hooks or lures are towed behind a boat (Fig. 36.4) and fish are pulled aboard when caught. This method is designed to target fast moving surface swimming fish such as tuna, marlin and kingfish. Troll lines for predatory fishes such as Spanish mackerel and barracuda, using buffalo horn, stainless steel, spoon and fish head jigs are popular.

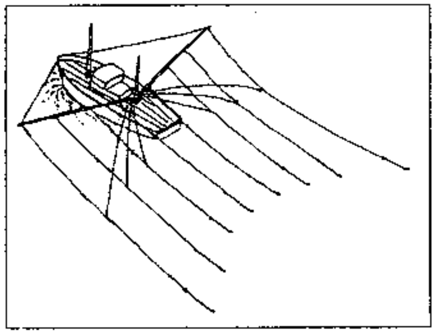


Fig.36.4. Trolling

Trolling is a widely used fishing method for predatory species such as tuna, barracuda, sailfish, Spanish mackerel, dolphin fish and many other oceanic species. Often, lures and baits are trolled at controlled speeds and depths using specific techniques, depending on the species being sought. In most cases, artificial lures are used in the sea, though live or cut bait can be effective for certain species or fishing conditions.

Jigging: Jigging is the setting of a line, with baited hooks or lures that is continually jerked. The motion achieved by hand or with a jigging machine, induces fish to take the hook, mistaking it for prey organism. Jigging is used to catch squid and cod (Fig. 36.5).

Inland fish harvesting systems

The inland fishery resources of India are rich and varied, comprising an extensive network of rivers (45,000 km), canals (126,334 km), reservoirs (3.12 million ha), estuaries (1.44 million ha), brackishwaters (1. 24 million ha), oxbow lakes and derelict water-bodies (1.3 million ha) and of ponds and tanks (2.41 million ha), having estimated catch of 4.6×10^6 tonnes at present out of which 3.5×10^6 is from aquaculture, contributed mainly by carps and prawns in freshwater and shrimps in brackishwater and 1.1×10^6 is from capture resources contributed by all available groups from small sized minor carps to big size cat fishes.

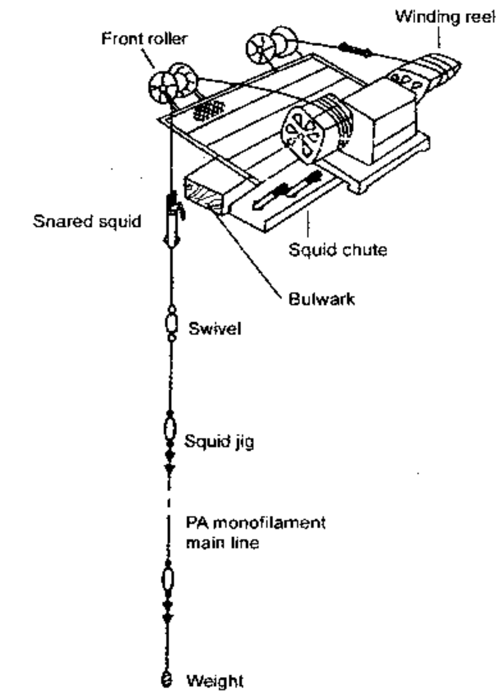


Fig. 36.5. Automatic squid jigging machine.

Inland fishing craft

Inland fishing craft of India, plying in backwaters, rivers, reservoirs and tanks are diverse ranging from small rafts to plank built boats. As inland waters are shallow and protected and fishing grounds are nearer to landing centers fishing craft deployed in inland waters are light and small with shallow draft, compared to marine fishing crafts. Most prevalent craft used in the inland sector are rafts, dug out canoes and flat bottom and round bottom plank built canoes. Coracles are the dominant crafts in south Indian reservoirs. The coracle consists of very large wide mouthed circular flat-bottomed basket. A hide is stretched outside and firmly tied to exclude the water. It is about 3.6 m in diameter. All types of fishing gears including gill nets, shore seines and long lines can be operated from this raft but more commonly used for gill net operations. Manned by 2 fishermen, 4 to 5 gillnets are operated from each coracle. These coracles are more conspicuous in Tungabhadra (Karnataka), Mettur (Tamil Nadu) and Nagarjunasagar (Andhra Pradesh) reservoirs.

Inflated rubber tubes of motor vehicles are used for fishing in Hussainsagar reservoir of Andhra Pradesh and reservoirs of Bilwara district of Rajasthan State and in many of the river systems in Odisha and in upper stretches of river Ganga and Yamuna. Catamarans used in inland sector is also made of logs tied together by rope as a raft on which the fishermen fish. A log catamaran locally known as *teppa* is used in the reservoirs of Nizamsagar and Hussain sagar of Andhra Pradesh. They are also in use in Mettur reservoir and backwaters of Tamil Nadu. The catamarans of backwaters are made of old logs discarded by marine fishermen and are used extensively by cast net fishermen.

Inland fishing gear

A variety of fishing gears are prevalent in the inland sector depending on the targeted species, area of fishing and fish availability. Fishing without gear is the simplest and oldest method of fishing. In this method, fishes or aquatic animals are caught by hand as in the case of collection of shell fish from rocky areas, collection of crabs from the holes or collection of fish and prawns by hand in shallow waters. Some times fishes are caught by grappling and wounding implements. Single or multi-pronged spears, bows and arrows and blowpipes used to catch fishes, belong to this category. Fishing with dynamite or poison is banned in all parts of world as well in India. However, their use is prevalent in certain hill streams and reservoirs, in India.

Gill nets: Gill nets are the most important gear in the inland sector. Gill nets are operated either as drift or set. Encircling gill nets and small meshed entangling gill nets are common in inland water bodies.

Lines: Hand lining is widely practiced in inland fishing, including recreational fishing. The other types are set lines with several hooks set in a fixed position and drift lines.

Traps and barriers: Fish traps are extensively used in all inland water bodies to catch fish. Tubular traps are long tubes without valves so that fish can enter on their own will but cannot retreat (Fig. 36.6). Traps providing spaces are used to lure the fish. Barriers like walls, fences and gratings are used to trap the fish. Trap nets are large uncovered gears fixed on sticks or anchors, set or floating with retarding devices. Aerial traps take advantage of the habit of the fish, which jump out of water when disturbed.

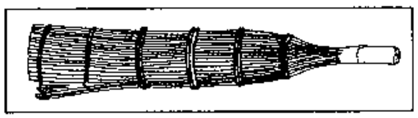


Fig. 36.6. Tubular trap.

Bag nets: Bag nets are fixed nets with totally or partially framed mouth kept open by force of water. Scoop nets are variously shaped small bag nets operated by hand. Skimming nets used in the river systems of India are triangular nets with two cross-shaped mobile or fixed rods to keep the net open. Push nets are triangular or semi-circular frame pushed by hand wading in water or operated from boats by handle. Dragged scoop nets are bag nets with rectangular frames dragged by a fisher wading through water. Stake nets used in the backwaters of Kerala are fixed conical bags, which are operated by the tidal flow to filter prawns and fishes. Similar type of nets with gaping wings is used in the rivers and backwaters of West Bengal.

Trawl nets: Sleep nets operated in the rivers of Asom are bag nets dragged through the water. Mechanized trawling has been experimentally tried in the Hirakud and Ukai reservoirs, particularly for eradication of predators and weed fishes.

Seine nets: Seine nets are prevalent in rivers and reservoirs. These nets surround certain area and tow the gear over that area with both ends fixed to a point. The nets with two sticks attached to the wings are used to encircle certain area where there is potential for fish. Large nets are operated near the beaches by pulling both ends to a beach, after encircling.

Drive in nets: In drive-in-nets, fishes are captured by driving them into the stationary gear.

Lift nets: In lift nets, fishes are captured by lifting the net after formation of fish concentration over it. Lift nets are either operated by hand with long poles or mechanically, when they are of larger size. The classical example of lift nets is the Chinese dip nets popular in Cochin backwaters.

Falling gear: A ubiquitous type of gear in inland, estuarine and coastal waters is the falling gear for capturing fish by covering from above. Cover pots or plunge baskets of wicker construction are clapped over the fishes. Cover pots of wicker construction with opening on the top are common in Rajastan, West Bengal and Odisha.

Cast nets are circular nets thrown over the water with skill. These are operated either from boats or from the shore/coast of any water body. The former mode is practiced commonly in rivers, reservoirs and lakes of Jammu and Kashmir, Haryana and Punjab.

Clap nets: Purse shaped clap net is operated in the rivers of West Bengal for the capture of migratory hilsa. Clap nets or purse nets have special significance in construction and operation, though they are basically traps.

Responsible fish harvesting systems

Continuous improvement in the efficiency of fish harvesting systems has considerably increased landings and the earnings of fishers. However unbridled expansion of fishing capacity and negative impacts of non-selective fishing systems have led to increasing pressure on the fish stocks. Effects of overfishing have underlined the need for scientific management to ensure sustainability of the resources. The emphasis of much of the recent technical innovation has been focused on greater selectivity of fishing gear and on gear with less impact on the environment, which is in sharp contrast to the focus in the past aimed to increase production.

Exploitation of the fishery resources needs to be controlled at such a level, which would ensure long-term sustainability, protect the biodiversity and ensure environmental safety. Interventions in terms of regulation of fishing capacity, promotion of selective, ecofriendly and energy efficient fishing systems are the need of the hour. The key principles of responsible fishing include (*i*) management of stocks using the best available science; (*ii*) application of the precautionary principle using conservative management approaches when the effects of fishing practices are uncertain; (*iii*) avoiding overfishing and preventing or eliminating excess fishing capacity; (*iv*) minimization of bycatch and discards; (*v*) prohibition of destructive fishing methods; (*vi*) restoration of depleted fish stocks; (*vii*) implementation of appropriate national laws, management plans, and means of enforcement; (*viii*) monitoring the effects of fishing on the ecosystem; (*ix*) working cooperatively with other states to coordinate management policies and enforcement actions; (*x*) recognizing the importance of artisanal and small-scale fisheries, and the value of traditional management practices. Focused research to develop–fish harvesting systems that are selective, energy-saving, with minimum consequences on non-target and protected species and fisheries environment, and optimizing their capacity based on the carrying capacity of the ecosystem–is required to address these issues effectively.

37. Fish Processing Technology

Annual growth of the Indian marine products industry is showing a downward trend off late. The industry still remains mainly shrimp oriented because it is more lucrative. Even though export of fish is high the value realization is less compared to shrimp. India exports mainly whole fish and shell fish, which is processed into several high value products in the importing countries and are again exported at a very high price. It is noticed that the catches from the capture fisheries are on the decline. Hence it is necessary to conserve the harvested catch judiciously and to increase the production through culture to meet the growing demand for fish.

Value-addition and introduction of new types of products from low cost fishes is the only solution to the problem. Present market trends reflect a rapidly growing demand for ready-to-cook and ready-to-serve convenience products. Value-addition can increase considerably the unit value of fish products. To attain this it is necessary to adopt modern technologies in processing of value-added fish products. The modern technologies can assure food safety by adopting modern quality requirements through Hyzards analysis and critical control points (HACCP) and ISO 9000 series. The increased demand for fish has prompted the development of many new preservation techniques which can be adopted by the fish processing industry without sacrificing safety, quality, shelf-life and consumer satisfaction. The recent developments have improved techniques in handling, product development, packaging, preservation and storage. Brief description of development in those areas is discussed here.

Chilled storage

Chilled storage in different containers has been used in the case of fish and fish products for a long time. Modified atmosphere packaging (MAP) or controlled atmosphere storage by the application of CO_2 at concentrations ranging from 50-100% to fresh fish in chilled condition is a recent introduction which substantially increases the shelf life.

In MAP fish/fish products are packed in an atmosphere of carbon dioxide and other gases like oxygen and nitrogen. The modified atmosphere retards the growth of microorganism and reduces the rancidity in fatty fishes. Hence MAP chilled fish has an extended shelf life of 10 days or more depending on the species. The Central Institute of Fisheries Technology has standardized the optimum concentration of various gases in MAP for different products to get maximum shelf life and retention of quality. The concentration of carbon dioxide varies from 40 to 80%. Studies on *Catla catla* fillets, whole pearl spot, dressed pearl spot, seer fish steaks etc. gave encouraging results. The threat of botulism, due to the presence of non-proteolytic psychrotrophic *Clostridium botulinum* types B, E and F has been reason for caution in expanding this technology. The MAP can be effective if used in conjunction with packaging materials of correct O_2/CO_2 permeability characteristics. Properties required may not be found in one polymer, hence laminated films are used.

Active packaging changes the condition of the package to extend the shelf life or to improve the safety while maintaining quality of the foods. The condition of food is regulated in numerous manners through the application of appropriate active packaging systems. There are two types of active packaging systems, viz. scavenging systems (absorbers) and releasing systems (emitters). Scavenging systems remove undesirable compounds such as oxygen, excessive water, ethylene, carbon dioxide, taints and other specific food compounds. Releasing systems actively add compounds to the packaged food such as carbon dioxide, water, antioxidants or preservatives. Most important active packaging concepts include: O_2 and ethylene scavenging, CO_2-scavengers and emitters, moisture regulators, anti-microbial packaging, antioxidant release, release or adsorption of flavours and odours.

The commercial use of atmosphere modifiers and oxygen scavengers in particular, with fish products has been mostly limited to the Japanese market and to dried seaweed, salmon jerkey, sardines, shark's fin, rose mackerel, cod, squid or smoked salmon products. These ambient stored products have low water activity (less than 0.85) and so the microbial deterioration is not shelf-life limiting. Here the oxygen scavengers prevent oxidative reactions, discolouration and inhibit mould growth. Other commercial products stored in active packages are fresh yellow-tail, salmon roe, and sea urchin. They are stored at superchilling conditions. Here the oxygen scavenger primarily prevent oxidation and discolouration and inhibit bacterial growth to a lesser degree. Different oxygen scavengers are chosen dependent on the amount of oxygen to scavenge (pack size and material) and water activity of the product. Oxygen scavengers for high water activity foods react faster compared to scavengers for dry foods but in general the absorption is slow and exothermic. The use of oxygen absorbers (ageless SS-100) had only a marginal effect on microbial growth in packages of fish products compared to effect obtained by MAP.

In MAP combined with active packaging partial vacuum is created in the package as a result of dissolution of CO_2 into the product and removal of O_2 using O_2 scavengers. In such cases, simultaneous release of CO_2 from inserted sachets is desirable. Such systems are based on either ferrous carbonate or a mixture of ascorbic acid and sodium bicarbonate. The commercial CO_2 emitters usually contain ferrous carbonate and a metal halide catalyst although non ferrous variants are available, absorbing the oxygen and producing equal volumes of carbon dioxide. Carbon dioxide could also be produced inside the packages after packaging by allowing the exudates from the product to react with a mixture of sodium carbonate and citric acid inside the drip pad, an approach used successfully for fish fillets. Studies conducted using salmon fillets with soluble gas stabilization technique with combined oxygen absorber and carbon dioxide emitter (ageless G-100) indicated slow microbial growth compared with those stored in air without absorbers. A techniqe developed at the CIFT indicated significant improvement in the shelf-life of catfish (*Pangasius sutchi*) steaks, seer fish (*Scomberomorus commerson*) steaks and dressed oil sardine (*Sardinella longiceps*) in active packaging systems compared to the corresponding air packed samples.

Freezing preservation

Freezing is the most satisfactory method for long-term preservation of fish products. The advancements in the freezing of fish products are mainly in the technological aspects of freezing and also in the introduction of newer frozen products. The freezing time has reduced considerably by the advancement of newer freezing system. The freezing time in plate freezers have been reduced to more than half by the introduction of double contact plate freezers. Semi-automatic and automatic horizontal plate freezers have also been introduced. For freezing unpackaged fish products rotary drum types of freezers are available.

For IQF (individually quick frozen) products spiral freezers and fluidized bed freezers replaced the conventional tunnel freezers. These freezing systems considerably reduce the space occupied by the freezers and also freezing time. Very efficient and effective cryogenic freezing systems are also developed. Another innovation in freezing is the pressure assisted freezing.

In this system freezing occurs due to the pressure induced melting point depression, which enables water to remain in liquid phase at higher pressures. The melting point of ice is lowered to –22°C at a pressure of 207.5 MPa (MegaPascal). Release of pressure enables rapid and uniform nucleation of water in a food product leading to freezing. This type of freezing produces smaller ice crystals rather than stress inducing ice front moving through the sample.

Curing and drying

Cured and dried fish represents fish products with low water activity. The water activity of fish products is reduced by drying, salting or salting and drying. The conventional method of drying is exposing fish with or without salting to sun by spreading over the sand (Fig. 37.1). Since this causes heavy contamination many a times, modifications have been made in sun drying itself to reduce contamination. Constrain of space and enhance drying rate and quality of product. Solar tent drying, drying on platforms or rack are the results of such attempts. These modified methods improve quality substantially.

The Central Institute of Fisheries Technology (CIFT), Kochi, has developed solar fish drier having capacity ranging from 10-1,000 kg with alternate backup system. The solar drier operates on eco-friendly technology. Water is heated with the help of solar vacuum tube collectors installed on the roof and circulated through heat exchangers provided in the poly urethine farm (PUF), insulated stainless steel drying chamber loaded with fish. When solar radiation is not sufficient during cloudy/rainy days, LPG back up heating system will be automatically actuated to supplement the heat requirement. Thus continuous drying is possible to obtain a good quality dried product.

Some of the solar dryers developed in the country are not having any back up

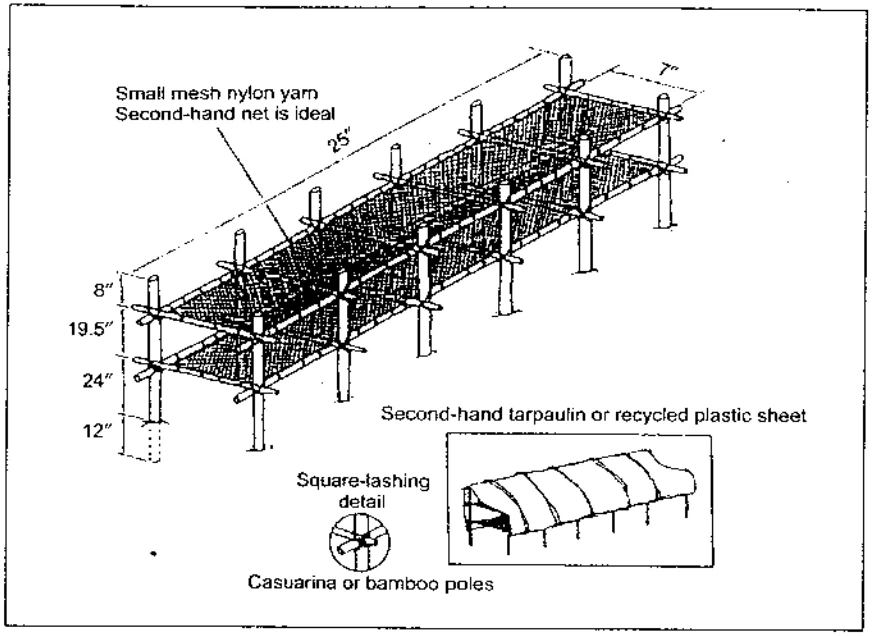


Fig. 37.1. A model rack drier.

heating system. These types of dryers cannot be used in adverse weather conditions. Mechanical driers have been developed to overcome this. When the quantity of fish to be dried is small or seasonal, batch driers are used. Kiln drier and cabinet or tray driers represent the important types of batch drying equipment. The modification in the batch type driers is the continuous hot air driers. They are operated by passing the material on a conveyor belt with co-current or counter current hot air flow. Other important types of driers are rotary driers, drum driers and osmotic driers. These dryers are used in drying of fish products, but hydrolyzed products can be dried using these.

Freeze-dried products

Freeze-dried fish products are prepared by freezing the product and subliming the ice under low pressure. In this type of drying the structural changes are minimum and flavour is retained to the maximum. There are different types of freeze dryers. Some of the important types are tray freeze dryer, continuous belt freeze drier, continuous circular plate freeze drier and fluidized bed freeze driers. Some of the process modifications include improved heat transfer using some vibrations and beds of alternate product layer and desiccant layer.

Extruded products

Extrusion is a process which combines shear, pressure and temperature leading to

molecular transformations in the constituents and involves denaturation of the proteins, fragmentation of the starch molecules and changes in the non-covalent bonds between proteins, lipids and carbohydrate. Fish-based extruded products have very good marketing potential. Formulation of appropriate types of products using fish mince, starches etc, attractive packaging for the products and market studies are needed for the popularization of such products. Extrusion is a multivariable unit operation in which a variety of raw materials undergo a number of operations, i.e. mixing, shearing, cooking, puffing and drying in an energy-efficient rapid continuous process.

The thermo-mechanical action during extrusion brings about gelatinization of starch, denaturation of protein and inactivation of enzymes, microbes and many anti-nutritional factors in a shear environment, resulting into a plasticized continuous mass which comes out through restriction called die. The quality of an extruded product determines its success or failure. So it is very much important to understand which extrusion processing parameters and ingredients interactions during processing influence product quality. Extrusion processing variables that directly control product quality attributes are called independent variables and dependent variables are those which are changed as a result of any change made to independent variables. Work carried out at the CIFT indicates that extruded product containing rice flour, bengal gram flour and fish at a temperature of 140°C with a moisture content of 17%, screw speed of 380 rpm gives the best result with good expansion ratio, low shear strength and colour.

The advantages of extrusion process are:

- The process is thermodynamically most efficient.
- High temperature short time enables destruction of bacteria and anti-nutritional factors.
- One step cooking process thereby minimizing wastage.
- Destruction of fat hydrolyzing enzymes during extrusion cooking.

Ready-to-eat fish-kure

The CIFT has standardized the production of extruded products by incorporating fish mince with cereal flours. One such popular combination is the minced *Nemipterus japonicus*, rice flour and Bengal gram flour. The product obtained is finally coated with *Chaat masala* to provide a mouth-watering snack that has been christened as fish kure. The raw material in the form of powder at ambient temperature is fed into the extruder at a known feeding rate. The material gets compacted and then softens and gelatinizes and melts to form a plasticized material, which flows down the extruder channel. The gelatinized material is then forced out through a set of dies to the desired form and shape. Extruded products like noodles, wafers, flakes, etc. from vegetable sources are well established in the consumer market. Extruded products with fish are yet to gain popularity.

Smoked products

Smoking of fish products like curing is a very old method of preservation. In addition to preservation, smoke imparts a particular flavour to the product. In addition to imparting a typical colour and depositing antimicrobial components, the smoking deposits carcinogenic compounds like polyaromatic hydrocarbons. Important among them is 3,4 benzopyrene. In coventional smoke kiln the control depositing solid particles and benzopyrene is very difficult. Modern sophisticated smoke kilns have the facilities to control or minimize to the acceptable level all the above factors.

Radiation preservation

Use of ionized radiation for the preservation of food is a novel concept and is a truly peaceful use of atomic energy. Irradiation of fish helps in disinfestation of stored dried fish and extending the shelf life of fresh fish by acting on the spoilage organisms. Many of the pathogenic bacteria like *Salmonella* and *Listeria* also can be destroyed at relatively lower radiation doses. Irradiation can be employed to bring about complete sterilization of the product, or for elimination of the pathogens and reduction in the viable organisms to improve the shelf-life. The second option however, will not bring about sterility in the product. Sterilization will require higher process of radiation and will bring about several unsavoury changes in the food. At lower doses, irradiation will only pasteurize the food and hence it is necessary to hold the food at lower temperature to prevent the remaining microorganisms from multiplying and spoiling the food.

Shelf-life extension of fresh fish and shell fish by gamma irradiation: Radurization of fresh fish (pasteurization of chilled fish) at 1 to 3 kGy (dose in kilo Gray, kGy, required for 90% of inactivation of initial population; one Gray is equivalent to 100 rads; one rad is equivalent to absorption of 100 ergs of energy per g) reduces initial microbial loads by 1 to 3-log cycle and extends their chilled storage life 2-3 fold. Studies showed that irradiation of food at an overall average dose of 10 kGy produces no adverse effect and the treated foods are toxicologically safe for consumption.

Sanitization of frozen fish by gamma irradiation: Frozen fish products, harbour several cold-tolerant spoilage and pathogenic microorganisms. Radicidation (sanitization of fresh and frozen products including fish mince by elimination of non-spore forming pathogenic bacteria) of frozen fish products at a dose of 4 to 6 kGy can eliminate non-spore forming pathogenic bacteria such as *Salmonella*, *Vibrio* and other species. The treatment, however, is limited in its ability to eliminate viruses and *Clostridium botulinum* type E spores.

Disinfestation of dried fishery products: A major problem of sun-dried fish stored in tropical countries is infestation by flesh flies, beetles and mites. Irradiation at doses in the range of 0.1 to 1.0 kGy can prevent development of beetle larvae and adults in packaged, salted and dried fishery products. Disinfestation studies of dried mackerel showed that eggs, larval and pupal stages of hide beetles *Dermestes maculates* could be inactivated at a dose of 0.2 kGy.

Several countries have accorded clearance for irradiation of various food items following the observation of the WHO and the International Atomic Energy Agency in 1980 that any food irradiated up to an overall average dose of 10 kGy does not pose any toxicological problem.

Labeling

Labeling laws differ from country to country. In the US as in many other countries labeling regulations require the usage of the Radura symbol (Fig. 37.2) at the point of sale together with usage of the word 'irradiated' or 'treated by irradiation'. However, the meaning of the label is not consistent. The amount of irradiation used can vary and since there are no published standards, the amount of pathogens affected by irradiation can be variable as well. In addition, there are no regulations regarding the levels of pathogen reduction that must be achieved. Food that is processed as an ingredient by a restaurant or food processor is exempted from the labeling requirement.

Fig. 36.2. Radura symbol.

Battered and breaded products

Battered and breaded products packed in consumer packs after freezing are sold through supermarkets as ready-to-fry items. Such products find good acceptance in fast food outlets. Fish and prawn cutlets also can be classified under battered and breaded products. A large number of coated products both for export and internal market based on shrimp, lobster, squid, cuttlefish, bivalves, certain species of fish and minced fish have been identified. The technology for their production is readily available. These products offer a convenient food valued widely by the consumer. Battering and breading enhance food product's appearance and organoleptic characteristics in addition to improving its nutritional value. Coating acts as a moisture barrier, minimizing moisture losses during frozen storage and microwave re-heating. The most important function of coating is value-addition by increasing the bulk of the substrate thereby reducing the cost element of the finished product.

There are several ingredients used in the formulation of coatings. The commonly used ingredients are polysaccharides, proteins, fats, seasonings and water. Besides small quantities of leavening agents, gums, spices, colour etc. may be added to provide specific functional effects. Most coated products are now available with a three-way cook option. These can be baked in a conventional oven, prepared under the grill or fried. The hunt is now on for coatings, which are suitable for use in a microwave oven. The production of battered and breaded fish products involves several stages. The method varies with the type of products and pickup desired. In most cases it involves portioning/forming, pre-dusting, battering, breading, pre-frying, freezing, packaging and cold storage.

Application of batter: Batter can be applied to a product using the battering and breading machine. Conventional batters are of low to medium viscosity and hence can be applied with total submersion or overflow batter applicators. Low viscosity batters are normally applied in an overflow configuration. Medium viscosity batters may require a total submersion system depending on the product requirements. The pre-dusted product is conveyed to the batter applicator and transferred to the next conveyor, which will draw it through the batter. The fish portion is totally submersed in the batter as it is drawn through it. Other applicators may use a pour-on application in addition to the submersion method. Irregular shaped products should be placed on the line with any concave surface upward to prevent air pockets from inhibiting batter pickup. Line speed is a very critical factor affecting batter pickup. An excessively fast line speed will reduce the batter pickup. Too low a line speed also can result in excessive batter adherence. Excess batter, if carried over to the breading section, will cause formation of lumps and this can cause blockages in the breading machine. This will also cause formation of shoulders and tails on the edges of the product and contaminate subsequent breading application. Therefore, to overcome the problems the excess batter is removed by blowing air over the product. The position of the air blower should be as close to the product as possible to control the airflow across the product. Carry-over from the pre-dusting operation also is critical. Where pre-dust is carried over, the viscosity of subsequent batter will increase leading to an increase in pickup.

Application of breadings: There are many types of breading applicators available and the appropriate machine depends on the ingredients used. The speed of the breading machine is so adjusted to closely match the belt speed of the batter applicator. For soft products the crumb depth should be maintained as thin as possible to avoid product damage when leaving the breading machine; however, frozen or hard products should have a deep bed of crumbs. Pressure rollers are used to apply sufficient force to press crumbs onto the battered product. Japanese style crumbs with their low bulk density and larger granule sizes make the crumb pickup difficult by the normal batter systems. Special batter formulations, sometimes containing raising agents, may have to be used at medium viscosity for a desired level of pickup of crumbs. Specially designed breading machines are used to apply uniform particle size distribution or granulation to both top and bottom of the product with minimum crumb breakdown. Air blowers are used to remove excess crumb from the product after breading. Excess crumb carried into the fryer can cause unsightly black specks on the product. Filters are used to remove small particles from the oil to prevent this phenomenon.

Pre-frying or flash frying: After coating with batter/bread crumbs many products are often flash fried prior to freezing. The purpose of pre-frying is primarily to set the batter/bread coating on the fish portion. Flash frying develops a characteristic crust and gives the product a characteristic fried (oily) appearance and taste. Therefore the temperature of frying oil and the time of frying are critical. The normal frying temperature is between 180 and 200°C and the frying time 20-30 seconds.

Freezing: Quick and efficient freezing method is very essential to keep the quality of the coated product. The fried fish portion for freezing is first air cooled and then fed to the freezer through conveyor belts. Freezing is usually carried out in spiral freezers. Freezing is completed when the internal and external temperature of the fish portion drop to about –10°C.

Packing and storage

The coated product may undergo desiccation, discolouration and become rancid

during storage. Use of proper packaging can prevent/retard these changes and enhance shelf life. Thermoformed containers are most commonly used for packing coated products. The packaged products are usually stored at –20°C. Some of the important coated fish and fishery products are fish fingers, fish portions, various shrimp based products, squid products, clam and other related products, fish fillets, mince based products such as fish cutlets, burgers, fish balls, imitation products and crab claw balls.

Individually quick frozen products (IQF): Radical changes have taken place in the freezing system of fish and fishery products over the years. An important improvement in freezing prawns is the shift from the conventional block frozen to the individually quick frozen products. With the advent and spread of aquaculture of shrimp, individual quick-freezing has become very popular. Farmed prawn offers the advantage of harvesting at a predetermined time and hence can be frozen in the freshest possible condition. Because of this, most of the farmed prawn is frozen as whole IQF. Lobster, squid, cuttlefish, different varieties of finfish etc. are also processed in the individually quick frozen style. IQF products fetch better price than conventional block frozen products. However, for the production of IQF products raw-materials of very high quality need to be used, as also the processing has to be carried out under strict hygienic conditions. The products have to be packed in attractive moisture-proof containers and stored at –30°C or below without fluctuation in storage temperature. Thermoform moulded trays have become accepted containers for IQF products in western countries. Utmost care is needed during the transportation of IQF products, as rise in temperature may cause surface melting of the individual pieces causing them to stick together forming lumps. Desiccation leading to weight loss and surface dehydration is another serious problem met with during storage of IQF products.

Some of the IQF products in demand are prawn in different forms such as whole, peeled and de-veined, cooked, headless shell-on, butterfly fan tail and round tail-on, whole cooked lobster, lobster tails, lobster meat, cuttlefish fillets, squid tubes, squid rings, boiled clam meat and skinless and boneless fillets of white lean fish. IQF products can be easily marketed as consumer packs.

Most of the speciality products from shrimp are frozen as IQF. Some speciality products from shrimp are stretched shrimp or Nobashi, barbeque, skewered shrimp, head on centre peeled and cooked shrimp. All these are frozen as IQF and packed in thermoformed trays under vacuum and then frozen stored.

Fish mince and mince-based products

Minced fish is the meat separated from lean whole fleshed fish in comminuted form free of bones and skin etc. Flesh can be separated from filleting waste also. Minced fish can be used as a base material for the preparation of a number of products of good demand. The properties of minced fish to a large extent are determined by the nature and quality of raw material. Meat-bone separators of different types are available for the preparation of minced fish. Minced fish is used for the preparation of products like fish sausage, cakes, cutlets, burgers, balls, pastes, surimi and texturised products etc. The processes for the production of most of these products are available and some of them are very much suitable for starting small scale industries. Fish mince from marine as well as freshwater fish can be used for processing a variety of coated products such as fish cutlets, burgers, balls etc.

Fish cutlet: Cooked fish mince is mixed with cooked potato, fried onion, spices and other optional ingredients. This mass is then formed into the desired shape, each weighing approximately 30 g. The formed cutlets are battered and breaded.

Fish burgers: More or less similar to fish cutlets, burgers are made using mince of lean white fish and are only mildly flavored. Cooked mince is mixed with cooked potato and mild spices and formed into burgers using forming machine. Burgers are battered, breaded and flash-fried before packing and freezing.

Fish balls: Fish balls are generally prepared from mince of low cost fish. Balls can be prepared by different ways. The simplest method is by mixing the fish mince with starch, salt and spices. This mix is then made into balls, cooked in boiling 1 % brine. The cooked balls are then battered and breaded.

Crab claw balls: Swimming legs of crab may be used for this purpose. Crab claws are severed from the body, washed in chilled portable water and the shell removed using a cracker. The leg meat is removed and mixed with 2% starch based binder and this is stuffed on the exposed end of the claw. Alternatively the body meat mixed with the binder also can be used for stuffing. The stuffed claw is then frozen, battered and breaded and flash fried. The coated products are packed in thermoformed containers with built in cavities.

Surimi: Surimi is the myofibrillar protein concentrate produced by repeated washing of fish mince to remove water soluble nitrogenous matter and flavour compounds. Washing enhances the gel forming capacity of the structural proteins. Surimi is used as a raw material for the preparation of seafood analogues, but in Japan, surimi is mainly used to prepare the traditional Kamaboko products.

Surimi has high concentration of myofibrillar proteins, readily forms gel as a result of unfolding and cross linking of actomyosin. Gel formation occurs rapidly when surimi is heated at 80-90°C but also takes place slowly at 40-50°C and even at 0°C when held at overnight. Surimi paste that has initially been set at 40-50°C gives a stronger gel if subsequently heated to 80-90°C. This peculiar property has been used for the processing of a large number of products with varying functional properties.

Surimi-based products: Surimi is an intermediate product, which has characteristic gelling and elastic properties. It can be used to develop products that can imitate the appearance, flavour and texture of expensive items like lobster tail, shrimp, scallop, crab leg etc. It can also be used as a substitute for ground beef in certain foods.

Texturisation of surimi involves modification of elasticity with ingredients such as egg white, starch, polyphosphates etc. The flour is modified by the addition of salts and extracts of natural seafoods.

Following are the traditional surimi products of Japan.

Chikuwa	-	tube-shaped fish paste
Kamaboko	-	boiled fish paste
Satsumaage	-	fried fish paste product
Hampen	-	floating type boiled fish paste

Diversified traditional products like Kanikam (artificial crab leg), hampen, cheese sandwiched hampen, easy to eat kamaboko, Satsuma.age with hampen taste, squid surumi kamaboko are also being marketed in Japan

Fish sausage: Fish sausage is an analogue of sausage made from pork. The main ingredient is surimi or ground fish meat. The surimi is mixed with salt (3-4%), sugar (2-3%), sodium glutamate (0.3%) starch, and soy protein in a silent cutter. At the end of mixing. lard or shortening (5-10%), polyphosphate (0.2-0.3%) and flavourings are added and the minced meat is placed in a casing tube made from vinylidine chloride. Stuffing is done by an automatic screw stuffer. The casing tube is closed by metal rings. The tube is heated in hot water at 85-90°C for 40-60 min. After heating, it is cooled down slowly to avoid shrinking of the tube and then stored at refrigerated temperature.

Fibreized products: Fibreized products are the greatest in demand among the surimi based imitation shellfish products. The ingredients used in the formulation of fibreized products include, besides surimi, salt, starch, egg white, shellfish flavour, flavour enhancers and water. All the ingredients are thoroughly mixed and is ground to a paste. The paste is extruded in sheet on the conveyor belt and is heat treated using gas and steam for partial setting. A strip cutter subdivides the cooled sheet into strings and is passed through a rope corner. The rope is coloured and shaped. The final product is formed by steam cooking the coloured and shaped material.

Frozen fish dessert: The CIFT has developed a ready-to-eat and highly nutritious product containing deodorized fish protein christened as maricream. It is a mixture of water, cooked cuttlefish meat, sugar, butter, egg white, flavouring substances, stabilizers and emulsifiers. This mixture is whipped and pasteurized to form a rigid foamy substance and finally frozen at -20°C. Sweet aroma and flavour is provided by butter, vanilla essence and cooked deodorized cuttle fish. One important difference with other desserts is that protein component is provided from a marine source. Colour and odour of the cephalopods are favourably suited for maricream.

Frozen fish fillets: Skinless and skin on fillets from lean/medium fat, white meat, fish have enormous market potential. Many varieties of deep sea fishes such as grouper, red snapper, reef-code, breams and jewfish are suitable for making fillets both for domestic market and export to developed countries in block frozen and IQF forms. In the importing countries these fillets are mainly used for conversion into coated products. Fish fillets can also be used for the production of ready-to-serve value-added products such as fish in sauce and fish salads.

Chilled fish: Chilled fish is another important value-added item of international trade. The most prominent among this group is sashimi grade tuna. Sashimi is a Japanese term for raw fish fillets mainly from tuna and it is a traditional delicacy in Japan. Two species, blue fin and big eye are mainly used for this purpose. The best quality sashimi tuna is that which is chilled at all stages from capture to final consumption. Other important products of this group are pomfret, shrimp, lobster and crabmeat.

Thermal processing

Thermal processing (canning) involves several heating processes such as cooking, blanching, pasteurization and sterilization. The objective of thermal processing is to inactivate or destroy the microorganisms and the enzymes. At the same time, maximum retention of nutrients is also very important. In preliminary cooking and also in sterilization it is observed that high temperature and short time process favour nutrient retention without sacrificing the rate of destruction of microbial spores. The major problem is the retention of some of the heat resistant enzymes by this method.

The thermal processing equipment or retorts has undergone significant changes. The still retort is the oldest type of equipment used in sterilization or thermal processing. In conventional system the method consists of loading crates of containers into the retort, closing it and heating with steam. Improvement in the systems has centered on the mechanics of handling the containers. The recent development is the introduction of a crate less container handling system. Continuous retorts have distinct advantages over batch type retorts like greater production rate, lower labour cost and higher rate of heat transfer. At least four types of continuous retort systems that use steam as heat transfer medium are in use. Aseptic processing is another method of thermal processing but it is not very much applicable for fish products. Another area, which has undergone considerable transformation, is the development of new containers. Different types of materials are used now for making containers for canning. The main materials used are glass, tin plate, steel, aluminum and metal foils laminated with plastics. Cans made into different styles from metals like beaded cans, cemented side seam cans, two piece cans, drawn and wall ironed cans, drawn and redrawn cans and necked in cans are available. Easy open end cans and retortable pouches were recently introduced and have become very popular

Ready-to-serve fish products in retortable pouch

Ready-to-serve fish products, viz. curry products, in retortable pouches are a recent innovation in ready-to-serve fish products for local market. The most common retortable pouch consists of a 3 ply laminated material. Generally it is polyester/ aluminium/cast polypropylene. Some of the products standardized by the CIFT are mackerel curry, rohu curry, sardine curry, tuna curry, pomfret curry, prawn curry, seer fish moilee, pearl spot moilee, fried mussel, fish sausage, prawn kurma, prawn Manchurian, fried mussel and mussel masala. These products have a shelf life of more than one year at room temperature. As there is increasing demand in National and International market for ready-to-serve products the retort pouch technology will have a good future. Coated products and fish mince and mince-based products are also becoming popular now. Retort pouches which are made up polyester/ aluminium/cast polypropylene, the product cannot be seen. During recent years pouches made up of polyester coated with aluminium oxide or silicon dioxide/ nylon/cast polypropylene are available. In these type of pouches the product can be kept for a period of one year at room temperature.

High pressure processing of foods

High pressure processing (HPP) is a method of food processing where food is subjected to elevated pressures (up to 87,000 pounds per square inch or approximately 6,000 atmospheres), with or without the addition of heat, to achieve microbial inactivation or to alter the food attributes in order to achieve consumer-desired qualities. Pressure inactivates most vegetative bacteria at pressures above 60,000 pounds per square inch. The HPP retains food quality, maintains natural freshness, and extends microbiological shelf life. The process is also known as high hydrostatic pressure processing (HHP) and ultra high-pressure processing (UHP).

High pressure processing causes minimal changes in the fresh characteristics of foods by eliminating thermal degradation. Compared to thermal processing, HPP foods have fresher taste, better appearance, texture and nutrition. High pressure processing can be conducted at ambient or refrigerated temperatures, thereby eliminating thermally induced cooked off-flavors. The technology is especially beneficial for heat-sensitive products. Most processed foods today are heat treated to kill bacteria, which often diminishes product quality. High pressure processing provides an alternative means of killing bacteria without a loss of sensory quality and nutrients.

In a typical HPP process, the product is packaged in a flexible container (usually a pouch or plastic bottle) and is loaded into a high pressure chamber filled with a pressure-transmitting (hydraulic) fluid. The hydraulic fluid in the chamber is pressurized with a pump, and this pressure is transmitted through the package into the food itself. Pressure is applied for a specific time, usually 3 to 5 min. The processed product is removed and stored/distributed in the conventional manner. As the pressure is transmitted uniformly in all directions simultaneously, food retains its shape, even at extreme pressures; and because no heat is needed, the sensory characteristics of the food are retained without compromising microbial safety.

Like any other processing method, HPP cannot be universally applied to all types of foods. HPP can be used to process both liquid and solid foods. Foods with a high acid content are particularly good candidates for HPP technology. At present, HPP is being used in the United States, Europe, and Japan on a select variety of high-value foods. Some products that are commercially produced using HPP are cooked ready-to-eat meats, avocado products (guacamole), apple sauce, orange juice, and oysters

The HPP cannot yet be used to make shelf-stable versions of low-acid products such as vegetables, milk, or soups because of the inability of this process to destroy spores without added heat. However, it can be used to extend the refrigerated shelf-life of these products and to eliminate the risk of various food-borne pathogens such as *Escherichia coli*, *Salmonella* and *Listeria*. Another limitation is that the food must contain water and not have internal air pockets.

Application for fish preservation

The main benefits of HPP include inactivation of contaminant microorganisms, texturization of proteins, shucking of oysters and improved freezing and thawing operations. At high pressure, the refrigerated storage life of Atlantic cod was greatly extended. Studies showed that after 30 days fish held in non-frozen state at –3°C and 238 atmospheres were not significantly different from frozen controls held at atmospheric pressure at –25°C. It is widely accepted that conformational changes of protein by high pressure takes place which may be the reason for extension of shelf-life. In many surimi based fish products gelling is an important function and fish muscle protein paste forms a gel upon application of high hydrostatic pressure. So the application of high pressure helps to formulate a number of products with good functional properties. Carp could be preserved at –8 or –15°C under 170MPa for 50 days without significant changes in texture. Shelf-life of prawns can be extended up to 28 and 35 days in samples treated with 200 and 400 MPa, respectively, as compared to 7 days for air stored samples. Tilapia fillets subjected to 50-300 MPa for 12 hours had a high freshness index as compared to control. The total plate count of fillets decreased from 4.7 to 2.0 log cfu/g for the fillets stored at 200 MPa. High pressure induced blue whitting gels were having lower adhesiveness, higher water-holding capacity, and less yellowness than heat-induced gels. Combination of pressure and temperature produced more elastic gels, whereas gels made under high pressure at chilling temperature were much harder, more deformable, and more cohesive. Cod fish (*Gadus morhua*) treated with 400 MPa decreased the oxidative stability of lipids due to the release of metal ions from complexes. Myosin was denatured at 100-200 MPa whereas actin and most sarcoplasmic proteins were denatured at 300 MPa. Several proteinases survived treatment at 800 MPa, although the activity of neutral proteinases decreased at a pressure higher than 200 MPa. The texture of pressure-treated fish differed from that of both raw and cooked fish, being harder, chewier, and gummier than the cooked product. Oysters treated with 100 and 800 MPa for 10 min at 20°C revealed the treatment killed various pathogens that are commonly found in oysters. Protein and ash contents decreased with increasing treatment pressure, while moisture content increased. Oyster muscles get detached from the shells, as a result of shucking, but the recovered tissue has good shape and is more voluminous and juicy than that of untreated oysters. The pH increased following high-pressure treatment.

Pulse light preservation

Pulse light technology is an emerging non-thermal processing method and involves exposure of foods to short-duration pulses of intense broad spectrum light. It involves the use of intense and short-duration pulses of broad-spectrum white light, where each pulse, or flash, of light lasts a fraction of a second and the intensity of each flash is approximately 20,000 times the intensity of sunlight at sea level. The spectrum of light includes wavelengths in the ultraviolet to the near infrared region. Usually a wavelength distribution having 70% of the electromagnetic energy within the range of 170-2,600 nm is used. These high intensity flashes of light pulsed several times in a second can inactivate microorganisms on food surfaces with remarkable rapidity and effectiveness. The technology can also be used to sterilize packaging material too. The material to be treated is exposed to at least one pulse light having an energy density in the range of 0.01-50 J/cm^3 at the surface. The effectiveness of light pulse treatment depends on several factors such as intensity, treatment time, food temperature and type of microorganisms. Light pulses have the ability to inactivate enzymes in food as well. However at present, industrial implementation of light pulse technology for food has been rather slow, despite its potential to produce safe, nutritious and high quality foods. Studies conducted at McGill University, Canada show promise for pulsed light treatment for cold smoked vacuum packaged salmon to control *Listeria monocytogenes* and *C. botulinum A* and *E.*

Fishery by-products

A majority of marine fish landed has been caught as by-catch by shrimp trawlers. The low-priced miscellaneous fish are either mainly discarded in the sea or converted to fish meal or dried. In tropics 80% of the catch is contributed by small fish, and these are not subjected to ideal pre-process handling techniques like chilling and packaging as these fish do not get good price. However, being a valuable protein source they can be further processed into value-added products which can be produced on a cottage industry scale. These products are stable at ambient temperatures and its shelf-life is very high and can easily be transported. The following is a brief description of various products that can be produced from fish by-catch or from fish processing waste.

Fish meal: Fish meal is highly concentrated nutritious feed supplement consisting of high quality protein, minerals, vitamins of B group and other vitamins and other unknown growth factors. Fish meal is rich in essential amino acids. It is produced by cooking, pressing, drying and grinding the fish, by-catch fish, miscellaneous fish, filleting waste, waste from canneries and waste from various other processing operations. The composition of fish meal differs considerably due to the variations in the raw material used and the processing methods and conditions employed. Traditional fish meal production in India was from the sun-dried fish collected from various drying centres and the products were mainly used as manure. Better quality fish meal has been a prominent item of export from the very beginning of this industry. The BIS has brought out the specification for fish meal as livestock feed for facilitating proper quality control.The fish meal in general has 6-10% moisture, 50-57% protein, 5-10% fat, and 12-33% ash. Fish meal is manufactured by dry rendering process and wet rendering process. Dry rendering process has only limited capacity since it is batch operation. The advantage of this process is that the water soluble materials are released in the meat. Wet rendering process is applied to fatty fish or offal where simultaneous production of fish meal and fish body oil is envisaged.

Fish body oil: The main source of fish body oil in our country is oil sardine. A survey of the oil industry revealed that the extraction is done on a cottage scale in isolated places near the leading centres and is not well organized. The method of extraction followed is cooking the fish in iron vessels and pressing and separating the oil. Apart from sardine oil, fish body oil is also obtained from the fish meal plants operating in the country. In India oil sardine is a fishery which exhibited wide fluctuations from as low as 1% to as high as 32% of the total landings. The seasonal variation in oil content is predominant in Kerala and Karnataka coast. During the peak season fish has oil content of 17%. By the wet rendering process the fish will yield, on average 12% oil having analytical characteristics similar to other fish oils. Fatty acid composition of oil revealed that they contain high amounts of polyunsaturated fatty acids (PUFA). At present the medicinal values of fish oils are well known.

Fish liver oil: The therapeutic values of fish liver oil were discovered in 18^{th} century and fish liver oil became a common medicinal product especially for vitamin A and D. Cod, shark and haddock livers are the important sources of vitamin A and D. The weight of liver, fat content and presence of vitamins are dependent on factors like species, age, sex, nutritional status, stages of spawning, and area from where it is caught.

Fish liver usually contains 45-67% oil, while shark liver contains 60-75%. The process for separation of liver oil depends on the vitamin and oil content of the liver. Certain speices of shark contain oil with high hydrocarbon, viz. squalene content. Process has been developed for the separation of squalene by the CIFT. Squalene has great commercial applications in cosmetic and medicines.

Preservation and storage: Vitamin oils are stored in rust free, well washed and dried air tight drums. The head space should be kept minimum to avoid oxidation. It is advisable to fill head space with inert gas such as nitrogen. If properly processed and stored the oil will remain in satisfactory condition without the use of preservative. Small amounts of antioxidants like BHA, a tocopherol, BHT, NDGA can be used to preserve the oil for longer periods.

Fish silage: Fish silage is made from whole fish or parts of the fish to which no other material has been added other than acid and the liquefaction of the fish is brought about by enzymes present in the fish. The product is a stable liquid with a malty odour which has very good storage characteristics and contains all the water present in the original material. It is a simple process and it requires little capital equipment particularly if non oily fish are used. The use of oily fish requires oil separation. This involves expensive equipment and is suited to fairly large scale operation. Almost any species of fish can be used to make fish silage though cartilaginous species like shark and ray liquefy slowly. Fish waste, cuttle fish/squid waste can be used for the preparation of silage. The production of silage involves preferably organic acids like formic acid (35 kg/tonne) to preserve the fish and then allow the enzymes already present in the fish to liquefy the protein. When 3.5% formic acid is added to the fish the *p*H will be nearly 4. Mineral acids like sulphuric acid also can be used for this purpose. But in this case pH would be about 2.5, which requires neutralization before formulating feeds to the poultry or cattle. There is an alternate method of production of silage by fermentation. The fish is mixed with a carbohydrate source like molasses and lactic acid is produced in the system to reduce the *p*H by introducing a lactic acid producing bacteria like *Lactobacillus plantarium.*

Fish protein concentrate: Fish protein concentrate (FPC) is any stable fish preparation, intended for human consumption, in which the protein is more concentrated than in the original fish. The Food and Agriculture Organization of the United Nations defines three type of FPC.

Type A: A virtually odourless and tasteless powder having a maximum total fat content of 0.75%

Type B: A powder having no specific limits as to odour or flavour, but definitely having a fishy flavour and a maximum fat content of 3%.

Type C: Normal fish meal produced under satisfactory hygienic conditions. Canadian process, Viobin process and CIFT process are the important methods used for the preparation of fish protein concentrate. This product has not become very popular, because of the consumer dislike.

Fish hydrolysates: This is also liquefied fish product but it differs from silage. These are produced by a process employing commercially available proteolytic enzymes for hydrolyzing and isolating protein from fish waste. By selection of suitable enzymes and controlling the conditions the properties of the end product can be selected. Hydrolysates find application as milk replacer and food flavouring agents. Enzymes like papain, nicin, trypsin, bromelein, pancreatin are used for hydrolysis of fish protein. The dried product is deliquescent, so care should be taken to keep it in fine airtight bottles. It can be incorporated into beverages as a high energy drink for children and convalescent persons.

Fish maws and isinglass: Isinglass is produced from air bladder. In India air bladders of eel and catfishes are used. Isinglass dissolves readily in most dilute acids or alkalis, but is insoluble in alcohol. In hot water isinglass swells uniformly producing opalescent jelly with fibrous structure in contrast to gelatin. It is used as a clarifying agent for beverages wine, beer, vinegar etc. by enmeshing the suspended impurities in the fibrous structure of the swollen isinglass.

Shark fins: Shark fins are in great demand particularly among the Chinese, for making the ceremonial dish called shark fin soup. Dried shark fin is an item of export from India mostly to Singapore, Hong Kong and the United Kingdom. The commercial value of the fins depends on their colour, size, variety and quality. Depending on the quality and quantity of rays present in the fins they are broadly classified into two varieties, generally known as black and white. The black fins usually fetch a lower price than the white fins. Fins are generally marketed in dried form. The preparation of shark fin does not require any elaborate treatment, but care is needed in cutting, trimming and drying operations. Fins are cut from sharks of about 125 cm or more in length as soon as they are landed avoiding as much flesh as possible and are washed thoroughly in water after removing the adhering flesh. They are then dusted with salt in the ratio 1:10 (salt to fin), the cut portion being sprinkled liberally with salt. A little lime also is often sprinkled at the cut portion and the fins are set aside for 24 hours. They are then dried in sun after gently rinsing with clean water to remove solid salt and excess lime to a moisture content not more than 10%. The dry fins are graded according to the size and type of the fin. The BSI has laid down standard specification for dried shark fins.

Shark fin rays: The dried fins are further processed, for the rays. The process followed differs considerably from place to place and also depending on the quality and type of final product. The price of fin rays depends mainly on colour, length and thickness of individual strands, quantity of connective tissues and cartilage present, physical presentation etc. The product can be classified as semi-prepared skin off but otherwise retaining the shape, small individual strands made in the form of cake, individual strands, skin off but made into flaps by splitting at the middle along the cartilage. The process of extracting good quality shark fin rays is simple and can be adopted even in small fishing villages by the fishermen. Though both white and black varieties of fins contain rays the yield from the black variety is only about half of that from white varieties. There exists wide variation in the content of rays in the fins from different body parts, the caudal fins containing the least. There is good scope of developing the industry for producing more sophisticated product of high unit value for export.

Shark skin leather: Skins of aquatic organisms especially of shark, seal, porpoise, dolphin, skates and rays are suitable for conversion to leather particularly for manufacture of small novelties. The production process is essentially the same as that followed for making leather from animal hides. The principal constituent of leather is collagen.

Shark teeth: Shark teeth and bones have become an export commodity in recent years. The teeth have become an export commodity to countries like USA, UK, Canada and Australia. This is used as ornaments for ladies. Among the various species, tiger shark teeth are in greater demand due to its more attractive shape and size.

Shark bones: Shark bones are cleaned and processed for use as source of chondroitin sulphate, which are used for treatment of arthritis and colon cancer.

Squalene: Squalene, a highly unsaturated aliphatic hydrocarbon, is present in certain shark liver oils, mainly of the family Squalidae, cod and some vegetable oils like olive oil, wheat germ oil, rice bran oil. Chemically it is known as 2, 6, 10, 15, 19, 23, hexamethyl-2,6, 10, 14, 18, 22 tetracosahexaene having a molecular weight of 410.70. It is an isoprenoid compound containing six isoprene units. Liver of certain species of deep-sea sharks (*Centrophorus* sp.) are rich in squalene, which is being now used in cosmetics and medicine.

Pearl essence: A lustrous substance is present in the epidermal layer and on the scales of most pelagic fishes, such as sardine and mackerel. The lustrous effect is due to the presence of an organic compound, guanine, (2-amaino, 6-oxypurin) a constituent of cell membrane. The crystalline guanine can be extracted from the fish scales. The suspension of guanine crystals in a suitable solvent is called pearl essence. When the particles are deposited on the inside of hollow beads or outside of solid one, they produce an optical effect very similar to genuine pearls. There is good demand for the product in countries like Japan.

Utilization of prawn shell waste: The head and shell of prawn and other crustaceans form the major fishery waste. The waste contains a good percentage of protein and chitin other than minerals. The protein can be extracted along with the flavour bearing compounds and converted into shrimp extract having potential use as a natural flavouring material. Chitosan, a deacetylated chitin, is one of such products, which has application in many fields. It is a modified natural carbohydrate polymer. It is a cationic polyelectrolyte, insoluble in water, organic solvents and alkaline solutions

and is soluble in most organic acids, and dilute mineral acids except sulphuric acid. It can form ionic bonds and films. Chitosan finds applications in many industries.

Chitin is the product obtained from prawn shell waste by alkali and treatment to remove protein and minerals respectively. The conditions of treatment determine the quality of chitin.

Glucosamine hydrochloride: Chitin can be hydrolysed to glucosamine hydrochloride by adding concentrated hydrochloric acid and warming until the solution no longer gives opalescence and diluting with water. The excess acid can be distilled off under vacuum. The crude glucosamine hydrochloride is diluted with water and clarified with activated charcoal. The solution is filtered and evaporated under vacuum. The crude glucosamine hydrochloride can be separated by adding alcohol.

Chitosan: Chitin is deacetylated by heating at 90-95°C with 40% (W/W) caustic soda for 90-120 min. The water present in the chitin cake should also be taken into account while preparing caustic soda solution. To achieve this 50% caustic soda is prepared and calculated quantity of it is added to the chitin cake. The reaction is followed by testing solubility of the residue in 1% acetic acid. As soon as dissolution is completed caustic soda is removed from the reaction mixture. The drained caustic soda can be reused for the next batch of deacetylation by fortification if necessary. The residue is washed with water free of alkali. It is centrifuged and dried under the sun or an artificial drier at a temperature not exceeding 80°C and pulverized to coarse particles. Chitosan is almost colourless, light in weight and soluble in dilute organic acids but soluble in water, alkali and organic solvents. It gives viscous solution when dissolved in dilute organic acids such as formic acid, acetic acid etc. Chitosan finds extensive applications in food industries, pharmaceutical applications, chemical industries, dental and surgical uses as a haemostatic agent, wound healing, biodegradable films as a substitute for artificial skins for removing toxic heavy metals, wine clarification, industrial effluent treatment, agriculture, photography, cosmetic applications and textiles. Collagen-chitosan membrane from collagen of fish air bladder was developed at the CIFT. Trial in different medical collages has shown that this absorbable membrane can be used as an artificial skin.

Surgical sutures from fish gut: The CIFT has developed make absorbable surgical sutures from fish gut collagen. It involves extraction of gut from live fish. The impurities and soluble proteins are removed to give pure collagen. The collagen fibres so prepared are twisted, cross linked and bodied to give fine threads of collagen. They are surface smoothened, cut to size and packed in isopropanol. Finally the packed sutures are sterilized to give absorbable surgical sutures. This will make sutures available at an affordable price and reduce pollution by the fish guts. Trials carried out in a Government Medical College, Kerala revealed that fish gut sutures are equally good in performance as commercially available sutures of similar grade.

As a human health diet: There is very good demand for sea food-based products in ready-to-eat/ready-to-cook convenience form. There are number of products prepared from low cost fishes which have very good demand.

Fish soup powder: Fish soup powder can be formulated from any type of fish having very low fat content. There are different types of soup available in the market. These are dry products rich in dietary constituents like protein and minerals. The soup powder prepared out of miscellaneous fish is also a rich source of animal protein and other nutritional factors.

Fish flakes or wafers: Fish wafers are partially deodourized thin flakes of cooked fish meat homogenized with starch and salt. On frying the wafers swell two to three times of its initial size and become crisp and delicious. It is an ideal snack. Fish mince and starch are the base materials for the preparation of wafers.

Fish noodles: This is similar to ordinary noodles available in the market, but contains 21% protein. Surimi is used as the base for the production of fish noodles. Cooked surimi is kneaded with salt and *maida*. The mix is allowed to pass through the extruder and dried gelatinized noodle is dried under sun or in an electrical drier at 50°C to a moisture level of 8%. The dried noodle is packed in air tight containers or polythene bags. The product has good dehydration property.

Lot of development has taken place in the field of Fish Processing and Packaging Technology. Seafood industry should gear up with the latest developments and introduce new products suitable for the world market. This will benefit not only the industry but also the poor fishermen of the country.

38. Demand and Supply of Fish

Fisheries sector, a sunrise sector in India, has recorded faster growth than that of crop and livestock sectors. In last 25 years, total fish production has been growing at an annual growth rate of about 4.60% in which marine sector was growing at a rate of 3.24% and inland sector at a rate of 6.20%. For some years now, aquaculture has been seen as a possible saviour for overburdened capture fisheries sector and an important source of food fish for the poor. Policy support, production strategies, public investment in infrastructure, research and extension for fisheries had significantly contributed to aquaculture and increased fish availability. Rapid growth has occurred in aquaculture production under freshwater and coastal brackishwater ponds and mariculture. The fish production has increased rapidly, tripling from 2.44 million tonnes in 1980 to about 7.64 million tonnes in 2008-09 thereby contributing to economic growth as well as human welfare, as it contributes to livelihood of large section of economically underprivileged population of country.

Domestic demand for fish in India is growing rapidly. Fish availability, higher economic growth, rising population, shift in dietary pattern, tastes and preferences because of high protein, vitamin and minerals compared to meat, are the driving forces for rapid growth in domestic fish demand and trade. The expansion of demand to match supply has to be a priority concern in the light of resource degradation, weak public support and investment, and potential worsening inequities in the global trade. Key questions emerged such as: Will past trends in supply, demand, and exports of fish be sustained in the future? Can the additional demand from rising population and per capita income be met by fish supplies? Which types of fish offer the most promising opportunities for growth in production, consumption, and trade?

This chapter presents the analysis of fish supply, demand and international trade of fresh fish by species group and projected by the year 2020 using disaggregate analysis.

Fish model

On the demand side, consumer preferences in the developing countries vary widely across fish types. On the supply side, fish is produced through various production environments, i.e. is capture and culture. Analysis of the disaggregated fish types would clearly be more useful for many applications such as allocation of resources for investment and research; comparison of policy options based on likely impacts; and projecting the marketing potentials within the fish sector over the medium and long term. Due to limited available projections of demand, supply and trade for the fish sector, a multi-market, multi-species fish sector model has been constructed.

The Asia Fish Model which consists of producer, consumer, and trade cores was employed for the disaggregated analysis of the fish sector. The time series data on fish production and farm survey data on fish farming at regional level were used to estimate producer core following the dual approach (Quadratic profit function). The multi-stage budgeting framework with Almost Ideal Demand system (AIDS) model was used for fish demand analysis based on consumer survey data. Armington approach was used for the trade core. The model is closed with a set of equilibrium conditions between supply, demand and trade. The model was run under various scenarios of total factor productivity. Projections of supply, domestic demand, and export by species group were obtained.

Construction of data set: The model required data on demand, supply, trade and prices for each fish type. These also needed extraneous information for variables like income, prices of non-fish food types, etc. To ensure a consistent data set, it was necessary to organize the information for each fish type in a balance sheet. Each balance sheet assumed that the total supply of each fish type (S) was equal to imports (M) and the sum of outputs from capture fisheries (Q_{CF}) and aquaculture (Q_A), that is,

$$S = M + Q_{CF} + Q_A.$$

Total demand (D) was the sum of exports (X), intermediate demand (ID), rural household demand (HD_R), and urban household demand (HD_U). In other words,

$$D = X + ID + HD_R + HD_U.$$

Finally,

$$S = D \text{ or } M + Q_{CF} + Q_A = X + ID + HD_R + HD_U$$

The outcome of the exercise was a series of balance sheets for different fish types. Besides balance sheet, the model also required parameters for its behavioural equations, namely producer, consumer and trade cores. Initially, we had estimated the demand and supply parameters and elasticity matrix using multi-species model for each source, and borrowed the elasticity for import and export trade. The demand and supply elasticities applied in the model have been presented in the subsequent section. The estimated parameters of consumer, producer and trade cores were transformed to suit the specification of the equations in the Asian Fish model. The intercept terms of all the relevant equations were then calibrated to ensure that the model replicated the baseline values. Using the values of exogenous variables, along with the assumed elasticities and the actual base year initial values of the endogenous variables, the model was solved using the Minos option of the Generalized Algebraic Modeling System (GAMS) software. The model was run assuming total factor productivity growth (TFPG) in the projected period 2% for aquaculture and 1% for capture production environments.

Fish species

There are a large number of species of inland and marine fish. These species are grouped into eight broad groups, namely Indian major carps (IMC), other freshwater fish (OFWF), shrimps (marine and freshwater), pelagic high value (PHV), pelagic low value (PLV), demersal high value (DHV), demersal low value (DLV), and molluscs and others (molluscs). The species group scheme is given here.

Classification of inland fish species

Indian major carps: Catla, rohu, mrigal, calbasu

Other freshwater fish: Silver carp, grass carp, common carp, murrels, hilsa (inland), and other unspecified inland fishes.

Prawn/shrimp: Penaeid shrimp production.

Classification of marine fish species

Pelagic fishes – High Value (PHV): Seerfish, oceanic tunas (yellowfin tuna, skipjack tuna), large carangids (*Caranx* sp.), pomfrets, pelagic sharks, mullets

Pelagic fishes – Low Value (PLV): Sardines, mackerel, anchovies, bombay duck, coastal tunas, scads, horse mackerel, barracudas

Demersal fishes – High Value (DHV): Rock cods, snappers, loethrinids, big-jawed jumper (*Lactarius lactarius*), threadfins (Polynemids)

Demersal fishes – Low Value (DLV): Rays, silverbellies, lizard fishes, catfishes, goat fishes, nemipterids, soles

Crustaceans - High Value: Shrimps, lobsters

Molluscs and others: Cephalopods (squids, cuttlefishes and octopus), mussels, oysters, non-penaeid prawns, etc.

Demand elasticity

The multi-stage budgeting framework with AIDS model was used for fish demand analysis based on consumer survey data. Income elasticities of different fish food groups across income groups are given in Table 38.1. The income elasticities vary substantially across fish species by income group. But at the aggregate level for all the households, income elasticities range with narrow difference 1.61 for shrimp/prawn to 1.66 for molluscs. Income elasticities for all the fish groups consistently fall with an increase in per capita expenditure (income) level of the household above the poverty line (Quartile II to Quartile IV). None of the groups under study became an inferior goods at the highest income quartile. This suggests that even a very rapid increase in aggregate per capita income in the projected period, fish consumption is not likely to turn an inferior goods in India. The results revealed that when

Table 38.1. Income elasticity of demand for different groups of fish in India

Fish group	Expenditure quartile				
	I	II	III	IV	All
Indian major carps	1.63	1.79	1.54	1.36	1.62
Other freshwater fish	1.64	1.80	1.54	1.36	1.62
Prawn/shrimp	1.14	1.72	1.54	1.39	1.61
Pelagic high value	0.72	1.76	1.54	1.37	1.62
Pelagic low value	1.66	1.81	1.54	1.34	1.62
Demersal high value	1.56	1.79	1.54	1.36	1.62
Demersal low value	1.64	1.80	1.54	1.36	1.62
Molluscs	3.75	2.01	1.55	1.12	1.66

Table 38.2. Own-price elasticity of demand for different groups of fish in India

Fish group	Expenditure quartile				
	I	II	III	IV	All
	Uncompensated own-price elasticity				
Indian major carps	-0.99	-0.99	-0.99	-0.99	-0.99
Other freshwater fish	-0.99	-0.99	-0.99	-0.99	-0.99
Prawn/shrimp	-0.96	-0.99	-0.99	-1.00	-0.99
Pelagic high value	-0.78	-0.98	-0.99	-0.99	-0.99
Pelagic low value	-1.04	-1.06	-1.04	-1.05	-1.05
Demersal high value	-0.46	-0.92	-0.96	-0.95	-0.95
Demersal low value	-0.88	-0.93	-0.85	-0.82	-0.88
Molluscs	-1.01	-1.00	1.00	-0.99	-1.00
	Compensated own-price elasticity				
Indian major carps	-0.36	-0.45	-0.50	-0.60	-0.52
Other freshwater fish	-0.83	-0.84	-0.89	-0.89	-0.87
Prawn/shrimp	-0.95	-0.93	-0.90	-0.83	-0.88
Pelagic high value	-0.78	-0.91	-0.87	-0.81	-0.86
Pelagic low value	-0.90	-0.97	-0.93	-0.96	-0.95
Demersal high value	-0.46	-0.90	-0.93	-0.92	-0.92
Demersal low value	-0.86	-0.90	-0.84	-0.81	-0.86
Molluscs	-0.99	-0.96	-0.96	-0.97	-0.97

total income increases, people tend to spend more on fish, and relatively less on other types of meat.

The uncompensated and compensated own-price elasticities of various groups of fish species, evaluated at the expenditure quartile-specific mean, are given in Table 38.2. Uncompensated elasticities of demand represent changes in quantity demand as a result of changes in prices, which capture both price effect and income effect. Compensated elasticities of demand refer to the portion of change in quantity demanded which capture only price effect. The own-price elasticities vary in the range of -0.88 for DLV and -1.00 for molluscs. The own price elasticities do not vary across income group except demersal groups. Compensated own-price elasticities were almost half in absolute terms as compared to un-compensated elasticities for IMC, reflecting its large share in total fish food expenditure. The compensated own price elasticity was estimated -0.97 for molluscs, followed by PLV (-0.95), DHV (-0.92), shrimp (-0.88), OFWF (-0.97), PHV (-0.86), DLV (-0.86) and minimum for IMC (-0.52). Fish demand is sensitive to price changes except IMC.

Supply elasticity

Aquaculture fish supply: Three outputs and three variable inputs over the time span of the study were considered. These were output of IMC, OFWF, shrimp and inputs including feed measure as crude protein, fertilizer measure as nitrogen, and labour measure as man days. The analysis suggests that Indian fish producer respond to price changes in an effective manner. Price instruments along with technological policy are likely to be quite effective in fish supply. The changes in relative fish species prices will change the supply mix consisting of various species.

The own-price elasticity estimates were greater than unity for IMC, and OFWF and less than unity for prawn/shrimp. The short run price effect on supply will be sharpener and quick for IMC and OFWF as compared to shrimps. IMC price will affect the prawn supply negatively. The cross price elasticity of IMC and prawn was negative and highly elastic (-4.03). The acreage effect on fish supply is quite high (0.7) for all the species groups, it can be used as an instrument for increasing fish supply to meet the domestic demand and export till new technological breakthrough in fish comes about.

Marine fish supply: Six outputs and two variable inputs over the time span of the study were considered. These were output of PHV, PLV, DHV, DLV, shrimp, and molluscs and inputs, namely fuel and labour. The coaster length and time trend had positive and significant influence on fish supply and input demand. The own-price was statistically significant determinants of fish supply for all the fish species groups. Diesel price and wage influence fish supply and factor demand negatively.

The own price elasticity of fish supply was highest for shrimp (0.49), followed by DHV (0.45), PLV (0.32), molluscs (0.28), PHV (0.28) and minimum for DLV (0.20). The effect of diesel price on shrimp supply was more negatively pronounced than that on the supply of other species groups. The effect of wage on fish supply was highly inelastic. It is because, the labour input is almost fixed for marine fishing for a given technology. As the diesel price elasticity of fuel demand was highly elastic (-4.6), its price inflation will hinder the process of modernization from traditional non-mechanized boats to modernized boats. Hence, there is a need to extend the diesel subsidy to help the fishermen to adopt the modern technologies. The operating costs accounted for a maximum proportion of 92% of the total cost in traditional fishing units than by any other fishing methods.

Demand projections

The increase in supply will make the fish available to the consumers at a cheaper price, which will increase the fish consumption in their food basket. The demand projection of fish by species group is presented in Table 38.3. Domestic demand for fish under the baseline scenario is likely to grow at an annual rate of 2.5 % between 2000 and 2020. Highest growth in demand is projected for IMC (3.98 %), followed by OFWF (3.96), PLV and DLV (2.0 % each). Declining consumer prices are the major drivers of demand growth. However, domestic demand for various species meant for international market is likely to decline due to increase in their prices. Between 2000 and 2020 consumer demand for shrimp would decline at an annual rate of -1.97 %, followed by DHV (-1.43 %) and molluscs (-1.14 %).

The domestic demand of fish would be 6.72 million tonnes at the end of 11th Plan. It is likely to grow to 8.46 million tonnes in 2020. Out of this, the in-home consumption as the fresh fish is estimated to be about 66 %, and the remaining would be consumed away from home and enter industrial processing. The annual per capita consumption at national level is projected to be 5.6 kg in 2011 and 6.3 kg in 2020 (Table 38.4).

Table 38.3. Domestic demand of fishes (in '000 tonnes)

Year	Population	IMC	OFWF	Shrimp all	PHV	PLV	DHV	DLV	Molluscs	Total
Base line										
2000	1,010.5	1,418.3	1,047.3	532.4	414.4	931.4	259.1	216.2	425.3	5,244.3
Projected										
2009	1,160.8	2,007.4	1,476.7	471.7	453.1	1,110.4	235.7	258.3	394.5	6,407.8
2010	1,176.7	2,087.2	1,535.0	462.8	456.8	1,132.5	232.5	263.5	390.2	6,560.6
2011	1,192.5	2,170.3	1,595.7	453.8	460.3	1,155.0	229.3	268.8	385.9	6,719.1
2012	1,208.1	2,256.8	1,659.0	444.6	463.7	1,178.0	226.0	274.2	381.5	6,883.8
2013	1,223.6	2,346.8	1,724.8	435.4	466.9	1,201.5	222.6	279.7	377.0	7,054.8
2014	1,238.9	2,440.5	1,793.3	[illegible]	470.0	1,225.4	219.2	285.3	372.5	7,232.5
2015	1,254.0	2,538.0	1,864.7	417.0	473.0	1,249.9	215.8	291.0	367.9	7,417.3
2016	1,269.0	2,639.4	1,938.9	407.9	475.8	1,274.9	212.4	296.9	363.2	7,609.3
2017	1,283.6	2,744.9	2,016.1	398.8	478.5	1,300.3	208.9	302.8	358.5	7,809.0
2018	1,298.0	2,854.7	2,096.5	389.8	481.0	1,326.3	205.5	308.9	353.8	8,016.6
2019	1,312.2	2,968.9	2,180.1	380.9	483.5	1,352.8	202.1	315.1	349.1	8,232.5
2020	1,339.7	3,087.7	2,267.1	372.2	485.7	1,379.9	198.6	321.4	344.4	8,457.0
CGR (%)	1.42	3.98	3.96	-1.97	0.72	1.99	-1.43	2.00	-1.14	2.47

CGR, Annual compound growth rate.

Table 38.4. Per capita consumption (in kg) of fish in India: projections till 2020

Year	Population	IMC	OFWF	Shrimp all	PHV	PLV	DLV	DLV	Molluscs	Total
Base line										
2000	1,010.5	1.4	1.0	0.5	0.4	0.9	0.3	0.2	0.4	5.2
Projected										
2009	1,160.8	1.7	1.3	0.4	0.4	1.0	0.2	0.2	0.3	5.5
2010	1,176.7	1.8	1.3	0.4	0.4	1.0	0.2	0.2	0.3	5.6
2011	1,192.5	1.8	1.3	0.4	0.4	1.0	0.2	0.2	0.3	5.6
2012	1,208.1	1.9	1.4	0.4	0.4	1.0	0.2	0.2	0.3	5.7
2013	1,223.6	1.9	1.4	0.4	0.4	1.0	0.2	0.2	0.3	5.8
2014	1,238.9	2.0	1.4	0.3	0.4	1.0	0.2	0.2	0.3	5.8
2015	1,254.0	2.0	1.5	0.3	0.4	1.0	0.2	0.2	0.3	5.9
2016	1,269.0	2.1	1.5	0.3	0.4	1.0	0.2	0.2	0.3	6.0
2017	1,283.6	2.1	1.6	0.3	0.4	1.0	0.2	0.2	0.3	6.1
2018	1,298.0	2.2	1.6	0.3	0.4	1.0	0.2	0.2	0.3	6.2
2019	1,312.2	2.3	1.7	0.3	0.4	1.0	0.2	0.2	0.3	6.3
2020	1,339.7	2.3	1.7	0.3	0.4	1.0	0.1	0.2	0.3	6.3
GGR (%)	1.42	3.98	3.96	-1.97	0.72	1.99	-1.43	2.00	-1.14	2.47

About 35 % of Indian population eats fish. Thus, annual per capita consumption of fish eating population is projected about 16.8 kg in 2010, and would rose to 18.5 kg by 2020 (Table 38.5).

Under the baseline scenario, the additional fish demand from the year 2000 to 2020 would be about 3.21 million tonnes (Table 38.6). Out of this, 52 % would be met from IMC followed by OFWF (38 %), PLV (14 %) and DLV (3.3 %). The additional consumption of shrimp, DHV and molluscs species would decline by 9%. The aquaculture holds the key for meeting the future demand challenges.

Table 38.5. Per capita demand of fish-eating population in India: Projections till 2020 (in kg)

Year	Fish eating population	IMC	OFWF	Shrimp all	PHV	PLV	DHV	DLV	Molluscs	Total
Base line										
2000	339.8	4.17	3.08	1.57	1.22	2.74	0.76	0.64	1.25	15.43
Projected										
2009	388.6	5.17	3.80	1.21	1.17	2.86	0.61	0.66	1.02	16.49
2010	394.4	5.29	3.89	1.17	1.16	2.87	0.59	0.67	0.99	16.64
2011	400.3	5.42	3.99	1.13	1.15	2.89	0.57	0.67	0.96	16.79
2012	406.3	5.55	4.08	1.09	1.14	2.90	0.56	0.67	0.94	16.94
2013	412.4	5.69	4.18	1.06	1.13	2.91	0.54	0.68	0.91	17.11
2014	418.6	5.83	4.28	1.02	1.12	2.93	0.52	0.68	0.89	17.28
2015	424.9	5.97	4.39	0.98	1.11	2.94	0.51	0.68	0.87	17.46
2016	431.2	6.12	4.50	0.95	1.10	2.96	0.49	0.69	0.84	17.65
2017	437.7	6.27	4.61	0.91	1.09	2.97	0.48	0.69	0.82	17.84
2018	444.3	6.43	4.72	0.88	1.08	2.99	0.46	0.70	0.80	18.04
2019	450.9	6.58	4.83	0.84	1.07	3.00	0.45	0.70	0.77	18.26
2020	457.7	6.75	4.95	0.81	1.06	3.01	0.43	0.70	0.75	18.48
GGR (%)	1.50	2.4	2.4	-3.4	-0.8	0.5	-2.9	0.5	-2.6	0.9

Table 38.6. Changes in consumption of fish by species groups by 2020

Species group	Consumption		Change in production		% share in total fish	
	2000	2020	('000 tonnes)	%	2000	2020
IMC	1,418.3	3,087.7	1,669.5	52.0	27.0	36.5
OFWF	1,047.3	2,267.1	1,219.8	38.0	20.0	26.8
Shrimp all	532.4	372.2	-160.2	-5.0	10.2	4.4
PHV	414.4	485.7	71.4	2.2	7.9	5.7
PLV	931.4	1,379.9	448.4	14.0	17.8	16.3
DHV	259.1	198.6	-60.5	-1.9	4.9	2.3
DLV	216.2	321.4	105.2	3.3	4.1	3.8
Molluscs	425.3	344.4	-80.9	-2.5	8.1	4.1
Total	5,244.3	8,457.0	3,212.7	100.0	100.0	100.0

Supply projections

Fish production by production environment is projected for two decade using year 2000 as the base year and presented in Table 38.7. Total fresh fish output growth is projected slightly above 3%. The aquaculture output is expected to expend with higher growth about 4% per annum as compared to capture output which is likely to grow at slower rates about 2% per annum. Thus, aquaculture would expand faster than the capture.

The higher share of aquaculture in total output of fresh fish bas been projected and would raise from 52% in the year 2000 to 61% in the year 2020. The total fresh fish production is projected 7.7 million tonnes by the end of 11th Plan and would raise to 10.2 million tonnes by the year 2020 comprising 6.2 million tonnes aquaculture and 4.0 million tonnes capture. Total fish output annual growth is projected to be 3.2% which would likely to be doubled as compared to crop sector. The supply projections by species group for the year 2001-2020 are given in Table 38.8.

The results revealed that the fish production would grow at the growth rate of 3.2% corresponding to the baseline scenario. It would be highest for IMC, OFWF and shrimp at about 4% and lower for PHV, PLV, DHV, DLV and molluscs at about 2% per annum. It was observed that for the species which are not entering in the export market, the prices will decline with the increase in supply. These species are IMC, OFWF from inland sources where prices of these species will decline in the projected period at the rate of about 2.6% per annum. Among the marine species which are of low value, fish

Table 38.7. Supply of fish by source in India

Year	Fresh fish production ('000 tonnes)			Share of aquaculture in total (%)
	Aquaculture	Capture	Total	
Base line supply				
2000	2,849.5	2,632.1	5,481.6	52.0
Projected supply				
2009	4,040.1	3,167.0	7,207.1	56.1
2010	4,201.0	3,233.3	7,434.3	56.5
2011	4,368.5	3,301.1	7,669.5	57.0
2012	4,542.7	3,370.4	7,913.1	57.4
2013	4,724.0	3,441.2	8,165.2	57.9
2014	4,912.6	3,513.6	8,426.2	58.3
2015	5,108.9	3,587.6	8,696.5	58.7
2016	5,313.1	3,663.2	8,976.3	59.2
2017	5,525.4	3,740.5	9,265.9	59.6
2018	5,746.4	3,819.4	9,565.8	60.1
2019	5,976.2	3,900.1	9,876.3	60.5
2020	6,215.2	3,982.6	10,197.8	60.9
CGR (%)	3.99	2.10	3.18	

Table 38.8. Supply projections by species in India ('000 tonnes)

Year	IMC	OFWF	Shrimp all	PHV	PLV	DHV	DLV	Molluscs	Total
Base line supply									
2000	1,418.3	1,047.3	639.7	374.1	931.4	367.7	216.2	486.9	5,481.6
Projected supply									
2009	2,007.4	1,476.7	890.1	445.9	1,110.4	437.1	258.3	581.2	7,207.1
2010	2,087.2	1,535.0	922.9	454.8	1,132.5	445.6	263.5	592.8	7,434.3
2011	2,170.3	1,595.7	956.9	463.8	1,155.0	454.4	268.8	604.6	7,669.5
2012	2,256.8	1,659.0	992.1	473.0	1,178.0	463.3	274.2	616.7	7,913.1
2013	2,346.8	1,724.8	1,028.6	482.4	1,201.5	472.4	279.7	629.0	8,165.2
2014	2,440.5	1,793.3	1,066.4	492.0	1,225.4	481.8	285.3	641.5	8,426.3
2015	2,538.0	1,864.7	1,105.5	501.8	1,249.9	491.3	291.0	654.4	8,696.5
2016	2,639.4	1,938.9	1,146.1	511.8	1,274.9	501.0	296.9	667.4	8,976.3
2017	2,744.9	2,016.1	1,188.1	522.0	1,300.3	510.9	302.8	680.8	9,265.9
2018	2,854.7	2,096.5	1,231.7	532.4	1,326.3	521.0	308.9	694.4	9,565.8
2019	2,968.9	2,180.1	1,276.8	543.0	1,352.8	531.3	315.1	708.3	9,876.3
2020	3,087.7	2,267.1	1,323.7	553.8	1,379.9	541.8	321.4	722.5	10,197.8
Annual compound growth rate (%)									
Supply	3.98	3.96	3.69	1.99	1.99	1.97	2.00	2.00	3.18
Price	-2.68	-2.59	3.29	0.56	-0.50	2.43	-1.12	2.38	-0.73

price will decline by less than –0.50% per annum for PLV and 1.12% for DLV. The price of export oriented fish species would continue to rise with the increase of their supply.

The higher growth in fish supply for the species used in the domestic market would benefit the common man as this fish species will be available at cheaper price in future. In the fish species which are export oriented, the rise in supply will not cut down the price in the domestic market substantially, and the price will keep rising and would benefit the producer. The price of shrimp, which is the most important exportable fish, will rise 3.35% annually. Other exportable fish species are PHV, DHV and molluscs for which also the price will rise annually about 2.4% for DHV and molluscs and 0.5% for PLV.

The changes in the share of different production environment and different species group in total production during the period 2000-2020 are presented in Tables 38.9 and 38.10.

The share of IMC in total fish production will increase to 30% in 2020 from 26 % in 2000 and of OFWF to 22 % from 19 %. The share of shrimp would increased by 1.3%. While the share of pelagic, demersal, and molluscs would decline from 23.8 to 18.9%, 10.6 to 8.5 % and 8.9 to 7.1 %, respectively, during this period. By the year 2020, the incremental production is projected to be 4.7 million tonnes. Out of this additional production the aquaculture contribution is projected more than 60%. Among species, IMC would contribute maximum (35.4%) followed by OFWF (25.9%), shrimp (14.5%), pelagic (13.3%), demersal (5.9%) and molluscs (5.0%). Aquaculture would provide

Table 38.9. Changes in fish supply by production environment by 2020

Production environment	Production ('000 tonnes)		Change in production		% share in total	
	2000	2020	Quantity ('000 tonnes)	%	2000	2020
Aquaculture	2,849.5	6,215.2	3,365.8	71.4	52.0	60.9
Capture	2,632.1	3,982.6	1,350.5	28.6	48.0	39.1
Total	5,481.6	10,197.8	4,716.3	100.0	100.0	100.0

Table 38.10. Changes in fish supply by species groups by 2020

Species group	Production ('000 tonnes)		Change in production		% share in total	
	2000	2020	Quantity ('000 tonnes)	%	2000	2020
IMC	1,418.3	3,087.7	1,669.5	35.4	25.9	30.3
OFWF	1,047.3	2,267.1	1,219.8	25.9	19.1	22.2
Shrimp all	639.7	1,323.7	684.0	14.5	11.7	13.0
PHV	374.1	553.8	179.7	3.8	6.8	5.4
PLV	931.4	1,379.9	448.4	9.5	17.0	13.5
DHV	367.7	541.8	174.1	3.7	6.7	5.3
DLV	216.2	321.4	105.2	2.2	3.9	3.2
Molluscs	486.9	722.5	235.6	5.0	8.9	7.1
Total	5,481.6	10,197.8	4,716.3	100.0	100.0	100.0

important opportunity for additional fish supply. Among aquaculture species IMC, OFWF and shrimp would emerge great opportunities for future fish supply scenario. Among capture PLV would be the major contributor in additional marine fisheries.

Policy implications and opportunities

The technological diffusion, resource management, subsistence and commercial orientation, and macro policies are the key factors that influence the supply response. The supply response to own-price has been recorded higher for aquaculture than capture which is consistent with the sharp increase observed in aquaculture in recent decades and predicted for future. Aquaculture freshwater species would account for the bulk of output, and would maintain its dominance in the growth of fisheries supply in the foreseeable future. These are mostly low price fish and would occupy a significant place in the diets as a primary source of protein. Higher productivity growth would tend to increase supply and demand and would control fish prices. More fish at lower real prices would be available to the consumers.

Considerable impacts of technology are expected on social welfare. Within freshwater fisheries, IMC is expected to become prominent. Capture fisheries is likely to register stagnant growth. Brackishwater aquaculture (shrimp) and capture shrimp would have dominance in the export basket. Sustainable management of fisheries resources and compliance of hazards analysis and critical control points (HACCP) standards would be the challenges needing attention in the wake of widespread poverty among fisher's folks and availing opportunities for fish trade. Government policies are needed to design machines and provide training to minimize the cost of compliance of international standards.

The new yield-raising technologies, species management of resources and development of infrastructure can serve the useful purpose of sustainable growth of fish supply. Scope for increasing productivity through increased extension activities is limited. By contrast, systematic breeding strategies would improve the stock permanently, as the genetic gain is cumulative and sustainable. The micro-level analysis has shown that the genetically improved strain of rohu (Jayanti Rohu) is economically viable and socially acceptable at various stages, viz. hatchery, seed-rearing farm and fish grow-out farm.

The mixed trend on complementarity and substitute-response has been investigated in the study, suggesting the need for more caution in developing and implementing the fisheries policy for improving sustainability of various production environments. Thus, national strategies need to be prioritized towards sustainability issues by improving stock and dissemination of latest technologies to the poor farmers and fisher folks. The success of research for Jayanti rohu in India has induced catalytic effects on policymakers to build strategies and institutions for the dissemination of improved strain on a large scale to benefit the resource poor farmers in India. Rohu is among the most preferred fish of the producers as well as consumers. Dissemination and seed policy for genetically improved strain of carp and shrimp can be seen as an important opportunity for fisheries growth in India to match the domestic demand and export.

39. Trade and Export of Fishery Products

Fishery trade plays an important role in the economy of many Asian, African and other low income countries. They also earn valuable foreign exchange. It is estimated that fisheries sector gives employment to more than 43.5 million people globally, accounting for 3.2% of Agricultural workforce (*Source:* FAO, 2009). Global fish exports reached US$ 102,000 million tonnes in 2008. Exports from India in terms of value touched a value of ₹ 10,048 crore (US $ 2,392 million) in 2010 and in quantity 678,436 tonnes (*Source:* MPEDA, Kochi, 2011). Trade in fish existed from time immemorial. 'A fisher returning with more fish than is needed to meet personal needs will tend to exchange surplus fish for other goods or services. The distribution of fish globally is very uneven. The role of trade and of the marketing chain is to redistribute fish and fishery products according to demand. Trade has always played an important part of the fisher's livelihood, even in subsistence fisheries' (FAO). International fish trade (Table 39.1) has been increasing at a rapid level in recent decades facilitated by the widespread use of refrigeration, improved transportation and communications. New international trade rules have been developed through several rounds of trade negotiations under General Agreement on Tariffs and Trade (GATT). The last of these, the 1994 Uruguay Round, agreed to establish the World Trade Organization (WTO) and concluded number of important agreements with relevance to fisheries. The FAO Sub-Committee on Fish Trade provides an inter-governmental forum for consultations on technical and economic aspects of this trade.

Table 39.1. Top three fish producers (2007)

Country	Quantity (tonnes)
China	56,160,587
Indonesia	08,063,308
India	07,308,233

According to the projections of FAO of the UN, world fisheries production from marine capture fisheries has reached a plateau and not likely to show much increase in coming years. However, per capita fish consumption, 17.4 kg, is expected to remain steady due to high food fish production by aquaculture. Aquaculture has emerged as a major food producing sector (Table 39.2). In India 1 out of every 2 fish harvested comes from culture practices. Globally more than 100 species are cultured today. Per capita consumption and export trends are given here.

Table 39. 2. Top five aquaculture producers in the world and total aquaculture production in the world

Country	Quantity (tonnes)
China	31,420,275
India	03,354,754
Vietnam	02,156,500
Indonesia	01,392,904
Thailand	01,390,031
World aquaculture total	50,329,007

Source: FAO, 2007.

- Per- capita consumption 17.4 kg
- Global export 90 million US $

- Developed countries 62% imports
- Developed countries 50% exports
- Poor nation's fish export is a major contribution earning to the tune of US $ 25 billion in 2008 (*Source:* FAO, 2007).

Production trends

According to the FAO of UN, global marine capture fisheries are under a crisis. Fifteen fishing regions in the oceans are over-exploited, resulting in stock depletion showing declining fish production. Four regions are already depleted. Nine regions are declining due to over exploitation. Factors contributing to this tragedy are:

- Building huge factory vessels
- High capture rate, 10 tonnes/hr
- 3.5 million fishing vessels today
- China has expanded their fishing fleet 6 times than that in 1979 (*Source:* FAO, 2008).

Over-fishing stems from 20 countries whose fleets lands 80% of the marine catch. Peru, Japan, Chile, USA, China are the top five countries that contribute to this phenomenon; India ranks 11th position in the list.

Utilization

About 75% of the total global fish production is used for direct consumption. Consumption of fish in fresh form is growing at a fast pace owing to improved preservation techniques, packing and transport. One-third of the fish harvested is traded internationally. Around 32 million tonnes of fish produced globally is used to produce fish meal and oil. Fish oil from pelagic fish like sardine, mackerel and *Anchoviella* are now used as neutraceuticals in view of the high omega-3 acid content in them. Fish meal is widely used as animal feed, for poultry and pig, and also in aquaculture as a vital component of feed. Fish trade has also become a major source of earning foreign exchange for many developing nations like India.

In terms of fish production and exports China leads the world. In 1992-2002, China's fishery showed quantum developments. China's export growth on average for that decade was 115%. But during the period 1999- 2007 the increase was 245% (2,656 in 1998 to 9,251 US $ million in 2007). China has also now relaxed policies for fish import and re-export. Four factors contributing to this development are:

1. High production from farming sector.
2. Development of fish processing industry.
3. Improved policies to cater exports.
4. Cheap labour.

Now China's position in world:

- Number one fish producer
- Exported 2.8 million metric tonnes in 2008 worth US $ 9,251 million.
- But increase in income by 10.11% due to value-addition.
- Increase in production of value-added products by 37% in quantity and 49% in value.

China and WTO: China signed WTO agreement and became a member in 2001. This caused a lowering of import duty (Table 39.3) and made fish import cheap. This stimulated export also.

Table 39.3. Lowering of import duty in China

Year	Per cent
2001	15.30
2003	11.00
2004	10.40

Indian seafood export: A new chapter in the history of Indian seafood processing industry was dawn in 1953 when late Shri R. Madhavan Nair exported half tonne of frozen shrimp from Cochin to the USA. With the entry of frozen shrimp and acceptance of this product by US consumers India virtually added a new chapter in export trade. In 1953 our total export frozen shrimp was 10.25 tonnes valued ₹ 57,000. From this humble beginning, India has emerged as one of the leading nations in Asia. The share of Indian seafoods in the world market has shown an increasing trend over the years since its inception in the 1950s and during 2001-06 the increase was 21 % (*Source:* MPEDA, 2008) with the global market share of 2.5%. India's seafood export during 2009-10 has been 678,436 metric tonnes valued at ₹ 10,048 crore (*Source:* MPEDA, 2011). There are historical evidences to indicate that India had trade relations with the Assyrians, Babylonians, Phoenicians and Polynesians even before the birth of Christ and with the Egyptians, Chinese, Spanish, Dutch, French and British after the dawn of the Christian era. However, the basic commodity traded was spices. This trade encouraged the development of a flourishing boat building industry in the West coast of India. Marine fishing in distant waters has become economical due to this boat building industry, which started making boats suitable for fishing. Deep-sea fishing needed development of nets and other gadgets for fishing different species of fish. Fishing thus became a commercial success.

But it was the spice trade that attracted the mariners from the West to come to India and eventually colonize the country and East Asia. It was the quest for the spice that leads for the exploration of unseen land and unexplored oceans. "History loves a paradox, and there can be none greater than a taste for spices being responsible for the exploration of our planet. Sovereigns pledged their prestige, and navigators risked their lives, not inquest for gold or thirst for power but to redirect the distribution of a few inessential and today almost irrelevant vegetable products" (*Source:* John Keay. *The Spices Route, A History*. 2005). Our export in terms of quantity in the last decade showed that it has become a plateau and the growth in quantity is 10.6% in 2008 (*Source:* MPEDA, 2008). Shrimps and prawns command the trade with an export earning of 43% of the total trade. In recent years, frozen finfish started to emerge as the second largest commodity with a figure of 19% of the total earnings (*Source:* MPEDA, 2008) from frozen squid and cuttle fish (17% of export by value in 2008). This trend is likely to continue in the coming years. The rest of the earning comes from more than 50 minor commodities.

There are several reasons for the declining or static export trade. Some of them are:

1. Lesser demand from developed countries due to economic recession.
2. Fish disease and export barriers.

3. Detection of antibiotic residues and antimicrobials in shrimp/fish.
4. Increasing internal demands due to affluence.
5. Today price of quality fish in local markets is much higher than export price realization.
6. Increase in GDP of developing nations and lesser need for foreign exchange.
7. High cost of electricity, labour and shipping reduced profit margin of exporters considerably.
8. Increase in crude oil price making fishing unprofitable operation.
9. Imposition of catch data as mandatory to importing fish to European Union.

Today a large number of seafood processing factories have implemented Hazard analysis and critical control points (HACCP) in their process line according to standards of European Union. Consequently European Union (EU) has emerged as the top market for Indian sea-foods. Cephalopods, squid and cuttlefish, are two important commodities earning good market price,but demands are basically from EU and Southeast Asian countries. Processed ribbon fish and surimi have also become important export items but market is very selective. The trend of our marine products export is given in Table 39.4. Since the fall in the export earnings during 2003-04, the dollar earnings have increased steadily till 2008-09.

Table 39. 4. Export trend of marine products from India 2008-09

Year		Export	Variation	(%)	U.V.
2002-03	Q	467,297	+42,827	+10.09	
	V	6,881.31	+924.26	+15.52	147.26
	$	1,424.90	+171.55	+13.69	3.05
2003-04	Q	412,017	-55,280	-11.83	
	V	6,091.95	-789.36	-11.47	147.86
	$	1,330.76	-94.14	-6.61	3.23
2004-05	Q	461,329	49,312	11.97	
	V	6,646.69	554.74	9.11	144.08
	$	1,478.48	147.71	11.10	3.20
2005-06	Q	5,12164	50,835	11.02	
	V	7,245.30	598.61	9.05	141.46
	$	1,644.21	165.74	11.21	3.21
2006-07	Q	612,641	100,478	19.62	
	V	8,363.53	1,118.23	15.43	136.52
	$	1,852.93	208.72	12.69	3.02
2007-08	Q	541,701	-70,941	-11.58	
	V	7,620.92	-742.61	-8.88	
	$	1,899.09	46.16	2.49	3.51
2008-09	Q	602,835	61,134.51	11.29	
	V	8,607.94	987.02	12.95	
	$	1,908.63	9.54	0.50	3.17

Q, Quantity in MT; V, value in ₹ crore; $, US Dollar in million (*Source:* MPEDA, Kochi).

Table 39.5. Major seafood items of export

Item	Share %		2008-09	2007-08	Growth (%)
Frozen shrimp	21.00	Q:	126,042.00	136,223.00	-7.47
	43.91	V:	3,779.88	3,941.62	-4.10
	43.97	$:	839.30	980.62	-14.41
		UV$:	6.66	7.20	-7.50
Frozen fish	40.00	Q:	238,543.00	220,200.00	8.33
	20.01	V:	1,722.29	1,303.41	32.14
	19.66	$:	375.23	326.29	15.00
		UV$:	1.57	1.48	6.16
Frozen cuttle fish	8.00	Q:	50,698.00	45,955.00	10.32
	8.84	V:	760.59	744.13	2.21
	8.81	$:	168.17	185.66	-9.42
		UV$:	3.32	4.04	-17.89
Frozen squid	9.00	Q:	57,125.00	34,172.00	67.17
	7.35	V:	632.35	408.42	54.83
	7.49	$:	142.87	101.29	41.05
		UV$:	2.50	2.96	-15.63
Dried items	5.00	Q:	31,688.00	22,414.00	41.38
	4.89	V:	420.75	258.88	62.53
	4.85	$:	92.51	64.72	42.94
		UV$:	2.92	2.89	1.10
Live items	1.00	Q:	3,434.00	2,498.00	37.47
	1.15	V:	99.00	69.07	43.33
	1.14	$:	21.82	17.21	26.84
		UV$:	6.36	6.89	-7.73
Chilled items	4.00	Q:	21,453.00	6,541.00	227.98
	2.53	V:	217.34	118.11	84.02
	2.54	$:	48.39	29.62	63.35
		UV$:	2.26	4.53	-50.19
Others	12.00	Q:	73,851.00	73,698.00	0.21
	11.34	V:	975.75	777.29	25.53
	11.54	$:	220.33	193.68	13.76
		UV$:	2.98	2.63	13.53
Total	100.00	Q:	602,835.00	541,701.00	11.29
	100.00	V:	8,607.94	7,620.92	12.95
	100.00	$:	1,908.63	1,899.09	0.50
		UV$:	3.17	3.51	-9.69

Q, Quantity in metric tonnes; V, Value in ₹ crore; $, US Dollar in million; UV, unit value per kg.
Source: MPEDA, 2010.

European Union continued as the largest market during the year with a percentage share of 32.6% in $ realization followed by China 14.8%, Japan 14.6% , USA 11.9%, South East Asia 10%, Middle East 5.5% and other countries 10.6%. Major six buyers of Indian fish products are European Union, Japan, China, South East Asia, USA, and Middle East nations (Table 39.6).

Table 39.6. Major export for Indian seafood items

Country	Share %		2008-09
Japan	10	Q:	57,271
	14.34	V:	1,234.01
	14.60	$:	278.61
USA	6	Q:	36,877
	11.87	V:	1,021.55
	11.91	$:	227.29
European Union	25	Q:	151,590
	32.53	V:	2,799.96
	32.63	$:	622.87
China	24	Q:	147,312
	15.06	V:	1,296.39
	14.77	$:	281.90
South east asia	15	Q:	88,953
	10.14	V:	873.09
	10.01	$:	191.08
Middle east	5	Q:	27,177
	5.53	V:	475.72
	5.51	$:	105.20
Others	16	Q:	93,654
	10.54	V:	907.21
	10.57	$:	201.68
Total	100	Q:	602,835
	100	V:	- 8,607.94
	100	$:	1,908.63

Q, Quantity in metric tonnes; V, value in ₹ crore; $, US Dollar million.
Source: MPEDA, 2010.

Port-wise exports

Exports were affected from 19 land/air ports. The major ports (Table 39.7) to handle the export cargo during the year in the order of US $ earnings were Kochi (17.6%), JNP (17.3%), Pipavav (16.1%), Chennai (12.6), Vizag (10.5%), Kolkata (8.4%), Tuticorin (8%), Mangalore (2.8%), etc.

Growth trends in the export of fisheries products

India's fish export has emerged as the largest group in agricultural exports (Table 39.8). Today fisheries export basket cover more than 60 items. A study conducted by the National Centre for Agricultural Economics and Policy Research (NCAP), New Delhi, under ICAR, has shown that export basket of fisheries product is reasonably diversified.

Trade policies in fisheries sector

In India fisheries is included in agriculture. India had followed protective policies in the past. Except for a few traditional commercial commodities, trade has been regulated through Quantitative Restrictions (QRs), canalization, licenses, quotas and high tariffs. After signing WTO several restrictions were removed. Now a number of fisheries products were moved to Special Import License (SIL) category. They are

Table 39. 7. Major port-wise exports

Major Indian ports		Share %	2008-09	2007-08	Growth(%)
Kochi	Q:	16.35	98,537	98,520	0.02
	V:	17.48	1,504.98	1,383.74	8.76
	$:	17.57	335.35	344.45	-2.64
JNP, Mumbai	Q:	21.04	126,853	104,670	21.19
	V:	17.28	1,487.28	1,120.86	32.69
	$:	17.26	329.52	279.25	18.00
Pipavav	Q:	27.18	163,866	149,734	9.44
	V:	16.36	1,408.35	1,075.31	30.97
	$:	16.12	307.69	268.79	14.47
Chennai	Q:	6.48	39,043	42,947	-9.09
	V:	12.53	1,078.44	1,158.50	-6.91
	$:	12.62	240.80	287.87	-16.35
Vizag	Q:	5.35	32,277	35,535	-9.17
	V:	10.43	897.93	1,018.60	-11.85
	$:	10.47	199.85	253.66	-21.21
Kolkata	Q:	5.58	33,625	27,666	21.54
	V:	8.37	720.36	689.70	4.45
	$:	8.38	159.96	172.06	-7.03
Tuticorin	Q:	4.87	29,354	29,697	-1.15
	V:	8.06	693.76	654.64	5.98
	$:	8.05	153.59	162.97	-5.75
Mangalore/ICD	Q:	5.49	33,083	26,155	26.49
	V:	2.77	238.44	162.61	46.64
	$:	2.77	52.81	40.65	29.89
Goa	Q:	3.51	21,146	19,297	9.58
	V:	2.15	185.16	111.22	66.48
	$:	2.20	42.04	27.80	51.24
Mumbai airport	Q:	0.38	2,319	2,383	-2.70
	V:	2.05	176.56	116.12	52.05
	$:	2.02	38.60	29.14	32.46

Q, Quantity in tonns; V, value in ₹ crores; $, US Dollar million.
Source: MPEDA, 2010.

Table 39.8. Growth trends in the export of fisheries products (1987-88 to 2000-01)

Items/commodities	Quantity	Value
Live fish	-0.23 (-0.03)	8.37 (2.16)
Fish, fresh/chilled	18.10 (2.10)	12.85 (9.02)
Frozen fish	28.08 (6.49)	27.58 (9.45)
Fish dried salted/ brine	17.77 (1.73)	9.12 (3.7)
Fish fillets	9.29 (3.21)	9.17 (3.70)
Crustaceans w/n	7.04 (15.19)	9.09 (2.76)
Shrimp and prawn	6.90 (13.50)	9.23 (9.38)
Lobster	2.63 (1.21)	1.60 (0.67)
Other crustaceans	15.10 (8.31)	21.47 (8.31)
Molluscs w/n	9.92 (6.10)	8.72 (5.28)

Figures in parentheses indicate t-values; *Source: Report of NCAEP*, ICAR, New Delhi, November 2002.

Table 39.9. Status of import policy of fishery products

Period	Total fish commodities	SIL	FREE	Restricted/prohibited
1992-97	121	-	7	114
1997-2002	121	62	21	38
2002-07	121	-	116	5

Source: Exim Policy, Ministry of Commerce, Government of India.

now freely importable. In the Export-Import policy announced in 2002, almost all fishery commodities were moved to the list of freely importable commodities, except five groups of live and whale shark (Table 39.9).

Imports of fish and fishery products

The tariff structure has undergone a sea change in recent years. India has brought down the tariff/custom duty. But there is no comparison to other countries in this region. It is in an elevated level in order to protect our local market and fishers. But at the current rate it will be impossible for our industry to import, reprocess and export. A quick comparison (Table 39.10) with the rate in China can clear a lot of confusion in our policies.

Table 39.10. Comparison of tariff/ duty structure, India and China

India		China	
Year	Rate (%)	Year	Rate (%)
1986-89	60.00	-	-
1998-99	24.20	-	-
2000-01	44.04	2001	15.30
2002-03	35.20	2003	11.00
2004-05	35.20	2004	10.40

Source: India: Ministry of Commerce; and China: FAO of UN.

Major problems faced by exporters

- To identify the buyer with integrity
- Shortage of raw material
- Infrastructure and hygiene at landing centres and fishing ports
- Fly by night exporters (suitcase companies)
- Shipment delays
- Ghost money in many ports by labour unions.

India needs a drastic look at export trade and try to mitigate the burning issues. If there is a delay, it is likely that our fish export trade may face many issues and they will eventually end in closure of many processing establishments.

Inland fish trade

India is yet to set up quality standards for fish and fishery products on a national basis. The inland fish quality is a state subject and it is controlled by the Municipalities or Corporations of the concerned State Ministry. There is a flourishing marine fish trade between Gujarat and Mumbai. Marine fish is coming from Gujarat to Mumbai by sea and land. The fish is preserved in ice and marketed fresh. Dried fish is exported from Gujarat coast to overseas markets where there are ethnic people of Indian origin. Dried Bombay duck (*Harpadon nehereus*) is an important item. Dried fish from Gujarat, chiefly from Veraval and Porbandar comes to markets of south India chiefly Kerala and Tamil Nadu.

Freshwater fish

Freshwater fish from Andhra Pradesh is send to Odisha and West Bengal and the trade is growing at a regular pace. Catla, rohu, mrigal and catfish such as *Pangasius sutchi* are the species transported to these places in trucks in ice.

Catch certificate and traceability

The Marine Products Export Development Authority (MPEDA), Government of India has made it mandatory for seafood exports from India to European Union to include catch data certificate of the fish used for processing. This certificate has to be procured from fishing vessel owners with regard to the location or area of catch in the sea (fishing ground) for fish used for processing after 1st January 2010. For this, the MPEDA has also identified 51 major fish harbors and landing centers across the Indian coast line. European Union Council Regulation (EC) No. 1005/2008 of 29 September 2008 was made for establishing a community system to prevent, deter and eliminate illegal, unreported and unregulated fishing, amending Regulations (EEC) No. 2847/93, (EC) No. 1936/2001 and (EC) No. 601/2004 and repealing Regulations (EC) No. 1093/94 and (EC) No. 1447/1999. The objective of the common fisheries policy, as set out in Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the common fisheries policy (3), is to ensure exploitation of living aquatic resources that provide sustainable economic, environmental and social conditions. As per annexure I of the EU notification, following fish species, freshwater fishery products and certain aquaculture products are exempted from catch certification.

Annexure I: List of products excluded from the definition of 'fishery products' set out in point 8 of Article 2

a. Freshwater fishery products
b. Aquaculture products obtained from fry or larvae
c. Ornamental fish
d. Oysters, live
e. Scallops including queen scallops, of the genera *Pecten, Chlamys* or *Placopecten*, live, fresh or chilled
f. Coquilles St Jacques (*Pecten maximus*), frozen
g. Other scallops, fresh or chilled
h. Mussels, snails, other than those obtained from the sea
i. Prepared and preserved molluscs

The template or proforma for filling information on fish catch as notified by EU9 Page 31 of EU council regulation No 2371/2002 of December 2002 adopted by MPEDA is given in Fig 39.1.

Demand and supply

It is estimated that the shortfall is around 3.0 lakh tonnes of fish annually within the country. The state of West Bengal is a major consumer of fish in country. The fish

EUROPEAN COMMUNITY CATCH CERTIFICATE

(Issued by the Competent Authority of India)

Doc. number

1. VALIDATING AUTHORITY

Name	Address	Tel. / Fax

2. FISHING VESSEL(S)

Fishing Vessel Name	Flag, Home port and Registration No.	Call Sign	IMO/Lloyd's No (if issued)	License No.	Valid to	Inmarsat No, Fax No, e-mail, telephone No. (if Issued)

3. DESCRIPTION OF PRODUCTS — Type of processing authorized on board

Species	Product code	Catch area(s) and dates	Estimated live weight (kg)	Estimated weight to be landed (kg)	verified weight landed (kg) where appropriate

4. REFERENCE OF APPLICABLE CONSERVATION AND MANAGEMENT MEASURES

5. NAME OF MASTER OF FISHING VESSEL - SIGNATURE - SEAL

6. DECLARATION OF TRANSSHIPMENT AT SEA

Name of master of fishing vessel	Signature and date	Transshipment date/area/position	Estimated weight (kg)	
Master of receiving vessel	Signature	Vessel name	Call sign	IMO/Lloyd' no (if issued)

Fig 39.1. Proforma for filling information on fish catch as per EU9 Page 31.

7. TRANSSHIPMENT AUTHORIZATION WITHIN A PORT AREA

Name	Authority	Signature	Address	Tel.	Port of Landing	Date of landing	Seal (Stamp)

8. NAME AND ADDRESS OF EXPORTER	Signature	Date	Seal

9. FLAG STATE AUTHORITY VALIDATION

Name / title	Signature	Date	Seal (Stamp)

10. TRANSPORT DETAILS

Country of exportation	place of departure	Date shipped on	Shipped on (vessel)	Flight No.	Shipped to	Cont/way/bill No.	Seal No.

Name of Exporter	Address	Signature

11. IMPORTER DECLARATION

Name and address of Importer	Signature	Date	Seal	Product CN Code
Documents under Articles 14(1), (2) of Regulation (EC) No 1005/08		References		

12. IMPORT CONTROL-authority	Place	Importation authorised (*)	Importation suspended (*)	Verification requested - date
Customs declaration (if issued)	Number	Date	Place	

*Tick as appropriate

production in the state is not sufficient to meet ever growing demand. At present this demand is met by bringing fish from neighbouring states like Andhra Pradesh, Odisha, and even Bangladesh. Andhra Pradesh is by far the chief supplier. All types of farmed carps are brought from Andhra Pradesh. It is roughly estimated that the value of fish imported from neighboring states is around ₹ 1,400 crore annually and still there is demand for additional fish. West Bengal is also a major exporter of fresh and processed fish from India. During the period 2004-05, total fish and fishery products exports were 18,492 mt valued ₹ 521.13 crore. There is a scope for increase in export of freshwater fish as there is a renewed interest from many countries like China, Hong Kong, UK etc. Shrimp farming is likely to go up and also culture of freshwater prawn *Macrobrachium rosenbergii*.

Fresh fish is marketed as whole in the state (Table 39.11, 39.12). Filleting, gutting and packing are not practiced till today as a commercial activity. Inland marketing of fish in processed form has not become an accepted commodity due to various reasons. There is a scope for promoting this type of marketing as it has many advantages. In cities like Kolkata, waste disposal is a problem particularly in the homes. Fish wending stalls should undertake this work and the consumer should be supplied with dressed fish in good packaging. The waste can be converted to animal feed for fish meal for poultry industry. This will also prevent environmental contamination by fish waste.

Table 39.11. Important fish markets of West Bengal

Markets		
Wholesale fish market	1	Howrah
Retail markets	1	Haragung
	2	Kalibaba
	3	Sakarail
	4	Bakra
	5	Shivpur
	6	Domjur
	7	Bagnar
	8	Kulgachi

Table 39.12. Average daily market sale (volume) of cultured fish in West Bengal imported from other states

Place	No. of trucks	Quantity of fish (tonnes)
Siliguri	4	32.2
Malda	2	16.1
Asansole	3	24.15
Durgapore	4	32.2
Bankura	1	8.05
Krishna Nagar	1	8.05
Ranghat	1	8.05
Sriram pur	4	32.2
Barshat	3	24.15
Patipukur (Kolkata)	7	56.35
Sealdaha (Kolkata)	6	48.3
Behala	4	32.2
Kharagpore	12	96.6
Howrah	9	72.45

Future of Indian fish trade

India has to develop export strategies for marketing freshwater fish and value added fishery products to realize better export earnings in the coming years. There is also good market for ornamental fish and live fish, but we are yet to tap this area. Though the contribution of ornamental fisheries to our total export basket during 2009-10 has been ₹ 5.4 crore (*Source:* MPEDA, 2011) and it is contributing significantly in providing employment opportunity to several thousands of rural population including women. This appears a promising venture in the coming years.

The Indian fish trade is export oriented almost 100%. No processing factory is there in the country to cater exclusively the local population. Appropriate quality

standards are also not available species-wise. There is an urgent need to set up standards for fish and fishery products sold within the country. Future of Indian fish trade depends on this as the purchasing capacity of the people is going to enhance in the years to come and market prices are going to be high for fresh fish in India. The target set by MPEDA for India seafood trade for 2011-12 is given below:

- Export quality: 690,618 tonnes
- Value: US $ 2,214 million
- Harvesting and processing of tuna to increase.
- Export of value added products to increase.

Major concerns of Indian fish export and marketing are

- Quality concerns in farmed fish, particularly antibiotic residues.
- Traceability of fish caught.
- Demand of safe fish by consumers, regulators and retailers.
- Many countries demand DNA barcoding of fish species to check product adulteration and to prevent illegal trade of protected species.
- Organic fish and sustainable fish products.

Conclusion

- Demand for fish will be increasing continuously
- Increase in population will reduce fish supply and the per capita fish consumption is likely to fall from 17.4 kg to 12.7 kg by 2050 (FAO)
- 1 billion people in developing countries will experience fish shortage
- This necessitates implementation of sustainable fishing and management of global fisheries and continuous efforts to increase aquaculture production.

40. Human Resource Development in Fisheries in India

Qualified and trained manpower is a critical input for Fisheries Research and Development. Education produces knowledge-empowered individuals who are responsible for sustenance of productivity, growth, food security, alleviation of poverty and unemployment besides devising efficient and effective delivery systems for the benefit of society and industry. Fisheries education had a late start in India as compared to veterinary and agricultural education. While education in veterinary sciences and animal husbandry started towards the end of ninetieth century with the establishment of veterinary colleges at Bombay (1886) and Calcutta (1893), agricultural education started with establishment of four agricultural colleges in undivided India in 1906 at Kanpur, Coimbatore, Nagpur and Lyallapur. The first fisheries college was however established at Mangalore in 1969 under the auspices of the University of Agricultural Sciences, Bengaluru Prior to this fisheries education in India was synonymous with training of in-service personnel of State Fisheries departments.

Emergence of fisheries education in India

Fisheries training in India started in 1945 with the initiation of two all India training programmes, one on marine fisheries at Mandapam camp in Tamil Nadu and the other on Inland fisheries at Barrackpore (West Bengal). The marine fisheries course at Mandapam camp, which was attached to Central Marine Fisheries Research Institute (CMFRI), was soon closed, as it did not find favour with maritime states. The inland fisheries course was later attached to the then newly established Central Inland Fisheries Research Institute (CIFRI) at Barrackpore in 1947 and Central Institute of Fisheries Education (CIFE), Mumbai in 1967. It was then a 10 month training course mostly given to in-service personnel of State Fisheries Departments. This course was later developed into a one year postgraduate diploma in Inland Fisheries and was conducted till 2009 in Kolkata centre of the CIFE at Salt Lake, Kolkata, West Bengal.

Establishment of training centres was followed by setting up of CIFE at Mumbai in 1961 with FAO/UNDP assistance to offer two year postgraduate Diploma in Fisheries Science (D.F.Sc.) for in-service officers of State Fisheries departments. To meet the trained manpower needs of ocean going vessels and fishing industry, Central Institute of Fisheries Nautical and Engineering Training (CIFNET) was established at Kochi in 1963. During the same year, Marine Products Processing Training Centre (MPPTC) was also established at Mangalore under Indo-Japanese collaboration for training processing technologists. The above stated training courses were of ad-hoc nature to familiarize personnel with the state of art of fisheries and its field manifestation.

In 1971, the University of Bombay, Mumbai accorded recognition to the CIFE as a study centre for M.Sc. and Ph.D. programmes by research in the fields of applied zoology and biochemistry.

Administrative control of the CIFE was transferred to the Indian Council of Agricultural Research (ICAR) on 1st April 1979. With this, the charter of CIFE was also enlarged to include Research and Extension activities in addition to imparting Education and Training. Recognizing the need for PG academic programmes, the CIFE started offering M.Sc. (Fisheries Management) course from 1984 onwards with affiliation to the University of Bombay, Mumbai. Recognizing the pioneer role played by the CIFE in Fisheries Education, the UGC conferred on it the Deemed to be University status in 1989. After acquiring Deemed to be University status, the CIFE initiated a two-year PG course on M.Sc. (Inland Fisheries Administration and Management) at its center in Barrackpore, Kolkata in 1989 and the M.Sc. (Fisheries Management) course affiliated to the University of Mumbai was discontinued. The M.Sc. programmes of the CIFE were later recast as Master of Fisheries Science (M.F.Sc.) in the year 1995. During the same year, the M.Sc. and Ph.D. courses in Mariculture at CMFRI, Kochi, offered till then under affiliation to the Cochin University of Science and Technology, Kochi were brought under the Deemed University of the CIFE.

Fisheries Extension Centres of the Government of India were closed by 1965 and reorganized into two training centres for imparting training to inland fisheries operatives one at Agra and the other at Hyderabad. These centers were later transferred to the CIFE to bring fisheries education under one umbrella. The centre at Agra was later shifted to Chinhat near Lucknow and initially offered a nine month Certificate course for inland fisheries operatives, which was upgraded to a one year PG Certificate programme, originally meant for candidates with secondary school leaving certificate, but admitted only graduates after its upgradation in 1990. The course offered specialized hands on training in various techniques of carp breeding and seed production, seed transport and reservoir fisheries. This course was wound up in 1995.

The centre at Hyderabad was re-designated as Central Fisheries Extension Training Centre in 1973. This centre was later shifted to Kakinada in Andhra Pradesh. It imparted specialized training at PG level mainly for in-service personnel from various States in India and abroad. The original 10 months programme which was upgraded to a one year Post Graduate Certificate programme in 1990 offered courses in methods and techniques of fisheries extension for aquaculture development. This programme was also wound up in 1995.

Training Programmes are also conducted by various State governments. About half a dozen states including Andhra Pradesh, Odisha, Uttar Pradesh, West Bengal and Tamil Nadu have their own training centres where the newly recruited extension officers are given practical training in techniques of seed production and fresh/brackishwater fin fish and cell fish culture. Some of the Co-operative Societies in Gujarat, Kerala, Maharashtra, and Tamil Nadu operate Fisheries Training Centres while, diploma courses in Fisheries Technology and Navigation are also conducted by the Government Polytechnic in Andhra Pradesh and Tamil Nadu.

Professional fisheries education in India

Professional education in fisheries in India started at the State Agricultural/

Veterinary Universities in 1969 with the establishment of first Fisheries College at Mangalore under the auspices of the University of Agricultural Sciences, Bengaluru. List of SAUs and one Central Agricultural University (CAU) offering Fisheries Education in the country are given in Table 40.1.

Table 40.1. Annual intake capacity of undergraduate and postgraduate programmes in fisheries colleges and institutions in India

Sl.No.	Name of the college/institute	Annual intake capacity		
		Bachelor's	Masters	Doctoral
1.	College of Fishery Science (Sri Venkateswara Veterinary University), Muthukur 524 344, Nellore District, Andhra Pradesh; Tel: 0861-2377477; Fax: 0877-2242786	30	10	-
2.	College of Fisheries,(Assam Agricultural University), Raha 782 103, Nagoan District, Asom Tel: 03672-285719; Fax: 03672-285719	20	-	-
3.	College of Fisheries (Rajendra Agricultural University), Dholi, Muzaffarpur 843 121, Bihar; Tel: 0621-229318	13	-	-
4.	College of Fisheries (Indira Gandhi Krishi Vishwavidyalaya), Kawardha 491 995, Chhattisgarh Tel: 07741-232066	38	08	-
5.	College of Fisheries (Junagarh Agricultural University), Rajendra Bhavan Road, Veraval 362 265, Gujarat Tel: 02876-221053; Fax: 02876-242052	24	-	-
6.	College of Fisheries (Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir), P.O. Box:1079; GPO, Srinagar 191 212, Jammu and Kashmir Tel & Fax: 0194-2262214	20	09	03
7.	College of Fisheries (Karnataka Veterinary, Animal and Fisheries Sciences University), Matsyanagar, Kankanady (P.O), Mangalore 575 002, Karnataka; Tel: 0824-2248936; Fax: 0824-2248336	40	20	14
8.	College of Fisheries [Kerala University of Fisheries and Ocean Studies (KUFOS, Kochi)] Panangad, Kochi 682 506, Kerala; Tel: 0484-2700598/2703781; Fax: 0484-2700337	50	14	04
9.	College of Fisheries (Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth), Shirgaon, Ratnagiri 415 629, Maharashtra; Tel: 02352-232241, 232678, 232987; Fax: 02352-232241	40	28	05
10.	College of Fisheries Sciences (Maharashtra Animal and Fishery Sciences University), Telangkhedi, Nagpur 440 001, Maharashtra; Tel: 0712-2511784; Fax: 0712-2511282	32	-	-
11.	College of Fisheries (Maharashtra Animal and Fisheries Science University), Latur 413 517, Udgir, Maharashtra	32	-	-
12.	College of Fisheries (Orissa University of Agriculture and Technology), Rangailunda, Berhampur, Ganjam 760 007, Odisha; Tel: 0680-2242235	48	10	02
13.	College of Fisheries (Guru Angad Dev Veterinary and Animal Sciences University), Ludhiana 141 004, Punjab Tel: 0161-2414061; Fax: 0161-2414054	18	05	02
14.	College of Fisheries (Maharana Pratap University of Agriculture and Technology), P.O. Box 171, Udaipur 313 001, Rajasthan; Tel: 0294-2471101; Fax: 0294-2470682	30	10	03
15.	Fisheries College and Research Institute (Tamil Nadu Veterinary and Animal Sciences University), Thoothukudi 628 008, Tamil Nadu; Tel: 0461-2340154; Fax: 0461-2340574	30	21	15
16.	College of Fisheries (Central Agricultural University), P.O. Box 120, Lembucherra, Agartala 799 210, Tripura; Tel: 0381-2865264, 2865291; Fax: 0381-2865291	33	10	-
17.	College of Fishery Science (Goind Ballabh Pant University of Agriculture and Technology), Udham Singh Nagar, Pantanagar 263 145, Uttarakhand Tel: 05944-233376, Fax: 05944-233377	25	12	03
18.	College of Fisheries (Narendra Dev University of Agriculture and Technology), Kumarganj, Narendra Nagar, Faizabad 224 229, Uttar Pradesh; Tel: 05270-262117	15	-	-
19.	College of Fisheries Science (West Bengal University of Animal and Fishery Sciences), Mohanpur Campus P.O. 741 252, West Bengal; Telefax: 033-24328763	32	20	03
20.	Central Institute of Fisheries Education (Deemed University), Mumbai 400 061, Maharashtra; Tel: 022-26363404, Fax: 022-26361656	-	69	39
	Total Seats	570	250	93

(Continued...)

(Table 40.1 Concluded)

Source: Biradar (2006) and also revision based on personal communication.

Six out of the 19 Fisheries Colleges offer only 4 year under graduate course leading to B.F.Sc. These colleges are College of Fisheries, Rajendra Agricultural University, Dholi, Muzaffarpur established in 1986; College of Fisheries, Assam Agricultural University, Raha established in 1988; College of Fisheries, Gujarat Agricultural

University, Veraval established in 1991; College of Fishery Science, Maharashtra Animal and fishery Sciences University, Nagpur established in 2006; and College of Fisheries, Maharashtra Animal and Fishery Sciences University Udgir, established in 2007. College of Fisheries, N. D. University of Agriculture and Technology, Faizabad initiated UG programmes under self financing category in 2006. Thirteen (13) colleges offer Post-graduate courses (M.F.Sc.) of two-year duration and six (6) take Ph.D programmes of three years duration with one-year course work in addition to CIFE (Deemed University), Mumbai. Semester system of education is followed in all these colleges. The College of Fisheries, Kochi, formerly under the Kerala Agricultural University has been now affiliated to the full-fledged fisheries university of the country, established in 2011 Kerala University of Fisheries and Ocean Studies (KUFOS) with its headquarters at Kochi.

Courses offered

The colleges offer courses in various specializations, viz. Aquaculture, Fishery microbiology, Aquatic resources and management, Aquatic environment and ecology, Fish processing technology, Fishery engineering, Fisheries economics, Fishery biotechnology, Fishery biology, Fisheries extension, Fishing hydrography, Fish pathology. The number of courses offered by a college vary, maximum are offered by Manglore (six) and Tuticorin (eight) Colleges and minimum(one) at Ludhiana, Udiapur and Srinagar colleges of fisheries. Annual intake capacity at various course levels also differs in different colleges (Table 40.1).

Deemed University

The Central Institute of Fisheries Education, Mumbai is a Deemed to be University under the Indian Council of Agricultural Research (ICAR). As indicated earlier it was established in 1961 as an in-service training Institute to impart two year Post-graduate Diploma in Fisheries Science, but now it occupies a unique place in Fisheries Education as the only Deemed Fisheries University in the country. It ofers M.F.Sc. in 11 specializations, viz. Fisheries Resources Management, Aquaculture, Fish Genetics and Breeding, Fish Nutrition and Feed Technology, Fish Physiology and Biochemistry, Aquatic Animal Health Management, Aquatic Environment Management, Fisheries Extension, Fisheries Economics, Fish Biotechnology and Post-harvest Technology. Ph.D. programme is conducted in 10 specializations, viz. Fisheries Resources Management, Aquaculture, Fish Genetics, Fisheries Biotechnology, Fish Nutrition and Biochemistry, Aquatic Animal Health Management, Aquatic Environment Management, Fisheries Extension, Post-harvest Technology and Fish Business Management. Students also have the option to carry out research work after completion of course work at the CIFE in sister ICAR Fisheries Research Institutions. Admissions to M.F.Sc. and Ph.D. programmes is through All India Entrance Tests conducted by the ICAR and CIFE respectively. The 2 year D.F.Sc. course which was responsible for the development of skilled and trained manpower in the country since 1961, was discontinued by the CIFE with effect from the academic year, 1998-99, subsequent to initiation of Master's degree programmes in several disciplines.

Fisheries related courses

Besides the Fisheries Colleges, number of Institutions offer fisheries related courses. The Indian Institute of Technology, Kharagpur, West Bengal offers a four year B. Tech. Degree programme in Naval Architecture and Marine Engineering besides M. Tech. and Ph. D. programmes in Aquaculture Engineering. The College of Engineering, Waltair offers a B. E. degree with Fishery Engineering and Naval Architecture as special subjects. Cochin University of Science and Technology under its Faculty of Marine Sciences offers M. Sc. and Ph. D. programmes in Marine Biology, Industrial Fisheries, Oceanography and Marine Geology. The Karnataka Regional Engineering College, Suratkal, offers a two year industrial programme in Fish Harbour Engineering. Indian Institute of Technology, Chennai offers M. Tech. in Coastal Engineering. The Central Institute of Fisheries Nautical and Engineering Training (CIFNET), Kochi offers a four-year graduate course in Fisheries Nautical Sciences under the Cochin University of Science and Technology. Barkatullah University, Bhopal offers M. Sc. Courses in Applied Limnology and Fishery Technology, Aquatic Environmental Sciences and Applied Aquaculture for regular and self-financing stream of students. The Institutions which offer M.Sc. Course in Marine Science subjects include Andhra University, Waltair in Marine Geology and Marine Biology; Annamalai University, Porto Novo in Marine Biology; Kerala University, Thiruvananthapurum in Fisheries and Aquatic Biology and Tata Institute of Fundamental Research, Mumbai, in Marine Geo-chemistry. The Universities of Agra (Uttar Pradesh), Annamalai (Tamil Nadu), Mumbai (Maharashtra), Burdwan (West Bengal), Calcutta (West Bengal), Cochin (Kerala), Kalyani (West Bengal), Kerala (Kerala), Madras (Tamil Nadu), Meerut (Uttar Pradesh), Viswa Bharti (West Bengal) and Waltair (Andhra Pradesh) offer Ph.D. courses in selected fisheries related and aquatic biological subjects in pure and applied zoological sciences.

The University of Madras offers a PG diploma course in Coastal Aquaculture, while IIT, Mumbai conducts a PG diploma in Dock and Harbour Engineering and the Indian Institute of Foreign Trade (IIFT), Ministry of Commerce, Government of India, conducts a one year diploma course in International Trade in sea-food industry.

Vocational education and training programmes

Various state governments notably Andhra Pradesh, Bihar, Haryana, Kerala, Karnataka, Maharashtra, Odisha and Tamil Nadu have introduced vocational courses on fisheries at 10+2 level with the active assistance from National Council for Educational Research and Training (NCERT) in developing curricula, books and instruction material. Seven vocational courses, viz. Aquaculture, Fishing Craft and Gear, Fisheries, Fish Processing Technology, Inland Fisheries, Maintenance and Repair of Marine Engines and Marine Fisheries are conducted in Fisheries. Non-availability of trained and qualified teachers, lack of infrastructural facilities and equipments have been hindering the progress and popularization of vocational courses in fisheries.

Short-term training programmes of varying duration on various aspects of fisheries and aquaculture are conducted by the ICAR fisheries institutes for the benefit of fishers, entrepreneurs, scientists and teachers. Under the scheme of Centre of Advanced Studies in Fisheries Science in operation at the CIFE, Mumbai since 1994, number of advanced training programmes have been conducted on various aspects such as Genetics and Biotechnology, Environmental Impact Assessment (EIA), Fish Disease Diagnosis and Control, Feed Formulation, Marine Biotoxinology, Computer Applications etc. Short-term training programmes are also conducted by private institutes like MAC School of Aquaculture at Tuticorin in Tamil Nadu and Raman Academy at Kakinada, in Andhra Pradesh. The MAC School of Aquaculture offers four courses, viz. (*i*) Five months Undergraduate Diploma in Shrimp Farming for SSLC, (*ii*) Five months Graduate Diploma in Shrimp Farming for B.Sc. (Zoology), (*iii*) Two months Postgraduate Diploma in Shrimp Farming for M.F.Sc., B.F.Sc. or M.Sc. (Biology), and (*iv*) 15 days Shrimp Farming training certificate for entrepreneurs. The Raman Academy offers certificate courses in Prawn Farming Management and Fish Farm Management and Diploma course in Aquaculture and Postgraduate Diploma course in Aquaculture of differing durations.

The CIFE based on current needs of various stakeholders introduced Professional Development Programme (PDP) in 2009 comprising different modules at its Kolkata centre. The modules are:

- Capture and enhanced fisheries
- Aquaculture
- Fish processing quality assurance and marketing
- Fisheries development management

After completion of each module of about 4 months duration, a certificate is awarded, while completion of three modules entitles the trainee to a Diploma. The Kolkata centre of the CIFE also offers Entrepreneurship Development Programme (EDP) of six months duration in Fish processing management and trade.

The Freshwater Fish Farmers Development Agency (FFDA) and Brackishwater Fish Farmers Development Agency (BFFDA), originally established in selected districts with financial support from the Government of India, are undertaking massive training programmes in semi-intensive fish and prawn aquaculture and have already developed large trained manpower at the primary level. Presently 411 FFDAs and 38 BFDAs are functional in different districts of the country.

Quality assurance

In order to ensure quality in agricultural education including fisheries education, the ICAR initiated series of steps. The important steps include setting up of Norms and Accreditation committee followed by establishment of Accreditation Board in 1996, revision of syllabi through Deans' committee and brining uniformity in PG courses through constitution of BSMA (Broad Subject Matter Area) committees. Third Deans' committee report followed by dialogue with different stakeholders was a major step in developing detailed curricula and syllabi for UG and PG courses at the national level. The uniform UG curricula for various academic programmes were implemented from the academic year, 1998-99. Model syllabus of ICAR for B. F. Sc. Degree

programme includes 160 credits, distributed over 8 semesters. The system of introducing the Fisheries Work Experience Programme on the RAWE (Rural Agricultural Work Experience) pattern in Agriculture and Internship in Veterinary and Animal Sciences is implemented during VIII semester in all colleges for UG courses.

The ICAR constituted IV Deans' committee in 2005 which submitted its report in 2006. The committee among other things recommended norms, standards and academic regulations, restructuring of UG programmes for increased practical and in practice contents, Central assistance for strengthening higher education, guidelines for assessing training needs and performance of teaching faculty and university governance. The committee has recommended department-wise and semester-wise credit hours for UG programmes. During the first 3 years (6 semesters) 128 credit hours are recommended followed by hands on training during VII semester of 25 credits and in plant training of 20 credits during VIII semester. The areas identified for hands on training are Ornamental fish culture, seed production, trade and export management, Aqua-clinic, Post-harvest technology, and Aqua-farming. A minimum of two areas should be decided by each college/university.

In order to bring uniformity at PG level, BSMA committees were constituted by the ICAR in 1998 including one on Fisheries Science. Based on the deliberations of this committee model curricula and syllabi for Masters degree programmes in four disciplines of fisheries have been developed. In order to meet the changing needs of the sector, the ICAR constituted another BSMA committee in 2008 for defining names and curricula of Master's and Doctoral programmes in different disciplines for uniformity and revision of syllabi for these courses. The committee proposed 14 and 12 discipliners respectively for Masters' and Doctoral Programmes in Fisheries. The Committee among other things recommended mode of admission, credit requirement, minimum credit load in a semester, minimum attendance, ratio of theory to practical marks, minimum grade point for pass marks, thesis evaluation etc. The minimum duration for Master's and Doctoral programmes is 4 (2 academic years) and 6 (3 academic years) semesters, while the maximum is 8 and 12 semesters respectively. Admission is based on the performance in entrance examination coupled with academic performance. Common academic regulations also prescribe maximum permissible workload per semester to be 18 credits for Master's and Doctoral programmes. The course work for M.F.Sc. programme in major courses is 25 credits comprising 12 credits of core courses and one credit seminar. The course work for Ph.D. in major courses is 14 credits including 6 credits of core courses and two credits for two seminars. Further 12 credits of supporting courses (outside discipline) are prescribed for both M.F.Sc. and Ph.D. programmes.

The ICAR has also established Centres of Advanced Studies now called Centres of Advanced Faculty Training (CAFT) for improvement of Faculty Competence. The CIFE is one such CAFT in fisheries.

Critical issues in fisheries education

An over view of academic professional fisheries education scenario in India indicates inadequate faculty and large number of vacancies. Issues related to faculty improvement are yet to be addressed fully. Declining students' quality and number are also major concerns. The graduates coming out from the colleges do not possess adequate field experience as many fisheries colleges do not have minimal farm, vessel and laboratory facilities. The passed out students are therefore not well suited to be employed in farms and industry except for teaching and research. The library facilities and accessibility to international literature is far from adequate. The problem of inbreeding of teachers is posing a great challenge in quality improvement of fisheries education. In general, there appears to be lack of interest on the part of Faculty members or Universities to utilize the national training facilities such as CAFT created under the National Agricultural Research System (NARS) for improvement of competence. Although fisheries sector has reached the status of an industry in India, a database with details of human resources in fisheries, aquaculture and allied areas is lacking.

Steps for ensuring quality education

Adequate and competent faculty: Efforts of Education Division of the ICAR have yielded results in bringing desired level of uniformity in UG curriculum. Recommendations of BSAM committees of 2008, if implemented will also ensure uniformity in nomenclature and course content in Master's and Doctoral programmes. For delivery of course content, adequate and qualified faculty is essential. Faculty is the key resource and recruitment of competent faculty is pre-requisite for quality improvement in fisheries education. An overview of faculty strength and faculty in position at various fisheries colleges in the country indicates great degree of variation. College of Fisheries, Andhra Pradesh has minimum sanctioned strength of 14, while College of Fisheries, Mangalore has sanctioned strength of 81. Large number of vacancies also exists in most of these colleges. Six of the 18 colleges have more than 50% vacant faculty positions. The oldest College of Fisheries at Managalore has about 65% vacant faculty positions, while newly started college at Udgir has about 72% vacancies. In many colleges subjects like Statistics, Economics and Extension are taught by faculty who do not possess their qualifying degree in these subjects. Such an arrangement needs to be discouraged. It appears increasing resource constraints and inadequate planning has lead to such a situation.

Fourth Deans' Committee has recommended minimum of 22 faculty positions to conduct UG programmes. Similar exercise need to be done for colleges imparting PG education. It should be made mandatory to ensure minimum staff strength with appropriately qualified faculty. Further in order to reduce inbreeding 15% of the posts at entry level may be recruited through open national level selection as recommended by IV Deans' Committee. Short-term faculty position on deputation from industry, NGO sector and development departments needs to be encouraged to share their life time experiences with students who are entrepreneurs of the future.

Adequate infrastructure: Freshwater and brackishwater fish farms, hatcheries, soil and water chemistry, fish microbiology, fish biology, fish nutrition, fish pathology and biotechnology laboratories with adequate instrumentation facilities, pilot processing

plants and ocean going vessels are some of the major facilities required for imparting practical and meaningful education and training in fisheries. In most of the colleges infrastructure facilities are inadequate. Laboratories are poorly equipped in about 50% of the colleges and libraries with Local Area Network (LAN) are found in about only 50% of the colleges. All the colleges seem to have adequate number of class rooms but lack audio-visual aids and museum facilities. Though ICAR has been helping these colleges to develop necessary infrastructure through development grants, one time catch up grant and through National Agricultural Technology Project (NATP) and National Agricultural Innovative Project (NAIP), still much needs to be done to ensure minimum infrastructure facilities. As it is very costly to provide every facility at all the colleges, certain colleges may be chosen to develop state-of-art facilities in a chosen discipline while maintaining minimum required facilities in other areas. Increased outlay for infrastructure development in fisheries colleges will go a long way in imparting quality education.

Course content and hands on training: Fisheries is a vocational subject. Hands on experience in the field and laboratory are very essential in developing necessary skills, which should form integral part of every course. In plant training for students in processing plants, aqua farms, hatchery, feed companies, boat building and net mending yards etc., is essential to get adequate exposure. This will infuse required confidence in the students to create their own enterprises and become entrepreneurs. In order to provide increased field exposure to students, course curricula needs to be revised with increase in practical content over 50% of the total course load as recommended by IV Deans' Committee. Further, infrastructure required for imparting field training also needs to be developed.

Periodical revision of course content to address the emerging needs of the sector is essential.Courses on more cultural, gender and social sciences along with innovative programmes offering scope for self employment need to be included in curriculum.

Information communication tools: Information communication tools (ICTs) can be effectively used to share UG and PG level courses and extension programmes. Various ICT tools will be handy in this endeavour. ICT makes linkages possible with minimal cost and effort. For example, increasing use of video conferencing would improve students' exposure to large group of experts from across the country and globe. The potential of ICT needs to be fully harnessed in imparting education. The ICAR under NAIP has come out with novel idea of development of e-courses for undergraduate programmes. College of Fisheries Mangalore, and Fisheries College and Research Institute, Tuticorin have been entrusted with this task. The main objective of this project is creation of e-content to supplement class lecture, delivery of e-contents online and offline and sharing of open course and web hosting.

Competent and well trained human resources: In the era of globalization, economy is knowledge driven and induced by innovations. Raising a cadre of human resources which can effectively function in the global economy is need of the hour. Quality control of fish and fishery products for example play vital role in export of fish and fish products. In production system also quality criteria needs to be met through sustainable and eco-friendly farming by avoiding use of antibiotics and chemicals. Hence, there will be a need to raise well trained human resources on sanitary phytosanitary (SPS) measures and Hazard Analysis at Critical Control Points (HACCP), Eco-friendly farming etc. In India, economic efficiency as measured by incremental capital output ratio (ICOR) of about 4, is one of the lowest as compared to many other countries. Main reason for low ICOR is attributed to the fact that majority of workforce do not possess requisite knowledge and skills required to effectively function in modern farms, industries and service sector. Further, global competitiveness report attributes lower competence level of workers as the main reason for low average workers productivity, while placing India at first rank in terms of abundant labour force. Therefore, need of the hour in the context of globalized economy is to raise competent and skilled human resources for fisheries sector.

Linkages: There has to be close linkages between industries and educational institutes. There appears to be mismatch between requirements of the sector and human resources being produced. It is reported that only about 20% of the graduates are employable. Close linkages between academic institutes and users/clients will ensure that curriculum and educational standards meet the requirements of the sector. In order to reduce capital investment, networking among Fisheries Colleges, ICAR fisheries institutes, Government of India Institutes dealing with fisheries needs to be established and strengthened wherever it already exists. In view of globalization of higher education, ample opportunity exists for establishing close linkages with foreign universities such as Tokyo University of Fisheries in Japan, Sanghai Fishery University in China, National University of Singapore and institutions like World Fish Centre, National Aquaculture Centres in Asia (NACA), South East Asian Fisheries Development Centre (SEAFDEC), Asian Institute of Technology etc., which needs to be pursued vigorously. In this connection it may be mentioned that fisheries colleges should take advantage of Indo-US Knowledge Initiative under NAIP to have tie up and linkages with foreign universities. To start with collaboration can be in development of curriculum and content delivery and later can be extended to sandwich PG programmes where student spends a semester or two for course/research work in other university.

Human resources requirement in fisheries: The human resource is required for fisheries sector at primary level, middle level and tertiary level. At primary level it is required to produce skilled work force for field level operations such as fishing, net mending, grow out operations, hatchery operations, feed mill operations post-harvest operations etc. A certificate course of 3-6 months duration for tenth pass may be imparted to develop required skills for these operations. Such type of training may be undertaken by training centers of State Fisheries Departments/Krishi Vigyan Kendras.

The human resources is required at middle level to produce skilled technicians for hatchery management, feed formulation, aquatic health management, seed production, laboratory test operations, fish processing, floor and quality control supervisors, maintenance of machineries, marketing etc. to provide para-fisheries services as in veterinary and agricultural sectors. A diploma course of 1-2 years duration on the lines ITIs may be imparted for 10+2 pass outs by KVKs/Fisheries Polytechnics/ Fisheries College/CIFE.

Tertiary university level education is required to produce professionals for Teaching, Research and Development, Extension, Administration and Management of the sector. Graduates can fit into the role of administrators and managers, while postgraduates can be executives, policy makers, researchers and faculty members. Fisheries colleges and CIFE at present offer Bachelor (B.F.Sc.), Master (M.F.Sc.) and Doctroal (Ph.D.) programmes in Fisheries. B.F.Sc. programmes should take more generalist theme to provide firm foundation of general topics and issues of fisheries and aquaculture while specializations can be introduced at M.F.Sc. and further strengthened at Ph.D. programmes.

Assessment of human resources required for fisheries sector has always been a debatable issue, as it is yet to be objectively worked out. The estimates reported by several authors greatly differ from one another. This variation is due to lack of uniform criteria for assessment of human resources requirements in fisheries sector. A realistic demand of human resources depends on several factors such as policy, future thrust areas of development, recruitment qualifications of major employers, national and international fisheries development scenarios etc. Permission to open new fisheries colleges or initiation of new academic programmes in the existing institutions needs to be based on the actual human resources requirement of the sector.

Institute of Applied Manpower Research (IAMR), New Delhi, under Agricultural Human Resource Development (AHRD) project of ICAR financed by the World Bank carried out a comprehensive study on 'Assessment of National Manpower Needs in Agriculture and Allied Sectors' during 2001. The study was undertaken at all India level, however restricting in-depth analysis to only ten selected locations in the country. The study estimated the demand and supply of graduates and above level in agriculture and allied sectors using different approaches up to 2010. The study also recommended computerized manpower information system at all India level. Although this has been a very comprehensive study for agriculture and allied sciences as a whole, but separate estimates for fisheries sector at graduates and above level are not available.

The National Academy of Agricultural Research and Management (NAARM), Hyderabad, is presently undertaking 'Assessment of Future Human Capital Requirements in Agriculture' in collaboration with IAMR, New Delhi, under NAIP project. It is hoped that this study will throw more light on the human resources requirement at different levels for fisheries sector.

Over the past five decades of planned development, the Indian fisheries has metamorphosed from traditional, subsistence activity into a sunrise industry. Fisheries sector has made significant contributions to the Indian economy by way of augmenting production of animal protein, employment and income generation besides huge foreign exchange earnings. Annual fish production of our country is about 7.6 million tonnes (2008-09). The country earned foreign exchange of about ₹ 8,608 crore during 2008-09. In spite of all these spectacular achievements, the full potential of our country's fisheries resources have not yet been realized. In order to harness the full potential of the sector, well qualified and adequately skilled competent human resource is required to carry out research and academic activities and to meticulously plan, execute and manage various fisheries development programmes across the country. Presently 17 fisheries colleges under State Agricultural/Veterinary/Animal Science and Fisheries Universities and one Fisheries College under CAU besides the CIFE, Mumbai offer professional fisheries education in India. In order to offer quality education and to produce competent professionals these colleges and institutions need to be well equipped with fish farms, mini processing plant, feed mill, boats and art-of-state laboratories. As no single college or institute can boast of having all these facilities, networking among these institutions is need of the hour. Emphasis should be on strengthening the infrastructure facilities of the existing colleges/institutions instead of opening new colleges.

WTO controlled regime is likely to globalize fisheries and thereby bring in not only huge investments, technology etc. to Indian fisheries but also the associated maladies common to commercialization. Further unprecedented growth in brackishwater prawn farming has invited many problems which are beginning to assume alarming proportions. All this calls for altogether different developmental strategies incorporating measures such as sustainability, eco-friendliness, social audit etc. The immediate input to achieve this perhaps is the trained and qualified human resource. To this end, the task ahead is really very challenging one. It is necessary to have a re-look not only at the course curriculum but also at the relevance, application and sustainability of the education system. The imperatives of actionable issues include sub-sector wise manpower need assessment, changes in course curricula and academic management.

41. Fisheries Extension

The term extension was first coined in England, and the term Extension Education was first introduced in 1873 by Cambridge University to describe a particular educational innovation. This was to take the educational advantages of the universities to the ordinary people, where they lived and worked. It is a dynamic and flexible type of education which serves the people wherever they are, whatever they are. Extension means to extend and to spread useful information and ideas to concerned people. Education should be conceived as a life long process of learning. By definition, extension and extension education are synonymous. There are many definitions of extension education, i.e extension education is an applied science consisting of contents derived from researches, accumulated field experiences and relevant principles drawn from the behavioural sciences, synthesized with useful technology, in a body of philosophy, principles, contents and methods focused on the problems of out of school education for adults and youths.

The aim of extension education is to bring the desirable changes in human behaviour. The National Commission on Agriculture (1976) refers to extension as an informal out-of-school education and services for the members of the farm family and others directly or indirectly engaged in farm production, to enable them to adopt improved practices in production, management, conservation and marketing.

Fisheries extension brings to the fishermen, fish farmers, and fish processors the educational assistance best suited to their needs and resources. It is an informal out-of-school educational system which assists people in the fish and fishing industry, through educational procedures, in improving fishing, fish farming and fish-processing methods, increasing production efficiency and income, and improving their socio-economic conditions.

Fisheries development is closely related with the development of the ability of the fisherman's/fish farmer's understanding and adoption of new technology. Fishers need to be provided with recent, useful and practical information. Thus, there is a need for an agency to interpret the findings of research to the fishermen/farmers and to inform the problems of the farmers to the research stations for solution. This gap is bridged by extension agency. Thus, fisheries extension bridges the gap between fisheries, research station and fishing/farming community by establishing suitable teaching organizations at various levels of administration.

Objectives of extension

Objective can be defined as an expression of the end or direction of movement towards which efforts are directed. The objective of extension is to raise the standard of living of rural people by helping them using their land, water and livestock in the right way. Rural people are helped in planning and implementing their family and village plans for enhancing production and improving quality of life. The specific objectives of fisheries extension are as follows:

1. To assist people to discover and analyze their problems and identify their felt needs.
2. To develop leadership among people and help them in organizing groups to solve their problems.
3. To disseminate research information of economic and practical importance in a way people would be able to understand and use.
4. To assist people in mobilizing and utilizing the resources which they have and which they need from outside.
5. To collect and transmit feedback information for solving management problems.

Objectives give direction of movement. Before starting any extension programme, its objectives must be clearly stated, so that one knows where to go, and what is to be achieved. Extension workers are interested in more concrete expression of purpose to develop a realistic action plan to help the rural masses in solving their immediate problems.

Basic principles

A principle is a fundamental truth that has been observed/tested and found to be true under varying conditions. It is a statement of policy to guide decision and action in a consistent manner. In the history of extension work, there are certain general principles of extension education, which have been applied and tested. These principles have more or less general applications. Thus, the extension work is based upon these 15 working principles and a sound knowledge of these principles is necessary for an extension worker to be a better performer, administrator or supervisor.

- **Principle of interest and need:** To be effective the extension work must begin with the interests and needs of the people, which should form the basis. Effective programme grows out of basic information and needs that people come to feel or recognize. Therefore, the major task of extension is to convince the people of the value of new and better practices. Once people are convinced of the value of new methods and that the new methods will help them reach their goal, they will change to attain this desired goal.
- **Principle of grass-root approach:** To be successful, extension work must start where the people are after studying the situation, needs interests and problems of the people. Things must spring from below and spread like grass with active participation of people.
- **Principle of cooperation and participation:** Cooperation and participation of the people is of fundamental importance for the success of any educational endeavour. It is the basis for existence of an extension service. People, who have opportunity to participate in making decisions affecting their well-being feel that it is their own programme, and are likely to act in accordance with their decision.
- **Principle of voluntary education:** Extension is a system of voluntary education. It is a people's programme with government assistance and not the government's programme with people's assistance. Therefore, the major task of extension is to convince the people of the value of new and better practices. Once people are convinced of the value of new methods and that the new methods will help them reach their goal, they will come forward to participate in the programme.
- **Principle of teaching methods:** A suitable combination of extension teaching methods leads to the higher success in diffusion of innovations and technology. In addition to this, different methods must be used under different situations. Because not all extension methods will reach the people or influence them, a combination of various teaching methods must be considered. By and large, the changes people make on their farms, in their homes, and in their communities are in proportion to the number of times they are exposed to information through personal visits, meetings, demonstrations, and the like. Obviously, if wide response is desired, rural people must be exposed to changes by different methods.
- **Principle of local leaders:** It may not be possible for an extension worker to visit all the farmers individually. Much can be done through the local leaders. A new agricultural practice will be adopted more easily if it is recommended by a recognized farmer.
- **Principle of trained specialists:** It is very difficult for an extension worker to know the latest findings of research in all the branches of science to deal with his day-to-day activity. There is a need to provide trained specialist in every field to help extension workers.
- **Principle of satisfaction:** One of the better sources of motivation is the satisfaction that human beings derive from their own activity, especially the activity that is meaningful. When a person receives satisfaction as a result of his participation in an extension programme, he seeks further help from extension agency.
- **Principle of whole family approach:** The family is the unit of any society. All the members of the family have to be developed equally by involving all of them. Women and youth not only perform much of the labour involved but also have a great influence in decision-making. Thus, extension must be directed to family as a unit.
- **Principle of democratic approach:** Extension involves no coercion of any sort. It is largely educational and operates through discussion and suggestion. Facts of a situation are shared with people. All possible alternative solutions are placed before the participants and ultimately people are left free to decide their own choice and line of action.
- **Principle of cultural differences:** Culture of a society is the way in which people live, their customs, traditions, methods of cultivation, etc. The culture of the society is learned by each individual member of the society. In order to make extension programmes effective, the approach and procedure must take into consideration culture, tradition, habits and customs of the local people. Different cultures require different approaches. A blue-print of work designed

for one part of the country may not be applied effectively to another part, mainly because of the cultural differences.

- **Principle of learning by doing:** Extension work is based on the principles of 'learning by doing' and 'seeing is believing'. Farmers, hesitate to believe and act on theories, or even facts, until they see with their own eyes the proof of these in material form. When people learn through more than one sense they understand and remember the message more clearly. That is why, demonstrations have a great significance in extension because these show how to do a new job or showing how to do an old job better.
- **Principle of use of local resources:** Extension worker should mobilize and organize the local resources in men and material and social groups for joint and cooperative action. As far as possible efforts should be made to plan and execute all programmes locally making full use of local resources, both human and material. In this way self development will be the habit of the people.
- **Principle of aided self-help:** The main job of extension worker is to motivate the people to make efforts for self improvement. Learning becomes more effective when the learner accepts major responsibility for his own learning. But they may lack the resources to achieve their objectives. Extension agencies should provide them the necessary aid to help in their efforts towards change.
- **Principle of evaluation:** Evaluation is essential to measure the extent of achievements of the fixed objective. It is a method for determining how far an activity has progressed and how much further it should be carried to accomplish the objectives. Continual evaluation is the map or chart to provide direction. It is, therefore, necessary to undertake objective evaluation to find out the strength and weakness of the extension programme and thereby modify further action so as to increase the speed of achievements in the desired direction.

Extension teaching and learning

Extension being an educational process involves teaching and learning, which is one of the most delicate, significant, and complex of all social processes because it changes the way people think and act. Extension worker must skillfully provide learning experiences effectively. He should make people learn how to do things for themselves. He should develop farmers' ability to understand and reason, to think through problem, and arrive at wise solution. For that he should have or learn effective teaching skill for creating meaningful learning experiences among the farmers.

Learning for adoption of any new practice is attained through the following principal steps: (*i*) creating awareness of new ideas; (*ii*) developing interest for consideration of ideas; (*iii*) creating desire for more learning ; (*iv*) helping people to acquire conviction and accept new ideas and practices; (*v*) ensuring action by the learner; and (*vi*) maintaining satisfaction.

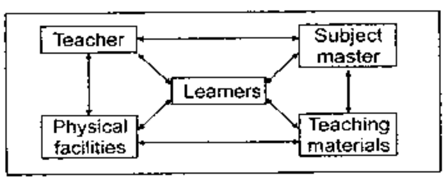


Fig. 41.1 Components of a learning situation

Learning experience is the core of the educational process. It is the mental and/or physical reaction of a learner to seeing, hearing, or doing the things to be learned.

An effective learning situation consists of five essential elements (Fig.41.1).

1. An effective instructor or leader
2. Learners who want and need to learn
3. Content or subject matter that is useful to learners
4. Appropriate teaching/instructional materials
5. An appropriate physical environment

There is a constant reaction by the learners with each of the other four major elements in the learning situation. For example, a learner may at one time be reacting to the dress of the teacher, to his mannerisms, or to his voice; at another time to his instructional aids, or to the manner in which he handles the subject matter; later to some aspects of the physical facilities or environment such as the hard chair, or poor light, noise from the fans or excessive heat. In addition to the mental focus on these elements, and many others not mentioned here, learners react to such items as outside obstructions, individual interpretation, members of the group, and personal problems. The great task of the extension worker is to minimize the almost infinite number of possible distractions to the mental process. The effectiveness of a learning experience is therefore related directly to the manner and extent of mental concentration on the subject matter.

Extension teaching methods

Extension teaching methods provide appropriate learning situation for extension workers to help people learn new ideas and practices. All methods have their own advantages and limitations. No single extension method is effective under all conditions, e.g. reading material is for those who can read, radio programme for those who have radios, meetings for those who can attend and demonstrations of recommended practices are for those who can come to demonstration site. Suitable combination methods of extension education lead to the higher success in diffusion of innovations.

Effective extension methods are classified into three categories, as given below, on the basis of the number of people they have targeted to reach.

- *Individual contact methods:* These are used in the situations where the extension worker deals with one person, e.g. farm and home visit, office calls, personal letter, result demonstration.
- *Group contact methods:* These are used in the situations where the extension worker wants to deal with a group of farmers, e.g. method demonstration; general meetings - lecture, symposium, panel; group discussion; field trip/field days.
- *Mass contact methods:* When the extension worker wants to reach large number of people he uses mass contact methods. The mass media like television, radio, newspaper, circular letters, exhibits, mobile units, audio-visual aids, campaigns, fairs, etc. are used to reach a large number of people.

Audio-visual aids in extension teaching

These are the aids or devices or means through which an extension worker conveys the messages meant for farmers. Audio-visual aids include pictures, posters, handouts, flip books, chalk boards, flannel graphs, slides, tape recorders, movie films, etc. All these help farmers understand the message more clearly because they do not only hear words but also see pictures. In this method, people learn through all their senses; that is to say, what they see, what they hear, what they smell, what they taste or what they feel. When more than one sense is used, learning becomes more meaningful and lasting. All these means help fish producers understand the message more clearly. These devices are categorized as:

Audio aids: These are the instructional devices which can be heard only, e.g. radio, tape recorder, audio cassette, audio CD, etc.

Visual aids: These aids can be seen only, e.g. photographs, posters, charts, etc. These can be of two types: (*a*) projected visual aids – light passes through them and these can be shown on the screen with the help of projectors, e.g. slides, film strips, etc., and (*b*) non-projected visual aids – these are opaque and cannot be projected on the screen, e.g. models, specimens, photographs, charts, posters, chalkboards, etc.

Audio-visual aids: These can be heard as well as seen, e.g. film, television, video conferencing, drama, puppet show, etc.

Mobile units

Mobile units consists of exhibits, models, displays and many other audio-visual materials in a vehicle, which can reach even remote rural areas and the entertainment value of the facilities attracts a large audience who otherwise might not learn the extension messages. It can reach large numbers of people in different parts of the community fairly rapidly, particularly those people who do not read newspapers or listen to radio programmes. However, it is costly and materials for use in mobile units take time to prepare. It is also hard to maintain the vehicles and equipment in a serviceable condition particularly when the units are operating in remote areas.

Trickle Down System (TDS) of aquaculture extension for rural development

Trickle Down System (TDS) approach was designed by the FAO/UNDP project Institutional Strengthening in Fisheries Sector, and subsequently was implemented in Bangladesh on a pilot scale through a FAO project Strengthening Rural Pond Fish Culture Extension Services. The activities were started in mid 1990 with the objective of providing extension services to 60 fish farmers to raise their average production from 1,000 kg/ha/year to at least 2,000 kg/ha/year. The extension services provided mainly training of selected farmers in the technology of semi-intensive carp polyculture and technical support through visits to the farmer's pond. The project did not provide any financial or material support to farmers. As per the designed TDS approach, each of the selected 60 fish farmers functioned as Result Demonstration Farmer (RDF) to neighbouring 10 fish farmers (FF). The fish farmers were invited to participate in

training and demonstration which were carried out in the ponds of RDFs. Most of the RDFs completed their production cycle and achieved an average production over 3,500 kg/ha/year. The main features of the technology included appropriate stocking density and stocking ratio, daily manuring and multiple harvesting and stocking. As against 15 ha of demonstration pond area which was the objective of the project, a total of over 130 ha and 570 ha were brought under demonstration through direct (under RDF) and indirect (under FF) operation, respectively, achieving an average production of about 3 tonnes/ha/year (*Source:* FAO, 1993).

The project could achieve outstanding performance and succeeded in developing a new extension model for technology transfer/dissemination, where the selected fish farmers (RDFs) after being trained on semi-intensive, low-cost methods by the experts in turn taught the other fish farmers (FFs) at no cost – a trickle down (TDS) extension approach. In recognition of the commendable success of TDS approach, the 1996-97 Edward Souma Award was given to the Department of Fisheries, Government of Bangladesh, by the FAO in 1997. The TDS was aimed at developing self-reliance and awareness in the minds of fish farmers about aquaculture by repeated training, demonstration and close supervision by field-extension personnel. It was also observed that farmer-to-farmer extension service in small groups was very effective.

Earlier attempts for transfer of technology in fisheries

Royal Commission on Agriculture (1928) noted that nothing was being done to develop country's fishing industry and recommended to Government that departments' utility should not be judged from the amount of revenue it earned. Grow More Food Campaign (1940) recommended an organized thrust for development of fisheries. Accordingly a Fisheries Experimental Station was set up at Barrackpore near Calcutta (*now* Kolkata) which is the present Central Inland Fisheries Research Institute. Training centres on fisheries were established in Barrackpore, Calcutta and Mandapam in 1945.

The first All-India Fisheries Conference (1948) convened in New Delhi recognized the importance of fishing industry at the hands of the concerned officials of the Central and State Governments and did focus its attention on the need to develop fisheries industry. The idea of subsidizing some part of the capital expenditure, especially on mechanism, originated in this Conference. National Demonstration Project was launched in 1964-65 and operated in 48 districts of 21 states of the country. Demonstrations on fish culture were done in the ponds of the farmers by the scientists. Significant increase in the fish production from the demonstration ponds in different states was achieved.

All India Coordinated Research Project (AICRP) on Composite Carp Culture started in 1971 for demonstrating composite carp culture technology in different agro-climatic conditions of the country. Production ranged between 3.5 and 6.3 tonnes/ha/year with a maximum of 10.5 tonnes/ha/year. The AICRP on Air Breathing Fish Culture was launched in 1971 in West Bengal, Karnataka, Andhra Pradesh, Bihar and Assam (now Asom) to evolve appropriate technology for air-breathing fish culture in swamps, ponds, tanks and derelict water-bodies. The Marine Products Export Development Authority (MPEDA) was established in 1972 to augment country's fisheries production and promote export of seafood.

The Rural Aquaculture Project by the International Development Research Centre (IDRC) was launched in 1975. The thrust was on demonstration of various aspects of aquaculture (carp production, carp seed production) by providing all necessary inputs and technical know-how for improving rural economy. This was operated in 75 villages in West Bengal and Odisha covering 111 ponds. Operational Research Project (ORP) was launched in 1974-75 to disseminate proven technology in a cluster of villages and to identify constraints (technical, extension and administrative) thereof for rapid dissemination of technical know-how.

The first Krishi Vigyan Kendra (KVK), was established in 1974 on a pilot basis, at Pondicherry (*now* Puducherry) under the administrative control of the Tamil Nadu Agricultural University, Coimbatore. KVKs are the grass root level institutions and are designed to impart need-based and skill-oriented vocational training in agronomy, animal husbandry, horticulture, fisheries, home science etc. to farmers, farm-women, unemployed youth and extension workers through work experience. Presently, there are 591 KVKs in India, distributed in 8 different zones.

World Bank-aided Inland Fisheries Project (1979) provided credit assistance for construction of modern fish-seed hatcheries. In total 63 hatcheries had come up with World Bank assistance in Uttar Pradesh, West Bengal, Bihar, Madhya Pradesh and Odisha.

The project basically involved reorganization of the already existing community development approach of extension by injecting an element of professionalism in extension service through a single-line of administration.

Lab to Land Project was started in 1979. The objective was to transfer technology from research laboratory to farmers' field in order to improve the economic conditions of small and marginal farmers. Enhanced fish production from the aquaculture ponds was also obtained under this project.

Fish Farmers' Development Agency (FFDA) was initiated by Government of India in 1974-75 to popularize fish culture as an alternative means of employment generation and removal of poverty. Under this scheme training was given to selected beneficiaries assisting in construction and renovation of the water resources, arranging credit facilities from Nationalized Banks, technical and input support and finally helping in marketing of produce.

National Agricultural Extension Project (NAEP): The basic objective of the project was to bridge the gap between well-developed research system and that of extension system, so that transfer of technology could take place at a faster rate was launched in 1983.

Brackishwater Fish-farmers' Development Agency (BFDA): This was established in 1985-90 with an objective to utilize country's vast brackishwater resources for fish/shrimp culture. The BFDA provides technical, financial and extension support to shrimp farmers, and it has made substantial contributions.

Institute-Village Linkage Programme (IVLP) (1996): This was launched for assessment and refinement of technology in the light of bio-physical and socio-economic constraints. The project achieved success in obtaining farmers' participation and increasing fish production.

Agricultural Technology Information Centres (ATICs): Project was started with the objective of 'single window system' delivery of products, information and services to farmers and entrepreneurs. Located near the main entrance of university/ research institution, ATIC is rendering services much more effectively. All contents are made available in the net having link with all other ATICs located elsewhere, thus making it possible to retrieve information from any ATICs sitting at one place. Presently there are 44 ATICs of which 3 are operating in specialized fisheries research institutes in the country to cater to the needs of the fishers.

Jai Vigyan Mission was, launched in 2000, for ensuring household food and nutritional security through enhancing productivity of fisheries in tribal, backward and hilly areas of Odisha, Chhattisgarh and Asom.

As it could be seen the thrust of Transfer of Technology (ToT) projects launched during seventies and eighties was on adoption of new /proven technologies generated elsewhere. This period also witnessed material support to farmers; being an integral part of extension efforts. A significant shift took place during nineties. The IVLP was launched to provide technology packages suitable to microsystem within which a farmer operates. Farmers' participation in the programme and their involvement in technology assessment and refinement gained momentum through IVLP. On-farm research/on-farm trial helped a great deal in bringing in the 'missing link' in technology-generation process. This had not only led to the generation of refined technology but also enabled greater acceptance among farming community.

Constraints to transfer of aquaculture technologies

Although fish farming is of national importance progressing impressively, some problems and constraints –social, technical, economic and institutional – remain. Some of these problems perceived by the fish farmers and fishery extension officers are given below.

Problems as perceived by farmers

High cost of feed: Feed constitutes around 50-60% of the total variable cost in fish farming. Low-cost technology using appropriate combination of locally available low-priced feed ingredients needs to be evolved and promoted.

Non-availability of quality seed: Fish farmers often do not get pure, healthy seed instead what they get is a mixed one. Smaller size and high mortality are some other constraints indicated by the farmers. Non-availability of exotic carp seed is also a limiting factor for culture operation. Aquaculture cannot be carried out without a reliable supply of fish-seed. To ensure sustained supply of fingerlings in rural areas, it is essential to involve the private entrepreneurs to produce and distribute seed.

Absence of organized marketing: Fish is a highly perishable commodity. Market for its speedy disposal is a pre-requisite for fish farming. Transportation also poses a problem for farmers. In the absence of organized market, farmers sell their produce to middleman. At times they are being deprived of remunerative price. Due to lack of refrigeration/preservation facilities at the village level, major portion of fish catch is sold as fresh. The most common marketing channel, reaching consumer is, Fish farmer, Whole seller, Retailer, Consumer.

As fish is marketed through middlemen, fish farmer is unable to get major share of the consumer price since all these intermediaries have profit margin. There is a wide spread gap between what consumer pay and what farmer (producer) receives.

Poor technical skill of farmers: Future technologies are going to be knowledge- and skill-intensive. Surveys have shown that majority of fish farmers follow old practices and as a consequence they get very low yield (sometimes below 1 tonne/ha/ year). Farmers lack expertise in dealing with disease and mortality. Technical competency to bring about the adoption of new knowledge and skill is being emphasized. Informal education, group discussion, community video, method demonstration - all help in reinforcing the skill for improved technology.

Paucity of credit: The introduction of scientific fish farming necessitates higher doses of certain inputs which call for substantial amount of credit. In India, most of the credit flows are from the private non-institutional sector. Merchants provide finance for fishing operation in inland capture. Apart from marketing agents, professional money-lenders advance credit against securities of gold and agricultural properties. Problems like multiplicity of ownership, non-recognition of aquaculture as a land-based activity, the absence of long-term leasing policy and non-assurance of seed supplies at the appropriate time constrained the access to credit. Logically any economic activity which ensures a net return higher than prevailing rate of interest should face no difficulty in getting funds for investment. It is suggested that fish farmers should get easy access to institutional credit of both short- and medium-terms.

Social issues: Multi-ownership is considered another constraint in the development of aquaculture in the country as sizable number of owners would not be willing for its use for fish culture or share initial investment for improving pond. As joint owners get all the benefits without any effort, it leads to conflict.

The improved technology envisages complete removal of weeds, predatory fishes, insects and animals like frogs and snakes from pond environment. Though initially the unwanted animals are eradicated through application of biocides, there is danger of willful introduction by rivals which causes biological hazard in the way of successful operation of composite fish culture. Poaching and poisoning are also indicated by farmers as social problems hindering aquaculture operation.

Constraints as perceived by fishery extension officers

The constraints perceived by the Fishery Extension Officers (FEOs) are reported as: lack of manpower; high target set for FEOs; lack of proper equipments; lack of proper linkage with research system; problems caused by middleman; undesirable intervention by local leaders; scanty guidance by superior; lack of opportunity for in-service training; FEOs are not provided with vehicle facility; absence of other facilities of modern life; no incentive for good work; and promotional avenues are limited.

Emerging issues of extension

Participatory fisheries management

Participatory fisheries management is an innovative approach to decentralize management authority and make fishermen resource managers. The idea of resource users as resource managers makes sense because it is in their interest to ensure that the fisheries resources' long-term productivity, stability, sustainability, equity, and biodiversity are looked after.

What is participation?

Participation means act of partaking or sharing in. It is also defined as a dynamic group process in which all members of a work group contribute, share or are influenced by interchange of ideas or activities towards problem solving or decision-making. Generally denoting it is the involvement of significant number of persons in situations or actions, which enhance their well-being.

Benefits from participatory fisheries management

Benefits of participatory fisheries management are: (*i*) rational exploitation of fishing resources; (*ii*) equitable distribution of benefits; (*iii*) conformity to agreed terms; (*iv*) amicable conflict resolution; (*v*) generates additional income; (*vi*) usufructory benefits - small indigenous species.

How to enlist people's participation?

A clearly defined fishery boundary in the form of definite location; type and number of stakeholders (members of the community, panchayat, fisheries department, etc.); fishery resource to be managed; a local institutional set up; bottom up planning; employment; benefit sharing.

Privatized fisheries extension

Shrinking public investment, growing willingness of farmers to pay for services, shifting priorities of aquaculture production towards high-value products — prawn, carb, ornamental fishes– have led to emergence of privatized extension services. Though it could be difficult to shift to privatized mode, a beginning should be made in well-endowed areas. Besides partial recovery of cost, privatization renders extension system more accountable to information seekers. Many private players are engaged in quality seed production, intensive and super-intensive culture, processing, value-addition, ornamental fish breeding and culture, etc. Some private firms have their own well-knit network of R&D, extension and marketing.

Gender issues in aquaculture

Women have been involved in fishery-related activities from time immemorial.

Until few years ago women's role was thought to be confined to processing catch and marketing it to nearby places. However, little is quantified about the contribution of women in fishing and other ancillary industries. Fishing has normally remained a man's domain. However, there are some fishing methods that are practised by women. Fishery activities often generate high income, which inevitably helps households, while at the same time variations along the gender line with respect to labour, techniques of aquaculture, and decision-making role are acute.

Gender is a neutral concept describing social, economical, cultural and political differences between man and woman. The roles and responsibilities associated with gender differ from society to society, depending on the social attitudes and values. Participatory rural appraisal technique, encompassing a large number of tools, helps us to understand gender issues in planning and implementing aquaculture projects.

Issues need to be addressed

- Marginalization by new tools and systems
- Marketing
- Inadequate recognition
- Gender bias
- No specific government strategy to address gender roles in fishery development.
- Poor extension linkage

What is the way out?

- Strengthen men and women's awareness of their rights and contribution as well as opportunities in fishery.
- Organize more technical skill training for women in fishery, and also conducting on-site training programmes for human capital development.
- Deployment of women extension workers to provide them better access to information.
- Promotion of cooperatives and women's association for landless and poor women to enable them have stronger bargaining power and effective control over market forces.
- Generate gender-sensitive strategies towards the formulation of fisheries development plans based on realities to avoid marginalization of women.
- Continued effort to understand the contribution of women to the fisheries sector and the constraints being faced by them.

Culture of ornamental fish in the backyards of households requires very little space, skill and time and has the potential to improve economic condition of the household. In Tamil Nadu, women were trained in various aspects of ornamental fish culture and they were organized into a fish growers' group. With their newly developed skill, they were able to generate a better income for the family. This revealed that, developing technical skill in fish-culture practices in women has been beneficial to improve the economic condition of the family.

Use of modern technologies

Modern tools including Expert system, Remote sensing, Geographic information system, Cyber extension are presently being used in fisheries. With these, there will be upsurge in application of information technology in extension in future. Some common tools using satellite communication are as follows.

VSAT

VSAT is an acronym of Very Small Aperture Terminal that is used to receive/transmit satellite transmission by the terminals installed at geographically dispersed locations connecting to a central hub via satellite using small diameter antenna dishes. This technology uses a cost-effective solution for users seeking an independent communication network connecting to a large number of geographically dispersed sites. VSAT networks offer value-added satellite-based services capable of supporting internet, data, LAN voice/fax communications. The main advantage of VSAT communication over cable are: VSAT connection cost does not depend on distance, and cost per connection comes down considerably when more new users are added. The VSAT system can be utilized in the following ways: interactive computer transaction; video teleconferencing; database enquiries; voice communication; e-mail; sales monitoring and stock control; distributed remote process control and telemetry. VSAT network comes in various shapes and sizes ranging from point to point, point to multi point, and on demand for those and of sites based on a dedicated facility located at their own site.

GPS

It is acronym for Global Positioning System. This equipment is a hand-held satellite navigation system and uses the satellites in space to find the position anywhere on the earth. Thus this system is a constellation of satellites that orbit the earth twice a day, transmitting precise time and positioning information to anywhere in the globe, in a 24-hr day. The GPS constellation consists of 24 satellites orbiting the earth in 6-fixed planes that are inclined at 60° from the equator. Each satellite is 11,000 nautical miles above the earth and orbits earth twice a day. This system was initially developed and deployed by the US Department of Defence, primarily to provide entire worldwide positioning and navigation data to US and allied military forces around the globe. GPS has got enormous use in civilian and commercial applications ranging from navigation and surveying to exploitation and tracking.

Some common applications of GPS in aquaculture

- Finding the aquaculture potential and threat sites in streams and locating these points on map.
- Measuring atmospheric parameters affecting the aquatic habitat and livings.
- Finding meandering nature of stream and assess the potential of arrangement of aquatic livings.
- Finding relative distance among threatened, exploited and potential sites and locating these features on map for path analysis.

Remote sensing

Remote sensing (RS) is the science and art of collecting data by technical means on the object on or near the earth surface and interpreting the same to provide useful information. It is a technique of observation which has progressed from simple process of viewing the landscape from a hill top to the complex process of gathering data and imaging satellites and processing the same through visual or computer analysis and presenting the information in the form of maps, graph or statistics.

The utility value of remote-sensing technique to fisheries and aquaculture can be as:

- Location and enumeration of water-bodies and maintaining their up-to-date inventory.
- Calculation of dimension of river and lakes.
- Study of geomorphology and productivity of water-bodies through measurement of chlorophyll and temperature.
- Study of environmental impact as a result of human intervention and natural phenomenon, location point of source of pollution, spread of groundwater.
- Study of ocean currents, freshwater flow into seas, and offshore upwelling of groundwater.
- Indicating sea-surface temperature gradients for identification of potential fishing sources in seas and oceans.
- Mapping surface water, seasonal variations and extent of floods.

Potential fishery zone forecasting

The Potential Fishery Zone (PFZ) information in the form of maps is generated by compositing daily sea-surface temperature (SST) images of 3 or 4 days and analyses of data to obtain maximum thermal gradient information. These images are filmed to prepare relative thermal gradient images. From image, features such as thermal boundaries, fine scale (0.2°C), relative temperature gradients to sharp (1°C) contour zones, fronts, eddies and upwelling zones are identified. Name of the landing centres and landmarks are also marked and the location of the PFZ area with reference to a particular fish-landing centre is drawn. The PFZ map also possesses the distance in km, bathymetry in meters, validity period and longitude and latitude bearing in degrees.

Geographical Information System (GIS)

In a nutshell, GIS is a computerized map-making device for displaying a variety of complex geographical and non-geographical information into a single map to be used for ready reference while planning for development and management. It is especially useful where many diverse factors have to be considered to reach a decision, where factors differ in importance and in situations where factors themselves are quite variable spatially. Precisely it provides information on aspects like where? ; how much area?; how far away ? etc., required for aquaculture administration.

The application of GIS in the field of fisheries are: Study of land-use pattern including mangroves and forest cover of a particular area; Mapping changing patterns of turbidity; Identification of suitable area for aquafarming and recommending dosages of different inputs for aquafarming; Determining best location for site of salmonid sea cages; Assessing proximity of aquafarm sites to market, processing plants; Coastal zone management and village-level planning; Identification of optimum areas for inter-tidal molluscan culture, extensive shrimp and fish culture in salt ponds; Explaining circulatory dynamics in estuarine environment.

Significance of indigenous technical knowledge (ITK) in aquaculture

Rural people of developing countries have no choice but to rely on traditional technologies because sophisticated technologies of developed nations are generally irrelevant and of course impossibly expensive. ITKs offer low-cost approaches with potentially high benefits. It can be incorporated into existing effort to enhance and expand effectiveness. It can also serve as a basis for new initiative. Exported technologies that ignore local approaches to local problem are superfluous and wasteful. Indigenous technology which is found to be valid after evaluation and assessment by the experts can prove useful for other similar regions as well.

Compilation of ITKs will be a great contribution to history of agriculture. These were passed on from generation to generation by words of mouth and with the passage of time by virtue of adoption of modern technologies, ITKs are now gradually disappearing. Unless conscious effort is made to track and document the valuable knowledge it will be lost soon and not to be regained in future at any cost. The ICAR has already made a compilation of ITK in agricultural sector, including fisheries/ aquaculture; and its usefulness in marine fisheries and freshwater fish culture operations (ICAR.2003. *Inventory of Indigenous Technical Knowledge in Agriculture*, ICAR, New Delhi).

New initiatives in fisheries extension

Single window delivery system, Agricultural Technology Information Centres (ATICs), established at selected State Agricultural Universities and ICAR Institutes, forged a better interaction between researchers and technology users. This serves as a single window system with an objective to help farmers and other stakeholders to provide solution to their location-specific problems and make available all technological information along with technology inputs and products for testing and use by them. Of the 44 ATICs operating in the country, three ATICs are operating in specialized fisheries research institutes, namely Central Institute of Freshwater Aquaculture (CIFA), Bhubaneswar, Odisha; Central Marine Fisheries Research Institute (CMFRI), Kochi, Kerala, and Central Institute of Fisheries Technology (CIFT), Kochi, Kerala, to cater specifically to the needs of the fishers.

Farm school on the AIR

Latest technologies are taught to farmers by offering series of lessons broadcast over a period of time (3 months usually). Each broadcast ends with a few questions, and audiences are encouraged to participate. Audiences are asked to send in reply within a weeks time. From among the right entries draw is conducted and selected ones are awarded.Aqua-service Centres. Unemployed educated youth have started operating aqua-service centres in the line of agri-clinics. These centres are offering services like soil and Water testing, feed analysis, disease diagnosis, market intelligence, etc. Besides, these centres are in the business of selling inputs like feed, fertilizers, pesticides, other therapeutics, etc. In Andhra Pradesh, several such service centres could be found in Kolleru lake area of West Godavari district. These are having various nomenclatures, namley farmer facility centre and aqua-service centre.

One-stop aqua shop

One-stop aqua shop (OAS) provides better access to farmers regarding appropriate aquaculture technology as well as information on government schemes and rural banking and micro-finance. It has been reported that in Purulia one such OAS (Matsya Seva Kendra) has been started by an unemployed youth. The shop is a single outlet for all inputs that a fish farmer may require in fish cultivation. The inputs include, fish feed, fertilizer, chemicals etc. Besides, OAS is helping farmers in providing information on fish farming through posters and though information brochures supplied by state departments, and research institutes. This is becoming quite popular. One OAS has also been established in Ranchi, Jharkhand, and four more have come up in Balangir and Nuapada of Odisha.

Initiatives in information and communication technology applications

Aqua choupal: Aqua choupal, the unique web-based initiative of ITC Ltd, offers farmers of Andhra Pradesh all the information, products and services they need to enhance productivity, improve farm gate price, realization and cut transaction costs. Farmers can access latest local and global information on weather, scientific farming practices and market prices at village itself through web portal– all in Telugu. Aqua choupal also facilitates supply of high-quality farm inputs as well as purchase of shrimps at their doorstep. The M S Swaminathan Research Foundation has developed info-villages to help ensure food security. The project includes local language content and wireless internet access. Started in 1998 in 10 villages in Puducherry, it also provides relevant information regarding fish density in ocean to fishermen community.

Rural knowledge centre: Rural Knowledge Centre is a part of nationwide plan and has been set in motion in July 2004 by the Centre in collaboration with the States, National Association of Software and Services Companies (NASSCOM), UNDP and a host of NGOs. Its primary aim was to set up multipurpose resource centres at all the six lakhs villages of the country by 2007, for which an initial sum of ₹ 100 crore was allocated by the Centre. The public–private partnership is expected to help eradicate poverty and improve the lives of the poor people through application of information communication technology (ICT). Each knowledge centre, to be run by local self help groups, would cater to knowledge-based livelihood and create income avenues for rural people, farm community and disadvantaged people. It is an innovative attempt to explore the in-depth interdependence between ICT and human development and

demonstrate empirical links between the two using millennium development goals of the United Nations as the benchmark. It will lead to rural knowledge revolution and aid in capacity building. Establishment of such knowledge centres is expected to go a long way in revitalizing traditional knowledge and lessen digital divide.

The fruits and benefits of an effective extension service have long been recognized, yet very often extension services in developing countries have failed to accomplish desired objectives and meet people's expectations. In Indian context, role of agriculture extension in bringing benefits of the Green Revolution to farmers and making country self-reliant in food production has been appreciated. In the same way, fisheries extension has to play a very important role in achieving the Blue Revolution in the country.

42. Responsible Fisheries and Aquaculture

Fisheries, which includes the catching, processing, marketing and management of fish and aquaculture (farming of fish and shellfish), is increasingly contributing to the economic growth and nutritional security of the nations. Millions of people all over the world depend upon fishing and fish farming for their livelihood. According to the FAO, capture fisheries and aquaculture supplied the world with about 110 million tonnes of food fish in 2006, providing an apparent per caput supply of about 16.7 kg (live weight equivalent). Of this, aquaculture accounts for 47%. Aquaculture continues to grow more rapidly than all the animal food-producing sectors. This sector has grown at an average rate of 8.8%/year since 1970 compared to only 1.2% for capture fisheries and 2.8% for terrestrial farmed meat-production system.

India is the world's third largest fish-producing nation, with second highest production from aquaculture. In India, out of the total fish production of 7.64 million tonnes (2008-09), the marine sub-sector accounts for approximately 39% and the remaining comes from the inland sector. Fisheries contribute to the national income, food and nutritional security, a source of foreign exchange and employment generation. It is the principal source of livelihood for a large section of people, especially in the coastal rural areas. The contribution of fisheries to the national GDP, which stood at 0.46% during 1950-51 has gone up and is around 1.10% currently. The share of fisheries in agricultural GDP has also increased during this period from a near 0.84% to 5.3%. Efforts should be intensified to sustain the growth rate of fisheries and its contribution to the national GDP through responsible development of this sector.

Issues or problems in Indian fisheries

Marine fisheries

The FAO data indicate that global marine capture fisheries increased more than four times since 1950, and peaked in 2004 at 103.7 million tonnes. According to the FAO, marine capture fisheries resources are now considered close to full exploitation world-wide with about 52% fully exploited, 24% over-exploited, depleted or recovering from depletion and 24% only with some capacity to produce more than they presently do. The situation is reported to be more critical for some of the highly migratory, straddling fishery resources which are mostly exploited in the high seas. The maximum capture fisheries potential from the world's ocean has probably been reached and calls for a more cautious and closely controlled development and management of world fisheries. An ecosystem approach to management is increasingly being recommended as the desired policy solution to the declining health of marine ecosystems and the size of fish stocks.

In India, the marine fisheries sector has passed through three recognized phases. The initial phase from 1950 to 1965 was a pre-development phase, wherein fishing

was largely dominated by small non-mechanized indigenous crafts and gear, and low level of mechanization of fishing craft and gear. In the second phase, 1965-80, there was major extension in the use of synthetic gear, focus on exports, increase in the number of mechanized vessels, investments in new fishing harbours, introduction of purse seine boats and the commencement of motorization of traditional craft to extend their areas of operation. The third phase (1981-2000) was characterized by rapid growth in motorizing the artisanal fleet and further extension of fishing operations in off-shore areas, extended voyages and introduction of closure of selected fisheries, etc. The current phase (2001 onwards) is characterized by stagnating fish catch, increased conflict over fishery resources, mounting investment needs, diminishing returns, increased energy and exploitation costs, export market fluctuations coinciding with the major changes in the global and domestic micro-economic environment.

Inland capture fisheries

Globally, inland fishery resources appear to decline as a result of habitat degradation, mainly caused by the increased utilization of freshwater for hydropower generation and agriculture, and over-fishing. In Indian rivers, there are wide variations in water flow from year to year and season to season due to fluctuations in monsoon intensity and climate change. Besides, many of the rivers, a few lakes and reservoirs are common to many states and the management of riverine fisheries resources varies from state to state, making it more complicated and ineffective. In the case of north-eastern states, private tanks are numerous and the demand for water to do fish culture is very high in view of the high value of fish in these regions. Rapid industrialization has caused pollution problems in inland water-bodies affecting fish life. Though catch statistics is inadequate to assess catch status, scientists have noticed signs of over-fishing as reflected in the catch which consisted mostly of small fish.

Aquaculture

From a production of less than 1 million tonnes per year in the early fifties the global aquaculture production reached 51.7 million tonnes in 2006, with the Asia-Pacific Region accounting 89% of the global aquaculture production. India has abundant fresh, brackish and marine water resources, currently either under-utilized or unutilized for aquaculture, and a rich biodiversity to harness for farming in fresh, brackish and marine water-bodies. The present scenario is that only freshwater aquaculture, notably carp culture, is witnessing considerable growth with minor contributions from catfish and freshwater prawns. In the freshwater aquaculture, 84% of India's aquaculture is on account of major carps and there is a need to bring more species and technology development for seed production for different varieties of fish. The coastal brackishwater aquaculture sector is under severe stress due to disease outbreaks and environmental problems, and hardly 12% of the potential area (1.2 million ha in the coastal area) has been developed. The mariculture sector is yet to take off, though sea-weed culture in Tamil Nadu and mussel culture in Kerala are taking roots.

The shrimp-culture sector witnessed substantial growth during the early nineties and production levels reached about 140,000 metric tonnes during the beginning of this decade. However, the setback caused on account of viral disease, the growth rate of the sector slowed down and the production level during 2008-09 declined to about 88,000 tonnes. Crisis witnessed during 1995-96 with an outbreak of viral disease (white spot) posed social, ecological and economical issues mainly on account of improper planning, unregulated growth, and unsustainable farming practices. The concerns against shrimp farming largely include: conversion of agricultural land, salt pans, mangrove areas; salinization of aquifers; destruction of mangroves; displacement of labour; use of poor-quality seed and feeds, and injudicious feed-management practices; outbreak of diseases; use of banned chemicals, antibiotics and pharmaceuticals; impact of farm effluents on the vicinity of discharge points; safety of the farmed product for human consumption; and social conflicts among different user groups. All these issues as well issues related to other forms of fishery are currently addressed by Code of Conduct for Responsible Fisheries.

FAO's Code of Conduct for Responsible Fisheries

The Code of Conduct for Responsible Fisheries (CCRF) was unanimously adopted by the FAO in October 1995. The CCRF or simply the 'Code' as it is popularly known, defines the general principle that "The right to fish carries with it the obligations to do in a responsible manner". The Code sets out principles and standards of behaviour for such practices and aims at effective conservation, management and development of living aquatic resources. The main objective is to ensure that the resources are utilized in a sustainable and responsible manner through adoption of sound national and international policies and programmes. The Code covers in its 12 articles not only the capture of fish and fishing operations but also the processing and trade in fish and fishery products, aquaculture, fisheries research and the integration of fisheries into coastal area management, etc.

The Code provides the required framework for national and international efforts to ensure sustainable exploitation of aquatic living resources in harmony with environment. On fisheries management, the code advocates conservation and management measures based on the best scientific evidence available. The code suggests setting up of mechanisms for monitoring, surveillance, control and enforcement of fishing. The Code advocates optimum fishing fleet and gear to ensure sustainability and precautionary approach as the guiding principle for fishery management and that regulations should facilitate resolution of conflict among fishers. The Code also advocates measures to minimize waste, discards, catch by lost or abandoned gear, catch of non-targeted species, etc. It also suggests integration of fisheries into coastal area management and urges an institutional framework and policy measures to facilitate sustainable use of coastal resources.

Steps initiated by India to implement responsible fisheries and aquaculture

Marine fisheries: Certain landmark decisions have been taken by the Government of India to implement various provisions of the Code to ensure sustainable development of fisheries. A national level Committee has been set up in the Department of Animal Husbandry, Dairying and Fisheries for the implementation of the FAO's Code with members drawn from research institutes, State Governments and other stakeholders. The Code has been translated into all the regional languages and copies have been made available for distribution to user groups. Various programmes have been designed to create the required awareness among the fishermen and fish farmers. Towards optimization of fishing fleet, a national level Committee was constituted which has made an overall assessment of the existing fishing fleet vis-à-vis potential and recommended future deployment of different categories of fishing vessels below 20 m over all length (OAL) in the territorial waters and its contiguous deeper zones.

Another national level Committee has revalidated the existing fisheries potential in the Indian Exclusive Economic Zone (EEZ) to have precise information on the potential resources for future planning and exploitation. For resource conservation, the monsoon fishing ban of 45 days in both east and west coasts has been imposed which reduces the fishing pressure and stimulate rejuvenation of fish stocks. The comprehensive marine fishing policy formulated by the Government of India in November 2004 underscores the need for stringent management regimes in marine fisheries in place of the open-access system in vogue in territorial waters. The broad objectives of the policy are to ensure development of marine fisheries at the sustainable level in a responsible manner and to ensure socio-economic security to the fishing community and to address concerns of ecological integrity and biodiversity.

Closed fishing season: The breeding season and periodicity of various marine fish and shell-fish species depend on a wide variety of oceanographic, meteorological and ecological parameters which vary from place to place in the Indian Ocean, the Arabian Sea and the Bay of Bengal. The maritime State Governments and the Government of India have been issuing ban orders for fishing operations in certain periods during the monsoon months every year. The monsoon ban was imposed to conserve and replenish the fishing resources of the Indian EEZ by protecting them during this period.

The Government of India constituted a Committee in January 2004 to study and report the impact of closed fishing season on the marine-fishing resources, its relationship with the population dynamics, maximum sustainable yield or maximum sustainable economic yield, etc. The major findings and recommendations of this Committee summarized are:

- There is no uniform closed season as the period and duration as well as the type of fishing craft or fishing banned varied from state to state.
- Closed season in its present operational regime has not positively impacted the fishery resources but has helped to some extent in allowing a respite for the resources for partial recovery.
- Though it is impossible to have a closed season coinciding with the peak breeding of all commercial species, closed season is very essential for recovery of the fish stock.
- Mandatory closed season for 47 days (from 15 June to 31 July in west coast and from 15 April to 31 May in east coast) every year is recommended.
- Only sustenance fishery using traditional and non-motorized or motorized boats

of less than 10 HP should be permitted and no further increase in such crafts should be allowed during closed season.

- Central assistance and Centrally Sponsored Schemes in fisheries in maritime states should be linked to total compliance to the regulations.

The Committee observed that the positive impacts can be ensured only if all the initiatives are uniformly implemented in toto – all along the coasts.

While formulating the regulatory-management tools, it is essential to consider the socio-economic condition and employment opportunities of fishermen belonging to different economic and ethnic groups, so that such measures could be implemented ensuring maximum benefit; there should be alternative opportunities for their livelihood and basic needs. As the success of implementation of regulatory measures largely depends on the involvement of fishermen, it is necessary to educate and empower fishermen communities to practice self-regulation to resolve conflicts.

Aquaculture: While a number of efforts have been taken to regulate coastal aquaculture activities to develop it as a sustainable and eco-friendly activity, similar efforts are still lacking in the case of freshwater aquaculture. The issues that need immediate focus include introduction of new species for culture; introduction of improved and innovative systems and practices; quality-assured cost-effective seed and feed, eco-friendly feed management; effective disease monitoring, surveillance and management; safety of the produce for human consumption and water-quality management.

In the case of coastal aquaculture, the Coastal Aquaculture Authority (CAA) has been established in December 2005 under an Act of Parliament to regulate coastal aquaculture activities in coastal areas to ensure sustainable development without causing any damage to the coastal environment. The Authority is empowered to make regulations for this purpose to promote responsible coastal aquaculture. Guidelines have been brought out to ensure that coastal aquaculture does not cause detriment to the coastal environment and the concept of responsible aquaculture is being followed to protect the livelihood of various sections of people living in coastal areas. Besides registration of coastal shrimp farms, the environmental assessment and the carrying capacity of the water-body are being insisted upon wherever necessary including incorporation of Effluent Treatment System (ETS). Environmental Impact Assessment (EIA) and Environmental Monitoring and Management Plan are insisted for aquaculture units above 40 ha size. The CAA has also the task of surveying the entire coastal area of the country to formulate suitable strategies for achieving eco-friendly development of coastal aquaculture through satellite imageries, data collected through GIS, hydrographic maps, etc. This would help to work out proper management plans and to decide zoning of coastal aquaculture farms and creation of aquaculture estates in future. The CAA is also concerned with fixing up of standards for all coastal aquaculture inputs, namely seed, feed, growth supplements and chemicals/medicines, for the maintenance of water-bodies and the organisms reared therein.

Quality inputs for coastal aquaculture: Quality seed and availability of disease-free broodstock are major requirements in the development of coastal aquaculture. Broodstock development through domestication, selective breeding and stock improvement should be a national priority for sustainable production and growth. The National Fisheries Development Board (NFDB) in collaboration with a Hawaii based company has initiated steps to set up a multiplication centre to produce specific pathogen-free *Penaeus monodon* seed for supply to the shrimp farmers registered with the CAA. In order to ensure supply of quality seed by the shrimp hatcheries, all the shrimp hatcheries need to be registered as per the provisions of the Coastal Aquaculture Authority Act, 2005.

Feed accounts for the largest operating cost and proper feed management is crucial for the profitability and sustainability of aquaculture. The CAA, in consultation with experts from research organizations and feed manufacturers, would shortly evolve standards for fish and shrimp feed and for feed additives. A sub-committee constituted by the CAA to suggest standards for probiotics has already started collecting information on the types of probiotics being used in shrimp aquaculture and the units producing such products.

Use of chemicals and antibiotics: The fast pace of development in shrimp farming has brought to focus the use of a wide variety of drugs, chemicals, antibiotics, etc. by the farmers. Lack of awareness and a strong marketing strategy by the drug and chemical manufacturing companies are responsible for their indiscriminative use. Chemicals and drugs presently in use are mostly derived from agriculture or veterinary or human health management sectors and have never been tested specifically from the aquaculture perspective. The CAA has banned the use of 20 antibiotics and other pharmacologically active substances in shrimp aquaculture. Also, the regulations of the Authority prescribed the sampling procedure for testing of chemicals or antibiotics in shrimp ponds and also designated institutions or laboratories for analysis of samples to take appropriate action against the violators.

Diversification of species: Efforts towards diversification of species have been limited and the present activities greatly rely on culturing a few species in brackishwater aquaculture. Diversification is an urgent need and it is high time that domestication of other potential species is given priority by the R&D institutions taking into consideration the suitability of the area and other constraints. Promotion of a variety of species of exportable value for coastal aquaculture is expected to raise our fish production. The CAA is engaged in bringing out suitable guidelines and code of practices for the culture of different species for coastal aquaculture. In the shrimp sector, the recent decision of the Government, to introduce the exotic variety of specific pathogen-free (SPF) *Litopenaeus vannamei*, is a significant development. The guidelines issued in this regard empowers the CAA for monitoring and inspection of hatchery production and culture of SPF *L. vannamei* with due care to the biosecurity aspects and sustainability. In the freshwater aquaculture sector, Indian major carps, namely catla, mrigal and rohu, contribute about 84% of Indian aquaculture production and it is time that serious efforts are undertaken to introduce more potential species for culture following the model of China.

Fish seed certification: The success of aquaculture depends largely on the availability of quality seed. Sustainable production of quality seed in substantial quantity using latest technology is the need of the hour. No definite guidelines have been framed or in practice for certification of seed in the fishery sector especially in freshwater side. At present, the entire quantity of seed used in freshwater aquaculture comes from induced breeding with a meagre supply from natural collection. To ensure the quality of the seed, it is essential to check the broodstock quality, breeding plan and environment management practices, disease screening and disinfection protocol. Realizing the need of seed certification policy for aquaculture sector, i.e. to secure, maintain and enable certain levels of genetic purity, physical purity and physiological quality of seed, three of the ICAR Institutes, namely the Central Institute of Freshwater Aquaculture (CIFA), Bhubaneshwar, National Bureau of Fish Genetic Resources (NBFGR), Lucknow, and Central Institute of Brackishwater Aquaculture (CIBA), Chennai, have collectively prepared a draft proposal on fish seed certification for the consideration of the administrative Ministry. As in the case of agriculture sector, seed certification in aquaculture is necessary to enhance fish production and ultimately achieving the goal of sustainability.

Introduction of exotic species: The potential of introducing new species need to be evaluated keeping in view their impact on environment and on the indigenous stock. Risk analysis in the aquaculture sector is primarily essential for resource protection (biosecurity) including human, animal and plant health as well as the aquatic organism and general environment. A National Committee on Introduction of Exotic Aquatic Species in Indian Waters has been constituted in the Department of Animal Husbandry, Dairying and Fisheries (Ministry of Agriculture) to review and assess the pros and cons of introducing exotics, to regulate and monitor their introduction and to develop guidelines/code of ethics for future introduction. The Committee is represented by all the fisheries research institutes under the ICAR, Zoological Survey of India (ZSI), Kolkata, Marine Products Export Development Authority (MPEDA), Kochi, Coastal Aquaculture Authority (CAA), Ministry of Environment and Forests and two non-official members who are experts in the field of fisheries.

The Committee, after a careful consideration of various issues, has permitted import of certain ornamental fish, red tilapia and the pacific white shrimp *L. vannamei* in recent times. Detailed guidelines have been issued for regulating the method of operation of aquatic quarantine for the import of SPF *L. vannamei* under the Livestock Importation Act, 1898 as amended by Livestock Importation Act, 2001. Since introduction of new or exotic species can always be associated with risks and hazards in spite of well-managed system, it is necessary to quarantine the imported stock to screen them for the disease-free status to prevent introduction of any new pathogen in the aquatic system. Aquatic animals are kept in the quarantine for a period of five days and quarantine certificate is issued by the Animal Quarantine Officer after confirming that they are proved negative to the Office International Des Epizooties (OIE), listed diseases. There is a proposal with Government to set up two aquatic quarantine units in the country -- one in the east coast and another in the west coast.

An Aquatic Quarantine Unit has been set up at Neelankarai, Chennai, mainly to quarantine the broodstock of *L. vannamei* imported by the Indian hatchery operators

with funding from the National Fisheries Development Board (NFDB) and operation and maintenance by the Rajiv Gandhi Centre for Aquaculture (RGCA), Sirkazhi, Tamil Nadu under Marine Products Export Development Authority (MPEDA). A Technical Committee has been set up to oversee the quarantine facilities and to suggest improvements. Standard Operating Procedures (SOP) for the quarantine have been published.

Separate Guidelines for regulating hatcheries and farms for introduction of *L. vannamei* have been issued through Coastal Aquaculture Authority (Amendment) Rules, 2009 which brings out the safeguards and regulation for operation of hatcheries and norms and regulations for approval and operation of farms. The Coastal Aquaculture Authority has been empowered to monitor and inspect the hatchery production and culture of SPF *L. vannamei* with due care to the biosecurity aspects and sustainability.

Compliance of aquatic animal health safeguards with trade-related agreements: The aquatic sector may continue to face increasing global exposure to disease agents on account of the increasing trade in live aquatic organisms and their products. Being a signatory to the trade-related agreements of World Trade Organization (WTO), we need to comply with the requirements of these agreements. The agreement on Sanitary and Phyto-sanitary (SPS) measures stipulates that steps are to be taken to protect human, animal and plant life for health using standards from the guidelines and recommendation of OIE. The Ministry of Agriculture (Department of Animal Husbandry, Dairying and Fisheries) vide a notification dated 7 July 2001 has made it mandatory that import of all livestock products shall be allowed only against a Sanitary Import Permit (SIP) to be issued by the Department. Through another notification issued on 16 October 2001, all aquatic animals including fish, crustaceans and molluscs have been covered under the purview of the earlier notification relating to SIP. Accordingly, all import of fish and fishery products require a SIP issued by the Risk Analysis Committee, set up in the Department of Animal Husbandry, Dairying and Fisheries, who screen the applications and specify standards for the imported products for food safety and health aspects.

Disease reporting and monitoring system: Under the SPS agreement, absence of a disease in the importing country can be used as a trade barrier for shipment of live aquatic organisms and products from the exporting country if we are unable to prove the absence of the disease. Hence diagnosis and control of aquatic disease through a network of disease-diagnostic laboratories need to be developed in the country. The OIE and Network of Aquaculture Centres in Asia-Pacific (NACA) have developed a disease-reporting system and provide regular and updated information on the diseases of concern to facilitate risk analysis and minimize the introduction of pathogens. Monitoring of aquatic animal diseases is being done by the field level officers of the Fisheries Departments in the states. For the purpose of Quarterly Aquatic Animal Disease reporting of important OIE-listed diseases, a proforma has been developed by the OIE which has been circulated to all the states. Suitable training to the field level officers of States is being imparted by the NBFGR on the disease-reporting system. The reports received from states are consolidated by the the Department of

Animal Husbandry, Dairying and Fisheries and after confirmation by the NBFGR, these are submitted to the OIE who publishes them region-wise. India appears in the Asian and Pacific Region of the Report.

Legislative measures to implement responsible fisheries and aquaculture

Constitutional provision: The Seventh Schedule of the Constitution of India specifies fishing and fisheries beyond territorial waters as a subject of Union Government. Fisheries within territorial waters is shown as a State subject and close reading of the entries would indicate that control and regulation of fishing and fisheries within the territorial waters (12 nautical miles) is the exclusive province of the State, whereas beyond the territorial waters, it is the exclusive domain of the Union of India. The Ministry of Agriculture within the purview of its allocated business helps coastal states and union territories for the development of fisheries within territorial waters besides attending to the requirements of the sector in the exclusive economic zone.

Indian Fisheries Act, 1897: The need for fisheries legislation was emphasized as long back as in 1873 when the attention of the Government was drawn to the destruction of fishery resources in the dams and reservoirs. The Government then enacted the Indian Fisheries Act which came into being in 1897 and is considered as the mother act of fisheries in India. The Act highlighted the conservation aspect and banned the use of explosives and poisoning of waters for the destruction of fish. It enables the Provincial Governments (States) to frame rules in selected waters for protection of fish. After Independence, various developmental programmes took place with the creation of large number of reservoirs stagnant and running water spreads offering scope for increase in inland fish production. New techniques were introduced for hatchery production of major fish seeds. The vast change and rapid industrialization created pollution problems affecting the fish life which necessitated the revision of the 1897 Act and for formulating new legislations.

Marine fishing regulations in the coastal states of India: In the marine sector, the fast pace of development of mechanization programme created conflicts between the traditional, mechanized and deep-sea fishing sectors and such instances were frequently noticed in the coastal waters of many parts of the country during the seventies. A Committee, appointed by the Government of India in 1977 (Majumdar Committee) to study these problems, recommended that the State Governments should be advised to enact necessary legislation to enable them to regulate fishing in their respective territorial waters as per the constitutional provision. A model bill was prepared and circulated by the Ministry of Agriculture in 1979 based on the recommendations of the above Committee advising the States and Union Territories to enact suitable marine-fishing regulations.

Based on the model bill, all the maritime states and the Union Territory of Andaman and Nicobar Islands and Lakshadweep Islands enacted the Marine Fisheries Regulation Act (marine fishing regulations in the case of UTs) which mostly provides the provisions are given here.

- Fishing in any specified area by a class or clauses of fishing vessels by licensing of the number of vessels to be used in specified areas.

- Restricting the catching of any species of fish for such period of time
- Regulating the mesh size of fishing vessels
- Licensing and registration of fishing vessels
- Conservation of fishery resources in ecologically sensitive areas
- Punitive action for violations of the Act/Rules.

All the states regulate the marine-fishing activities under these Acts while the Gujarat Fisheries Act, besides regulating marine-fishing operations in territorial waters, also regulates fishing in inland waters providing standards for sale of fry and fingerlings, mariculture, prohibition of fishing within a radius of 100 m downstream in the river mouth and prohibition of exotic fish introduction, etc.

The Marine Fishing Regulation Act enacted by the states indicates that there is no uniformity in the regulations of fishing and the areas exclusively earmarked for traditional fishing operations varied from 5 km from shore in Odisha and Goa, 6 km in Karnataka, 8 km in Andhra Pradesh and 10 km in the case of Gujarat and Kerala. Hence there is a need for harmonizing this regulation at least with regard to the adjoining states. The implementation of the marine-fishing regulations poses a greater challenge to the maritime states in the absence of suitable infrastructure and manpower for its enforcement. The Government of India, under a Centrally Sponsored Scheme, provided assistance to the State Governments to procure patrol boats to monitor the operation of fishing vessels in the coastal areas. However, most of the states have not put this in use effectively for various reasons. It is high time that the coastal states revisit the provisions of these Acts with a view to incorporate suitable changes/additions by amending the Acts to suit the current requirements and for their effective implementation by creating the required enforcement mechanism.

Exclusive Economic Zone Act, 1976 and the Maritime Zones of India Act, 1981: By declaration of 200 nautical miles Exclusive Economic Zone (EEZ) on the seas around India through enactment of the Territorial Waters, Continental Shelf, Exclusive Economic Zone and Other Maritime Zones Act, 1976, India has acquired exclusive rights to exploit the living and non-living sources of this area comprising 2.02 million km^2. It has, therefore, become obligatory to take necessary steps to exploit the deep-sea fishery resources. Under this imperial Act, Ministry of Agriculture enacted the Maritime Zones of India (Regulation of Fishing by Foreign Vessel) Act, 1981 to regulate fishing by foreign vessels in the EEZ of India. Initiatives were taken by the Government to enable Indian companies to acquire fishing vessels through a scheme of hiring of foreign fishing vessels and subsequent acquisition of vessels on ownership basis either through import or indigenous construction. This activity was abandoned due to practical problems and on the recommendations of the Murari Committee set up by the Government to review the deep-sea fishing policy. The Deep Sea Fishing Policy, 1991 permitted Indian companies to enter into joint venture arrangements with foreign companies and to acquire fishing vessels for fishing in the Indian EEZ flying the Indian flag. This has undergone further change and with the announcement of the comprehensive marine fishing policy, guidelines were issued for fishing operations in

Indian EEZ as well as for joint venture operations under certain terms and conditions to operate deep-sea fishing vessels in the Indian EEZ. Under these guidelines, permission is accorded through a letter of permission by the Ministry of Agriculture for acquiring and operating on deferred payment basis only resource-specific fishing vessels, i.e. long lining for tuna, tuna purse seining, squid jigging and mid water pelagic, trawling and trap fishing. The main regulatory measures include daily reporting position to the Coast Guard organization, clearance of foreign fishing crew by the Ministry of Home Affairs, registration of these vessels with Director General of Shipping and monitoring of the operations by the Coast Guard, submission of voyage reports and installation of inmarshaft 'C' or comparable terminal with GPS facility as prescribed by the Government and vessel monitoring systems (VMS), etc. This programme, however, has not so far helped to develop our own capacity building in this sector.

Legal instrument requirement for Indian vessels operating in EEZ: While the operations of small mechanized boats below 20 m OAL are generally governed by the respective Marine Fishing Regulations of the concerned maritime states, there are no such regulations in case of Indian owned deep-sea fishing vessels of more than 20 m OAL operating beyond territorial waters but within the EEZ. Introduction of a legislation for wholly Indian owned deep-sea fishing vessels operating in the EEZ is essential to optimally harvest the catch based on the revalidation of the harvestable potential from the off-shore waters and to share the catch data with research organizations for further analysis to evolve future programmes. A model legislation prepared by the Government of India (Ministry of Agriculture) for this purpose was circulated to the State Governments and others concerned seeking their comments before its finalization for enactment. This would ensure conservation of resource as well as towards achieving limited access fisheries.

Legislation in inland fisheries sector: There is no regulatory measure in respect of inland fishery activities in the country as a whole except for the limited legislative measures taken by a few states like West Bengal, Asom, Gujarat, Manipur, Mizoram which too are for some specific purposes and not for the purpose of regulating the operations in the inland sectors. The Andhra Pradesh Aquaculture Seed Act, 2006 and the Rules framed there under provide for registration of all freshwater aquaculture farms and hatcheries. The Act also prohibits export and import of seed and movement of seed within and outside the state with a view to prevent spread of disease and to safeguard the biodiversity.

The problems in inland fishery sector are multifarious in view of the fact that the administration of the water-bodies varies from state to state and the water-bodies are under the control of different agencies such as Departments of Forestry, Revenue, PWD, Fisheries and Panchayati Raj, etc. From the nature of migratory behaviour of fish inhabiting the rivers, it is not possible to regulate or to act single handedly without the active cooperation of the adjoining states. Also some of the lakes and reservoirs are under the control of more than one states. In states like Asom and Manipur, there are privately owned large water-bodies where there is no control by the Government agencies. It is, therefore, necessary that such private property should also have the protection of law and it is essential to have uniform regulations in all the states for safeguarding the inland fishery wealth of common waters. The Government of India (Ministry of Agriculture) set up a working group to formulate a model bill for inland fisheries and aquaculture sector in March 2004 with the terms of reference to review the existing fisheries acts or rules of the States and UTs and to evolve a basic draft of the model bill which would be circulated to all the States/UTs for taking suitable follow-up action. It is observed that registration of freshwater fish farms and licensing of fishing in inland waters are found lacking in the model bill. There is a need to have consensus on such important issues as well as on a uniform leasing period for ponds and reservoirs before suitable legislative measures are initiated by the State Governments. The ultimate objective of regulation should be the management of water resources, to ensure sustained increase in national wealth with due concern to the conservation of fishery resources.

Legal and administrative framework for responsible coastal aquaculture activities (Coastal Aquaculture Authority Act, 2005): The experience gained in the field of coastal aquaculture, especially shrimp culture, in the Asian countries including India, has clearly shown that coastal aquaculture, if not scientifically managed and judiciously monitored, will not be sustainable and may cause a number of environmental and social problems, besides increased incidence of disease outbreaks. The Coastal Aquaculture Authority was, therefore, established on 22 December 2005 under an Act of Parliament, viz. The Coastal Aquaculture Authority Act, 2005 (Act 24 of 2005) on 23 June 2005. The main objective of the Authority is to regulate coastal aquaculture activities in coastal areas to ensure sustainable development without causing damage to the coastal environment. The Authority is empowered with regulations for the construction and operation of aquaculture farms in coastal areas, inspection of farms to ascertain their environmental impact, registration of aquaculture farms, removal or demolition of coastal aquaculture farms which cause pollution, etc. The powers and functions of the Authority have been enlisted in the CAA Act, 2005 and the Rules framed thereunder.

The major function is to promote responsible aquaculture for which the Central Government shall take all measures deemed necessary or expedient for the regulation of coastal aquaculture by prescribing Guidelines to ensure that coastal aquaculture does not cause any detriment to the coastal environment and the concept of responsible coastal aquaculture contained in the Guidelines shall be followed in regulating the coastal aquaculture activities to protect the livelihood of various sections of the people living in the coastal areas.

Besides registration of coastal aquaculture farms, the CAA also has to:

- ensure that the agricultural lands, salt pan lands, mangroves, wet lands, forest lands, land for village common purposes and the land meant for public purposes and national parks and sanctuaries are not converted as aquaculture farms in order to protect the livelihood of coastal community living in coastal areas;
- survey the entire coastal area and advise the Central Government and the State/UT Governments for formulating suitable strategies for achieving eco-friendly development;

- advise and extend support to the State/UT Governments for constructing common infrastructure line, common water intake, discharge canals and common effluent treatment systems;
- fix standards for seed, feed, growth supplements and chemicals/medicines used for the maintenance of the water-bodies and the organisms reared and other aquatic life;
- collect and disseminate the data and other scientific and socio-economic information related to coastal aquaculture;
- give publicity and train personnel regarding sustainable utilization and fair and equitable sharing of the coastal resources;
- direct the owners of the farm to carry out modifications to minimize the impacts on coastal environment;
- order seasonal closure of farms for ensuring sustainability; and protection of livelihoods in the interest of coastal environment;
- cancel the registration where any person has obtained registration by furnishing false information or contravened any of the provisions of these rules or of the conditions mentioned in the certificate of registration; and
- make suitable recommendations to the Government for amending the guidelines from time to time.

Other Fishery-related laws in the country

The ecosystem for coastal and inland fisheries as well as aquaculture sectors relies on various natural resources and there are several regulations and legislations promulgated by various Government Departments at the Centre as well as in the States. The important legal frameworks directly or indirectly related to fisheries are:

1. The Indian Fisheries Act, 1987
2. The Indian Wildlife (Protection) Act, 1972
3. The Marine Products Export Development Authority Act, 1972
4. The Merchant Shipping (Amendment) Act, 1998 (Original: Indian Merchant Shipping Act, 1958)
5. Water (Prevention and Control of Pollution) Act, 1974
6. The Territorial Waters, Continental Shelf Exclusive Economic Zone and other Maritime Zone Act, 1976
7. The Coast Guard Act, 1978
8. The Forest (Conservation) Act, 1980
9. Maritime Zones of India (Regulation of Fishing by Foreign Vessels) Act, 1981
10. The Environment Protection Act, 1986
11. The Foreign Trade (Development and Regulation) Act, 1992
12. The Biological Diversity Act, 2002.

Standards, testing and certification for fishery products: With the liberalized global trade practices, it is imperative to maintain high standards for food safety and quality which is also applicable to aquaculture products. In all fishery products, the OIE standards should be used as international benchmarks to create the required market access. The Bureau of Indian Standards (BIS) has been designated by the Government of India as the WTO (technical barriers to trade) enquiry point, while the Ministry of Commerce is responsible for implementing and administering the WTO agreement relating to other trade aspects. India also accepted the Code of Good Practice in December 1995 and the Indian standards are formulated by the BIS, who endeavours to align Indian standards as far as possible with international standards. The BIS is also a founder member of the International Standards Organization (ISO). The Indian and foreign manufacturers who meet the BIS standard may carry the BIS certification and the BIS laboratories provide conformity testing for products for BIS certification. Voluntary certifications are also issued for environment-friendly products, environmental management systems, quality systems and hazard analysis and critical control points (HACCP). The licences issued by the BIS are valid for a period of three years and BIS carries out regular surveillance audits and inspections to ensure that the systems and products meet the relevant standards. More intensive efforts are required to implement these standards to promote our trade of fishing products.

For the purpose of food safety and quality, the fish and fish products are covered by the Prevention of Food Adulteration Act, 1954. India's legislation on labeling and marking is contained in the Prevention of Food Adulteration Act, 1955. The standards of weights and measures for packaged commodities are governed by the rules issued in 1977, which regulate packaging and rationalized standard quantities and measures.

Future strategies

Fisheries management, which is perceived as a response to sustainable management, has not received the desired attention for developing fisheries and aquaculture. Although it was originally the target groups and administrators who alone were involved in the development of these sectors, the need for involving expertise in other related disciplines has been well realized recently. Inclusion of certain crucial sectors such as environmental conservation, public health, legal support, economic incentives, risk analysis, insurance, information dissemination, international cooperation are also equally important besides coordination of production with marketing and international trade, etc. Fisheries management deals with multiple user groups and sustaining a fishery resource requires the active participation of all user groups coming together.

A participatory approach with a harmonious blend of technology, organizational development, institution building and human resource development should therefore be developed to streamline new strategies that are more responsive to the felt needs of these sectors. Implementation of the code of conduct for responsible fisheries, therefore, needs collective action so that fisheries have a tomorrow and future generations are not deprived of fish. The renewable fishery resources, if properly managed in a responsible manner, can produce long-term sustainable yields and support continuous economic activity.

43. Fisheries Legislation

Fish has constituted an affordable and rich source of protein for people in many parts of India since time immemorial. Starting purely as traditional activity in the fifties, fisheries has now emerged as a sunrise sector of our economy. It plays a very important role in the socio-economic development of our country, in view of its contribution to the food basket, nutritional security, sustainable large foreign exchange earnings, generation of employment and income besides stimulating subsidiary industry. Most importantly, fishery is a source of livelihood for a large section of the economically backward population.

Fish production in the country has increased from 3.84 million tonnes in 1990-91 to 8.00 million tonnes in 2009-10, of which 4.93 million tonnes were from the inland sector. The overall annual growth rate of sector stands at 4.7% though, growth rate in marine fisheries in recent years has been slow compared to inland fisheries. India has become second largest producer of fish in the world and also the second largest producer of inland fish. About 14 million persons depend directly on fisheries sector for their livelihood. The share of fisheries sector in GDP is as much as 1.10% equal to 5.34% of the contribution from agriculture. The share of fisheries exports in agricultural exports is about 18% equal to about 4.0% of the total exports of our country.

Fishery resources

India is endowed with vast and varied marine and inland fishery resources, an outline of which is given here:

Marine fishery resources		
Coastline	:	8,129 km
Exclusive economic zone	:	2.02 million km^2
Inshore area (< 50 m depth)	:	0.18 million km^2
Continental shelf	:	0.50 million km^2
Estimated annual production potential	:	3.93 million tonnes
(a) From area within 50-m depth	:	2.21 million tonnes
(b) From area beyond 50-m depth	:	1.69 million tonnes
Inland fishery resources		
Rivers and canals	:	0.20 million km
Area under reservoirs	:	3.15 million ha
Tanks and ponds	:	2.25 million ha
Beels, oxbow lakes and derelict water-bodies	:	0.82 million ha
Brackishwater area	:	1.24 million ha
Estimated annual production potential	:	4.5 million tonnes

Constitutional provision

Entry 57 of List I of Seventh Schedule of the Constitution specifies Fishing and Fisheries beyond Territorial Waters (12 nautical miles) as Union Subject, whereas

Entry 21 of List II speaks of fisheries within territorial waters as a State Subject. Reading both the Entries together, it follows that control and regulation of fishing and fisheries within territorial waters is the exclusive province of the State, whereas beyond the territorial waters, it is the exclusive domain of the Union. The Ministry of Agriculture within the purview of its allocated business helps the coastal States and Union Territories in development of the fisheries within the territorial waters, besides attending to the requirements of the sector in the Exclusive Economic Zone (EEZ).

Indian fisheries legislations

The need for fisheries legislation was emphasized as long back as in 1873 when the attention of the then Government of India was drawn towards widespread slaughter of fish, fry and fingerlings and the urgency to adopt legislative measures to conserve the fisheries resources. At that time, the Government of India enacted the Indian Fisheries Act, which came into being in 1897.

The Act highlighted the following:

- Use of destructive methods of fishing such as dynamiting or other substances in inland and coastal waters (up to one marine league) was prohibited. Similarly, poisoning of water with noxious materials was also prohibited.
- Provincial governments were empowered to make rules in selected waters for protection of fish with previous notification, restricting the creation and use of fixed engines (dams, weirs, bar pattas, etc.) for catching fish; to put a limit on mesh size, size of fish and catch, and to ban the fish in certain seasons and certain places for a period of 2 years (declaration of closed season and sanctuaries).

The Merchant Shipping Act, 1958

The main objective of this Act is to foster development and ensuring an efficient maintenance of an Indian Mercantile Marine in a manner best suited to serve the national interests. The main implementing agency is the Ministry of Shipping, Road Transport and Highways. The Act was amended in 1983 to provide for registration and control of Indian fishing boats. The Act enables defining a fishing vessel and prescribes registration procedure besides provision for data collection.

Indian Wildlife (Protection) Act, 1972

It is under this act marine that protected areas/sanctuaries are declared, like the marine parks in the Gulf of Mannar and the Gulf of Kachchh. Certain marine species such as 10 species of shark, seahorse, sea cucumbers, giant grouper, turtle and some mollusk species are protected under this Act by listing them in Schedule I of the Act, which prohibits hunting and trading in these species. Thus in this Act a two-pronged conservation approach is adopted, wherein specified endangered species are protected regardless of location, while all species are protected in designated areas called national parks and sanctuaries.

India is a member of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES), which prohibits trade in turtle products by member countries. In 1981, India became a party to the Bonn Convention on the Conservation of Migratory Species of Wild Animals. Further, efforts are also made to reduce the mortality of turtles by attaching turtle excluder devices (TEDs) to the trawl and by declaring closure of fishing during the mass nesting season. The Act also recognizes the need to protect the occupational interests of fishermen, while declaring a sanctuary in territorial waters. The Act has been amended twice during 1993 and 2002. The 2002 amendment includes fish in the definition of animals and a clause on settlement of rights while declaring a sanctuary.

The Marine Products Export Development Authority Act, 1972

The Marine Products Export Development Authority (MPEDA) was established in 1972 under an Act of the Parliament, namely the Marine Products Export Development Authority Act, 1972 (Act 13 of 1972), under the Ministry of Commerce, Government of India, when it was felt and declared that it is expedient in the public interest that the Union should take under its control the marine products industry. The functions of the Authority laid down under clause 9 of the Act are as follows:

(*i*) It shall be the duty of the Authority to promote by such measures as it thinks fit, the development of the marine products industry with special reference to exports under the control of the Central Government, (*ii*) without prejudice to the generality of the provisions of the sub section (1) the measures therein may provide for – developing and regulating offshore and deep-sea fishing, and undertaking measures for the conservation and management of offshore and deep-sea fisheries; registering fishing vessels, processing plants or storage premises for marine products and conveyances used for the transport of marine products; fixing of standards and specifications for marine products for purposes of export; rendering of financial assistance or other assistance to owners of fishing vessels engaged in offshore and deep-sea fishing and owners of processing plants and acting as an agency for such relief and subsidy schemes as may be entrusted to the Authority. Further the Authority can carry out inspections of marine products in any fishing vessel, processing plant, storage premises, conveyance or other place where such products are kept or handled, for the purpose of ensuring the quality of such products; regulating the export of marine products; improving the marketing of marine products outside India. The functions of the Authority also include collecting statistics from persons engaged in the catching of fish or other marine products, owners of processing plants or storage premises for marine products or conveyance used for the transport of marine products, exporters of such products and such other persons as may be prescribed or any matter relating to the marine products industry and the publishing of statistics so collected, or portions thereof or extracts there from; training in various aspects of marine products industry and such other matter may be prescribed. The MPEDA Rules 1972 was made in exercise of the powers conferred under Section 33 of the Marine Products Export Development Authority Act 1972 (13 of 1972). The jurisdiction of the rules is throughout India.

Section 32 of the Rules, empowers the Authority to undertake various measures on the discharge of its functions, in additions to the functions specified under Sub section (2) of Section 9 of the Act.

The Territorial Waters, Continental Shelf, Exclusive Economic Zone and other Maritime Zones Act, 1976

This Act was enacted to establish sovereignty over the Indian maritime zone. It paved the way for establishment of a 200 nautical mile Exclusive Economic Zone (EEZ). The EEZ provisions are comprehensive which provide the basis for our country to exercise control over the zone for the purpose of international law. It provides the following rights:

(i) Sovereign rights for the purpose of exploration, exploitation, conservation and management of the natural resources, both living and non-living as well as for producing energy from tides, winds and currents;

(ii) Exclusive jurisdiction to preserve and protect the marine environment and to prevent and control marine pollution; and

(iii) No person (including a foreign Government) shall, except under, and in accordance with the terms of any agreement with the Central Government or of a license or a letter of authority granted by the Central Government, explore or exploit any resources of the EEZ or carry out any research or excavation or conduct any research within the EEZ or drill therein or construct, maintain or operate any artificial island, off-shore terminal, installation or other structure or device therein for any purpose whatsoever : Provided that nothing in this sub-section shall apply in relation to fishing by a citizen of India.

The Coast Guard Act, 1978

It provides for the establishment of Coast Guard to ensure national security of maritime zones, protection of national interests in such zones and safety at sea. It provides among other things protection and preservation of maritime environment and endangered species; prevention and control of pollution in the maritime zones; assistance to fishermen in distress at sea; safeguarding life and property at sea; preventing poaching in Indian waters; assisting in ocean research related activities and enforcing maritime law.

Marine Fishery Legislation in the Maritime States of India

There are 10 maritime states/union territories in India, namely Gujarat, Maharashtra, Karnataka, Goa and Kerala along the west coast, bordering the Arabian Sea; and Tamil Nadu, Puducherry, Andhra Pradesh, Odisha and West Bengal along the east coast, bordering the Bay of Bengal. The two island union territories, namely Lakshadweep, and Andaman and Nicobar Islands are situated in the Arabian Sea and Bay of Bengal respectively.

The introduction of small mechanized boats of 9 to 10 m has rapidly caught on since the 1960s, and at present, about 53,000 such boats are operating in the inshore area, engaged mostly in bottom trawling, gill netting and purse-seining. During the 1970s, purse-seining was introduced for pelagic shoaling fishes like mackerel and sardines. It was in this backdrop that the scope and possibility to safeguard the interests of traditional fishermen were recognized by the 10th Meeting of the Central Board of Fisheries held on 22-23 March 1976, at New Delhi. Based on its recommendations, the Central Government constituted a Committee in May 1976, for examining the questions of delimiting the areas of fishing for different types of boats. The Committee submitted its report in December 1978, with a model Marine Fisheries Regulations Bill. The model bill was circulated to all maritime states and union territories in 1979 for enacting suitable legislation.

Various state governments have issued regulations under the Indian Fisheries Act 1897 for regulation and protection of fisheries. The regulations concerning Indian marine fisheries are:

(i) The Indian Fisheries Act, No. IV of 1897, Government of India
(ii) The Indian Fisheries Act as adopted and applied by the State of Saurashtra, 1897
(iii) The Mysore Game and Fish Preservation Act 2 of 1901, Government of Mysore
(iv) The Game and Fish Protection Regulation Act 12 of 1914, Government of Travancore (1914) (modified 1921)
(v) Cochin Fisheries Act 3 of 1917 (modified 1921), Government of Cochin
(vi) Andaman and Nicobar Islands Fisheries Regulation 1 of 1938
(vii) The United Provinces Fisheries Act 45 of 1948
(viii) Government of Travancore-Cochin Fisheries Act 34 of 1950
(ix) The Maharashtra Fisheries Act 1960 (modified 1962), Government of Maharashtra
(x) The Indian Fisheries (Pondicherry Amendment) Act 18 of 1965
(xi) The Indian Wildlife Act 1972. 21b-The Territorial Waters, Continental Shelf, EEZ and other Maritime Zones Act, 1972
(xii) The Marine Products Export Development Authority Act, 1972
(xiii) The Maritime Zones of India (Regulation of fishing by foreign vessels) Act, 1981
(xiv) The Kerala Marine Fishing Regulation Act and Rules, 1980 (Act 10 of 1981)
(xv) The Goa Marine Fishing Regulation Act, 1980
(xvi) The Maharashtra Marine Fishing Regulation Act, 1981, Government of Maharashtra
(xvii) The Orissa Marine Fishing Regulation Act, 1981 (Orissa Act 10 of 1982) and the Orissa Marine Fishing Regulation Rules, 1983
(xviii) The Tamil Nadu Marine Fishing Regulation Rules, 1983
(xix) The Karnataka Marine Fishing Regulation Act, 1986
(xx) The Andhra Pradesh Marine Fishing Regulation Act, 1994
(xxi) Lakshadweep Marine Fishing Regulation – Rules, 2000
(xxii) The Gujarat Fisheries Act, 2003
(xxiii) Andaman and Nicobar Marine Fishing Regulation Act, 2003

The marine fishing regulation Acts (xiv-xxiii) have been formulated following a model bill circulated by the Government of India to all maritime state governments for regulation of exploitation of marine fisheries resources in territorial waters of India. The Marine Fishing Regulation Acts (MFRAs) have provision for regulating fishing and conservation measures in the territorial waters. These include regulation of mesh size to avoid catch of juvenile fish; minimum-maximum fish sizes, regulation of gear to avoid over-exploitation of certain species; reservation of zones to traditional fishermen and declaration of closed seasons. These Acts demarcate fishing zones in territorial waters for fishing by non-mechanized and mechanized fishing vessels (Fig 43.1). The distance from the shore earmarked for each category varies from state to state. In general, 5 to 10 km is reserved for operation by artisanal (non-mechanized) vessels. Kerala and Goa were the first to enact the Marine Fisheries Act in 1980 followed by Maharashtra (1981), Odisha (1982), Tamil Nadu (1983), Karnataka (1986), West Bengal (1993) and Andhra Pradesh (1994). Lakshadweep did so in 2000. Gujarat as well as Andaman and Nicobar Islands enacted the Act in 2003. The Government of Puducherry has issued executive orders.

Unlike regulations of fishing areas provided in the Acts, the decision on seasonal closure is taken on a year-to-year basis normally prior to or during the onset of the south-west monsoon. As per the order issued by Department of Animal Husbandry, Dairy and Fisheries, Government of India, dated 9 March 2011, uniform ban on fishing by all fishing vessels in the Indian Exclusive Economic Zone (EEZ) beyond territorial waters on East Coast including Andaman and Nicobar islands and West coast including Lakshadweep has been imposed for conservation and effective management of fishing resources and for sea-safety reasons (Fig.43.1). Along the east coast, uniform seasonal

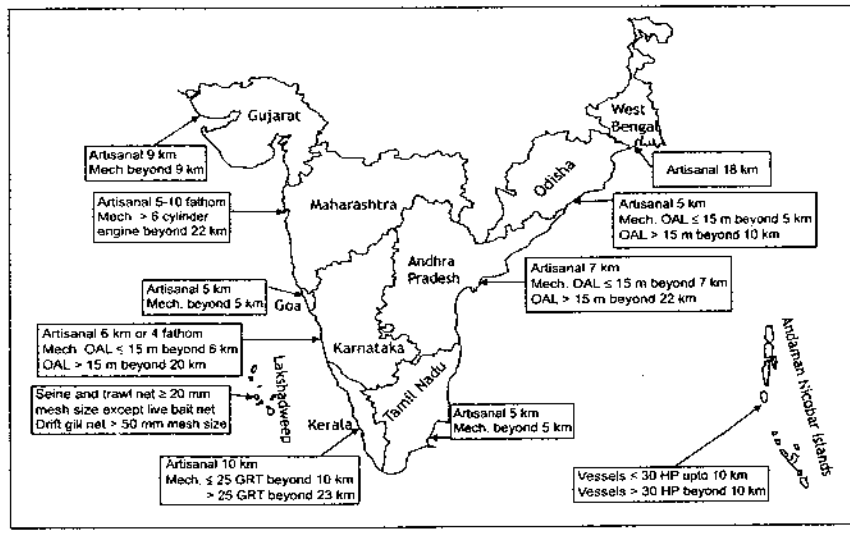


Fig. 43.1. Regulation of fishing areas in Indian territorial States

closure of 47 days is being implemented from 15 April to 31 May, while along the west coast, it is from 15 June to 31 July.

Under the Marine Fishing Regulation Act, the procedure for licensing of fishing vessels is simple. Owner makes an application to the Authorized Officer in the prescribed proforma furnishing all the particulars. The application is submitted along with prescribed fee and registration certificate. Authorized Officer or Licensing Officer makes enquiry about the condition of the fishing vessel, fishing gears and accessories. Adjudicating Officer can impose penalties in case of violation of any of the provisions of the act and can cancel, suspend and amend the licenses. There is also a provision for the constitution of Advisory Committee in acts of some states like Maharashtra and Karnataka. Zonation and other fishing regulations in different states are summarized here:

Gujarat

(i) The area up to 9 km from the shore is reserved for non-mechanized vessels and mechanized vessels beyond 9 km.
(ii) In case of trawl net, square mesh of minimum 40 mm size at cod ends need to be used.
(iii) Gill net with mesh size less than 150 mm cannot be operated.

Maharashtra

(i) Operation of trawl net by mechanized fishing vessels is prohibited from the seashore to 5 fathoms and 10 fathoms depth zone in specified areas;
(ii) Operation of trawl gear by mechanized fishing vessels is prohibited between 6 PM and 6 AM.
(iii) Fishing by mechanized fishing vessels of any type with more than 6 cylinder engines is prohibited within the territorial waters of Maharashtra up to 22 km.
(iv) Purse-seine shall not be operated by any mechanized fishing vessel within the territorial water of Greater Mumbai, Thane, Raigad, Ratnagiri and Sindhudurg districts.
(v) Mechanized fishing vessels operating purse-seine gear beyond the territorial waters shall not land the catch caught by such gear in any port other than Mirkarwada (Ratnagiri Port).
(vi) No trawl gear having less than 35 mm mesh size shall be operated by any mechanized fishing vessel within territorial waters of Thane, Greater Mumbai, Raigad and Sindhudurg.
(vii) No trawl gear having less than 25 mm mesh size shall be operated by any mechanized fishing vessel within territorial waters of Ratnagiri.

Goa

(i) The area up to 5 km from the coast line is the specified area and mechanized fishing vessels are prohibited from fishing in the area.
(ii) Restrictions on mesh size of nets, i.e. 20 mm for prawn and 24 mm for fish.

Karnataka

(i) The area up to 6 km from the shore or up to 4 fathoms (whichever is farther) is reserved for traditional crafts.
(ii) Mechanized boats [up to 15.24 m (50 feet)] are allowed to operate beyond 6 km.
(iii) Deepsea vessels (of 50' and above) are required to operate beyond 20 km.

Kerala

(i) The area from shore up to 30 m line in the sea along the coast from Kollencode in the south to Paravoor (Pozhikkara), a length of 78 km, is called the First Zone.
(ii) The area up to 20 m line in the sea along the coast line from Paravoor in the south to Manjeswar in the north for a length of 512 km is called the Second Zone.
(iii) Mechanized fishing except fishing by motorized country craft is prohibited in the First and Second zones. Only fishing with country craft and traditional craft is allowed in these zones.
(iv) Small mechanized vessels (< 25 GRT) are allowed to operate between 40 and 70 m depth in the First Zone and between 20 and 40 m in the Second Zone.

Tamil Nadu

(i) Areas up to 5 km are reserved for traditional non-mechanized boats.
(ii) Mechanized boats are permitted to use areas beyond 5 km.
(iii) Fishing within 100 m below a river mouth is prohibited.
(iv) No gill net of mesh size less than 25 mm shall be used.
(v) No shrimp trawl net with mesh size less than 37 mm at cod end shall be used.
(vi) No fish trawl net with mesh size less than 40 mm at cod end shall be used.
(vii) The number of mechanized fishing vessels which may be used for fishing in any specified area shall be decided by the Authorized Officer.

Andhra Pradesh

(i) The area up to 8 km from the shore is reserved for traditional craft.
(ii) Mechanized boats are allowed to operate beyond 8 km.
(iii) Mechanized fishing vessels of 25 Gross Tonnes (GRT) and above or 15 m and above of length shall be allowed to operate only beyond 15 km from the coast.
(iv) No vessel to be engaged in fishing using nets with mesh size below 15 mm.
(v) Shrimp trawlers engaged in fishing without Turtle Excluder Device (TED) shall be liable for confiscication of entire catch and impose a fine of ₹ 2,500.

Odisha

(i) Non-mechanized traditional craft shall be allowed to operate freely without restriction. Waters up to 5 km from the shore have been exclusively reserved for such fishing craft.
(ii) Mechanized fishing vessels up to 15 m in length shall be allowed to operate

beyond 5 km from the coast.

(iii) Mechanized fishing vessels of 25 gross tonnage (GRT) and above or 15 m length shall be allowed to operate beyond 10 km from shore.

West Bengal

(i) The area up to 18 km from the shore is reserved for artisanal fishing craft and craft fitted with engines less than 30 HP.

(ii) Fishing craft fitted with more than 30 HP engine are allowed to operate beyond 18 km.

(iii) No gill net with mesh size less than 25 mm shall be used.

(iv) No bag net/dol net with mesh size below 37 mm shall be used.

(iv) No shore seine drag net with mesh size below 25 mm to be used.

(v) Trawl net of standard mesh size fitted with turtle excluder devices to be used.

Andaman and Nicobar Islands

(i) Vessels up to 30 HP only are allowed to operate up to 10 km.

(ii) Vessels above 30 HP are allowed to operate beyond 10 km.

(iii) Every year 15 April to 31 May shall be closed season for bottom trawlers and vessels engaged in shark fishing.

(iv) Every year 1 May to 30 September closed season for fishing sea shells.

(v) Fishing nets below 20 mm mesh size are prohibited.

(vi) Trawl nets of standard mesh size fitted with turtle excluder device alone are permitted.

(vii) Only gill nets, shore seines and dragnets with mesh size above 25 mm are allowed to operate.

Lakshadweep

(i) Use of purse seine, ring seine, pelagic, mid water and bottom trawl of less than 20 mm mesh size is prohibited except live bait net.

(ii) Use of draft gill net of less than 50 mm mesh size and shore seine of less than 20 mm mesh size is prohibited.

The Maritime Zones of India (Regulations of fishing by foreign vessels) Act, 1981

This act was introduced to control activities of foreign fishing vessels within Indian Maritime Zone. The Act provides basis for joint ventures and chartered vessels and also for bilateral or multilateral fishing access agreements. The owner of a foreign vessel or any other person who intends to use such vessel for fishing within any maritime zone of India, may make an application with prescribed fee to the Central Government for the grant of a licence. The licence granted under this section shall be in such form as may be prescribed and valid for such areas, for such period, for such method of fishing and for such purposes as may be specified therein. The licence may be renewed from time to time subject to such conditions and restrictions as may be prescribed. A person employed by the owner complies in the course of such employment, with the provisions of this Act, or any rule or order made there under the conditions of such licence.

Every Indian citizen who intends to use any foreign vessel for fishing within any maritime zone of India may make an application with prescribed fee to the Central Government for a permit to fish using foreign vessels. The permit shall be valid for specified areas, period and fishing methods and may be renewed from time to time. The Central Government may suspend or cancel the licence or permit if there is any reasonable cause to believe that the applicant has provided incorrect or false material particulars or has contravened any of the provisions or rule or order of this Act. If any foreign vessel enters any maritime zone of India without a valid licence or permit granted under this Act, the fishing gear if any of such vessel shall, at all times while it is in such zone, be kept stowed in the prescribed manner. However, Central Government may in writing permit a foreign vessel to be used for fishing within any maritime zone of India for the purpose of carrying out any scientific research or investigation or for any experimental fishing in accordance with such terms and conditions as may be prescribed.

Any officer of the Coast Guard constituted under the Coast Guard Act, 1972, or such other officer of Government as may be authorized by the Central Government may stop or board a foreign vessel in any maritime zone of India and search such vessel for fish and for equipment used or capable of being used for fishing. The authorized officer may ask the master of such vessel to produce any license, permit, log book or other documents relating to the vessel, any catch, net, fishing gear or other equipment on-board such vessel or belonging to the vessel and examine the same. If the authorized officer has reason to believe that any foreign vessel has been, is being or is about to be used for committing an offence under this Act may with or without warrant seize and detain such vessel including any fishing gear, fish, equipment etc. belonging to the vessel. The authorized officer may direct the master of the vessel so seized or detained to bring such vessel to any specified port or arrest any person who such officer has reason to believe, has committed such an offence.

If any foreign vessel is used in contravention of the provision of section 3 of the Act in any area within the territorial waters of India be punishable with imprisonment for a term not exceeding three years or with fine not exceeding rupees fifteen lakhs or with both. If such contravention takes place in any area within the exclusive economic zone of India be punishable with fine not exceeding rupees ten lakh. The penalty for contravention of licence is not exceeding rupees ten lakh. The penalty for contravention of permit related to area of operation or method of fishing specified in such permit will be not exceeding rupees five lakhs and rupees fifty thousand in other cases. If any person intentionally obstructs any authorized officer in the exercise of any powers conferred under this Act or fails to afford reasonable facilities to the authorized officer or fails to stop the vessel or produce the licence permit, log book or other document or any fish, fishing gear or other equipment on-board the vessel when required to do so by the authorized officer, shall be punishable with imprisonment for a term which may extend to one year or with fine not exceeding rupees fifty thousand or with both. No suit, prosecution or other legal proceeding shall be against the Government or any person for anything which is in good faith done or intended to be done in pursuance of the provisions of this Act.

Fisheries-related policies

Recognizing the importance of coastal ecosystems and the country's reliance on these natural resources, several regulations and notifications have been promulgated by the central and state governments.

These Acts are meant for regulating fishing in public and private waters through a system of licensing by government authorities. In order to protect the corals and coral reefs, there is a provision under the powers conferred under Section 10 (3) of the Mines and Minerals (Regulation and Development) Act, 1957. The Government of Tamil Nadu (southeast coast) has issued a mining lease for collection of coral limestone under certain terms and conditions. Marine turtles and mammals such as whales, dolphins and tortoises are the endangered species occurring along the Indian coast. To protect the turtle population, the Indian Wildlife (Protection) Act (1972) was promulgated wherein all species of sea turtles were placed as endangered species in Schedule I and thereby protected. India is a member of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES), which prohibits trade in turtle products by member countries. In 1981, India became a party to the Bonn Convention on the Conservation of Migratory Species of Wild Animals. In order to protect endangered species, certain areas have been declared as wildlife sanctuaries, national parks and protected areas. Further, efforts are also made to reduce the mortality of turtles by attaching turtle excluder devices (TEDs) to the trawl and by declaring closure of fishing during the mass nesting season.

The Environment (Protection) Act, 1986

It authorizes the Central Government to protect and improve environmental quality, control and reduce pollution from all sources and prohibit or restrict the setting and or operation of any industrial facility on environmental grounds. It also makes it mandatory to conduct Environmental Impact Assessment (EIA) for specified developmental activities. Public hearings are also made mandatory for all developmental activities that require environmental clearance from the Ministry of Environment.

The Coastal Regulation Zone (CRZ) 1991 notification was issued under the provisions of Environment (Protection) Act, 1986. It outlines a zoning scheme to regulate development in a defined coastal belt. It declares the coastal stretch influenced by tidal action in the landward side up to 500 m from the high tide line (HTL) and the land between the low-tide line (LTL) and the HTL as the CRZ. It imposes restrictions on setting up and expansion of industries, operations or processes etc., in the said CRZ. The CRZ has been classified into four categories for regulation of developmental activities.

- The CRZ-I includes areas that are ecologically sensitive and important which include national ponds/marine parks, sanctuaries, reserved forests, wildlife habitats, mangroves, corals/coral reefs areas close to breeding and sparing grounds of fish and others marine life and areas rich in genetic diversity. The CRZ-I also includes area between the Low Tide Line and the High Tide Line.
- The CRZ-II includes the areas that have already been developed up to or close to the shore line.
- The CRZ-III includes the areas that are relatively undisturbed and those which do not belong to either CRZ-I or II. These will include coastal zone in the rural areas (developed and undeveloped) and also areas within municipal limits or in others legally designated urban areas which are not substantially built-up.
- The CRZ-IV includes coastal stretches in the Andaman and Nicobar, Lakshadweep and small islands except those designated as CRZ-I, CRZ-II or CRZ-III.

In the CRZ, setting up of new industries (except directly relating to water front or directly needing foreshore facilities) are prohibited. Hatcheries or withdrawl of groundwater in 200-500 m zone is permitted when done manually through ordinary wells for drinking, horticulture, agriculture and fisheries purposes. Setting up and expansion of fish-processing units including warehousing (excluding hatchery and natural fish drying in permitted areas) is prohibited. However, the existing fish-processing units for modernization purposes may utilize 25% additional plinth area required for additional equipment and pollution-control measures only subjected to existing Floor Space Index/Floor area ration norms and subject to the condition that the additional plinth areas shall not be towards seaward side of existing unit and also subject to the approval of State Pollution Control Board.

New Deep Sea Fishing Policy, 1991

In March 1991, the Indian government announced New Deep Sea Fishing Policy (NDSP) as part of the economic reforms programme. The policy involved three schemes: (*i*) leasing out of foreign fishing vessels to operate in the Indian EEZ, (*ii*) engaging foreign fishing vessels for test fishing and (*iii*) forming joint ventures between foreign companies and Indian companies on 49:51 equity basis in deep-sea fishing, processing and marketing. The Government of India started giving licenses to joint venture, lease and test fishing vessels. There was opposition to the policy by artisanal fishers.

Murari Committee, 1995

The Murari Committee comprising 41 members including bureaucrats, experts, activists and representatives from fishing communities was constituted. It was divided into five groups and went around all the coastal states to collect opinion from all sections of Fisheries Sector. All the five groups unanimously recommended the cancellation of all licenses to foreign vessels and review of the deep-sea fishing policy. The Committee came up with 21 recommendations, the important ones include:

- No renewal, extension or new licenses be issued in future to joint venture/charter/lease/test fishing vessels
- The present licenses be cancelled as per going through the legal procedures

- Upgrade the skill of the fishing community to equip them with exploiting the deep-sea resources
- Stop pollutions
- Supply of fuel at subsidized rate
- Fishing regulations in the entire EEZ
- A separate ministry to deal with the entire fisheries
- Monsoon trawl ban
- The area already being exploited or which may be exploited in the medium term by fishermen operating traditional craft or mechanized vessels below 20 m size should not be permitted for exploitation by any vessels above 20 m length except currently operated Indian vessels which may operate in the current areas for only three years.

The Central Government accepted all the recommendations of the Committee in September 1997. The Minister of Food Processing Industry nominated a small committee from the National Fisheries Action Committee against Foreign Fishing Vessels to oversee the implementation of Murari Committee recommendations. The Deep Sea Fishing was transferred from the Ministry of Food Processing to the Ministry of Agriculture under the Department of Animal Husbandry and Dairying. Though the separate ministry as recommended by the Committee could not be created, fisheries were added to the name of the department, making it the Department of Animal Husbandry, Dairying and Fisheries.

Broad Guidelines for the Operation of Indian Deep-Sea Fishing Vessels in Indian EEZ

Outline of broad guidelines circulated by the government for operation of Indian deep-sea fishing vessels in the Indian EEZ is given here.

Permission in writing (LOP) is required from the nodal ministry for operating any fishing vessel in Indian EEZ. Presently, permission is accorded only for (*i*) long-lining for tuna; (*ii*) tuna purse seining; (*iii*) squid jigging and squid hand lining; and (*iv*) mid-water/pelagic trawling and (*v*) trap fishing.

The operation of Indian deep-sea fishing vessels will be governed by the executive orders issued/to be issued from time to time. The area of operation of the deep-sea fishing vessels will be regulated by the instructions/orders issued by the Government of India from time to time. For proper monitoring of the operations of Indian deep-sea fishing vessels and sea safety point of view, it is mandatory for all deep-sea fishing vessel operators to report their vessels' position, intended course and speed and area of operation with latitude and longitude to Coast Guard at 08.00 hours daily or any other time specified by the authority. Date of commencement of voyage, likely period, together with crew list should be furnished to Coast Guard and Fishery Survey of India, Mumbai, before each sailing. Intimation on completion of each voyage shall also be furnished to these agencies on return. The operator shall furnish an undertaking to the effect that (*a*) they will not resort to any type of fishing other than what has been permitted to them, (*b*) the company will not exploit any endangered species of marine

turtles, mammals and fish species and the vessel will not resort to bottom trawling/pair trawling/bull trawling and (*c*) will not violate the Code of Conduct for Responsible Fisheries (CCRF). The operator should take clearance from the Government for assignment of foreign crew.

All the vessels should be fitted with INMARSAT 'C' (Mobile earth station capable of providing two way telex and data link between ship and other party at sea or land) or comparable terminal with Global Positioning System (GPS) facility as prescribed by the Government. Vessel Monitoring System (VMS) shall be set up by each vessel within the period to be stipulated by the Government of India. The base port for operation of vessel would be any one on East Coast and one on the West Coast. Government reserves the right to inspect the vessel and machinery, and equipment on the vessel and shore-based processing plants of the company at any time without notice. The operator should submit the voyage report in the prescribed format to the Fishery Survey of India, Mumbai, within 15 days from the date of completion of each voyage. Government reserves the right to impose any other conditions from time to time. Penalty will be levied for any violation, which shall be decided by the Government. Besides, the letter of permission is also liable to be cancelled without notice, if any one or more of these conditions is not followed or violated and shall have the right to seize the vessel.

Biological Diversity Act, 2002

Main objective of the Act is to protect biological diversity of India. The Act provides for the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the use of biological resources, knowledge and related matters. There is a provision for setting up of National and State Biodiversity Boards. The Act encourages conservation and has a provision to declare a fish stock threatened if it is over-exploited.

The Marine Fishing Policy, 2004

The Ministry of Agriculture has been paying due attention in the past decade to the development of deep-sea fishery in the country. On realization that most of the deep-sea fishery resources are beyond the conventional fishing limit and fishing capability of the indigenous craft and can be gainfully exploited only if upgraded and sophisticated vessels of adequate size and capabilities are inducted into the fishery, Government addressed this issue in 1981 Charter Policy.

Consequent upon the introduction of the Charter Policy in 1981 which permitted entry of foreign fishing vessels to fish in the Indian EEZ, the Central Government enacted the Maritime Zones of India (Regulation of Fishing by Foreign Vessels) Act, 1981 and the Rules there under in 1982. The enforcement of this Act is resting with the Ministry of Agriculture. Subsequent to the Charter Policy of 1981, initiatives were taken by the Government from time to time to enable Indian companies to acquire fishing vessels. After the expiry of five years of operation of this policy the government revised the policy to rectify the deficiencies noticed during its operation and to make it more beneficial to the country. Accordingly, a revised 1986 Charter Policy was pronounced. The Charter Policy envisaged acquisition of vessels by Indian companies either through import/construction in India or through joint venture etc. As a result of the above 97 companies were permitted to operate 311 foreign fishing vessels. Having laid the foundation for the Indian deep-sea fishing industry, the Government went ahead to broad base the initiative through 1991 policy. The New Deep Sea Policy of 1991 permitted Indian companies to enter into Joint Venture arrangements with foreign fishing companies and acquire fishing vessels for fishing in the Indian EEZ, flying the Indian flag.

In the absence of a legislation, the limited regulation which the Central Government has enforced so far with respect to the wholly Indian owned fishing vessels is through Executive Orders issued from time to time. These Executive Orders have been largely with respect to the enforcement of closed seasons, co-terminus with the closed seasons enforced by some of the coastal states in their territorial waters under their Marine Fishing Regulation Act (MFRA). The application of the Executive Orders issued by the Central Government has been largely restricted to fishing vessels above 20 m OAL and falling under the deep-sea category.

The Marine Fishing Policy seeks to bring the traditional and coastal fishermen into the focus together with stakeholders in the deep-sea sector, so as to achieve harmonized development of marine fishery both in the territorial and extraterritorial waters of our country. The objectives of policy are: (*a*) to augment marine fish production of the country up to the sustainable leveling in a responsible manner so as to boost export of sea-food from the country and also to increase per caput fish protein intake of the masses, (*b*) to ensure socio-economic security for the artisanal fishermen whose livelihood solely depends on this avocation, and (*c*) to ensure suitable development of marine fisheries with due concern for safeguarding the rich bio-diversity.

The policy measures suggested for harvesting sectors include protection and consideration of subsistence-level fisherman; area demarcation for traditional, motorized and mechanized sectors; motorization of traditional craft; provision of infrastructure support in terms of landing and berthing facilities for deep-sea vessels; introduction of more resource-specific vessels of above 20 m length; special incentives for wholly Indian-owned vessels for venturing into international waters and engaging in fishing in the EEZ of other nations under license, regulation of fishing capacity; and incorporation of code of conduct for responsible fishing operations into every component activity. Encouragement to subsistence-level fishermen would include scheme to motorize the traditional craft and also providing better material and technology, for their traditional craft. The small-mechanized sector would be encouraged by providing incentives for acquisition of multi-day fishing units. Proposals for import of resource-specific fishing vessels by wholly Indian owned enterprises would be screened and approval accorded for such imports by a designated authority in accordance with well-laid out norms. These additional fishing units in the deep-sea sector would be for tuna fishing and squid jigging.

Fishing in Antarctic waters by Indian owned vessels or with equity participation or

under license would be promoted by working out sustainable strategies. Assessment of existing fishing capacity and plans for regulating or developing one or the other sectors of EEZ would be taken up.

For post-harvest operations, total utilization of harvested fish for food and non-food uses would be the central theme of the policy. Implementation of international quality regimes such as hazard analysis and critical control points (HACCP), ISO 9000 and Codex Alimentaries for fish and fishery products, harmonization of existing domestic standards with the International Standards, packaging and bar-coding of fish and fish products, legislation to streamline hygiene in fishing harbour/pre-processing and processing centres and protection of consumer rights are other highlights of the policy.

The policy also advocates a stringent fishery-management system to be in place in view of resources within 50-m depth zone showing symptoms of depletion. The model bill also calls for a review of implementation of Marine Fishing Regulations Acts (MFRAs) and prescribing a fresh model bill if need be on coastal fisheries development and management with re-orientation on limited access in coastal marine sector through policy initiative, sound legislation and awareness creation. Standards for fishing-vessel construction, especially for those below 20 m registered length is to be developed and control would be exercised through new legislation. Provisions would be made to comply with requirement of registration of vessels and standards of training certification and watch keeping of fishing-vessel personnel. The other measures for resource conservation include implementation of closed season, ban on destructive methods of fishing and mesh size regulations. The policy also envisages prohibition of catching of juveniles and non-targeted species and discarding less-preferred species once they are caught through legislation. Monitoring control and surveillance system (MCS) would be enforced through posting of observers on commercial fishing vessels. Seed production for sea ranching, designation of certain areas as marine sanctuaries and regulating capture of broodstock from these locations would form important components of resource-enhancement programme. Open-sea cage culture and fish-aggregating devices form other important areas of resource management.

The policy highlights ensuring socio-economic security of the fishermen. Artisanal fisheries deploying Out Board Motors (OBMs) and small-mechanized boats up to 12 m would be treated at par with agriculture while small-scale fisheries involving mechanized boats under 20 m registered length would be treated at par with small-scale industries. Fishing vessels above 20 m and fishing activity involving mother ships or factory vessels would be treated as industrial activity. Further, full-time occasional fishermen, whose household does not own a boat, would be treated at par with landless labourers and would qualify for special care and protection. Contribution towards insurance coverage and saving-cum-relief scheme, would be restricted to the fishermen who do not own a boat. The policy envisages strengthening of cooperative movement and greater participation of NGOs and local governments in the developmental process. Housing scheme for fishermen, greater focus by financing institutions and improved safety at sea are the other components of fishermen-welfare programmes.

In respect of environmental aspects, the policy lays major emphasis on making HACCP in effluent discharge systems mandatory. Further planting of mangroves will be encouraged with a view to provide nurseries for shrimp and fish and also as a coastal-area protection. The latter activity would be introduced as participatory programme of the stakeholders particularly fishing community. Sustainable changes in Coastal Regulation Zone (CRZ) keeping in view the topography of each region will be undertaken if necessary after a review.

For infrastructure development for marine fisheries, the draft policy includes drawing up of development of infrastructure for the next ten years and exploring private sector initiative through Build-Operate-own and Build-Operate-transfer systems. The policy also mentions reviewing existing legal framework for regulating the fishing operations and introduction of additional legal instruments in areas such as operation of Indian flag vessels in the EEZ, introduction of new fishing units, ensuring conservation of resources, limited access fishing and fishing-harbour management. The policy also has taken note of increased incidence of straying by small-mechanized boats into territorial waters of other countries and vice-versa and envisages a mutually agreeable system to be put in place with neighbouring countries to have a lasting solution to the problem. The policy document indicates endorsing international laws and conventions in the marine fisheries sector and hormonising the national laws with the international ones wherein necessary with active participation in the regional fisheries management bodies and greater cooperation amongst countries in the region. Further, the use of information technology, strengthening of database in marine fisheries, human resources development and eco-labeling of marine products are the other components of legislative support. The marine fishing policy 2004 also outlines policy for development of fisheries in the Union Territories of Lakshadweep and Andaman and Nicobar Islands.

Marine Fisheries (Regulation and Management) Bill, 2009

The Union Government proposes to bring fishing vessels of Indian origin in the Indian EEZ, along with other categories, under a legal regime called the Marine Fisheries (Regulation and Management) Bill 2009, through a common legal framework for regulation of fisheries, and conservation and sustainable use of fishery resources in all maritime zones including territorial waters. The scope of the proposed Bill 2009 includes the territorial waters (can be up to 12 nautical miles from the base line), contiguous zone (can be up to 24 nautical miles from the base line), EEZ (can be up to 200 nautical miles from the base line) and the continental shelf (can be up to 350 nautical miles from the base line). It proposes to bring into its ambit Indian fishing vessels constructed in India, owners of such vessels and fishery and fish-workers on board these vessels and their operations, especially in the EEZ.

Fisheries in territorial waters are a state subject, while that of other zones are a Union subject. The regulation of fishing in territorial waters is being legally undertaken by the State Fisheries Departments under marine fishing regulation acts/rules (based on a model bill prepared by the Central Government). In the EEZ, Indian citizens have been given more or less freedom to fish. The Maritime Zones of India (Regulation of Fishing by Foreign Vessels) Act 1981, and the Maritime Zones of India (Regulation of Fishing by Foreign Vessels) Rules, 1982 are meant to regulate foreign fishing vessels in the Indian EEZ that are owned and/or operated by both Indian Citizens and foreign nations. Thus there is a legal vacuum in relation to the regulation of Indian fishing vessels of Indian build in the EEZ with no legal responsibility or accountability except the requirement to follow the seasonal monsoon ban and the prohibition on taking certain endangered or protected species under the 1972 wildlife (Protection) Act. This Bill seems to be proposed mainly with the purpose of bringing all Indian and foreign vessels and related interests in the EEZ under a legal mechanism, so as to meet India's obligations under 1982 United Nations Law of the sea convention and the 1995 United Nations Fish Stocks Agreement and to draw upon relevant sections from the 1995 FAO Code of Conduct for Responsible Fisheries.

International Agreements

Management of deep-sea fishery resource has become more complicated subsequent to developments in the international areas – widening its scope further. The Code of Conduct for Responsible Fisheries (CCRF) evolved by the FAO has been endorsed by India which aims at long-term sustainable measures for optimal exploitation of fishery resources. The Code also serves as an instrument of preference to establish or to improve the legal and institutional framework required for the exercise of responsible fisheries. The Code is voluntary in nature, but certain parts of the Code include major articles and provisions from a number of United Nations (UN) conventions and agreements. The CCRF defines the general principles that 'The right to fish carries with it the obligation to do so in a responsible manner'. The Code calls for effective legal and administrative framework for the refusal, withdrawal or suspension of authorization to fish in the event of non-compliance with conservation and management measures. Also the member countries should implement effective fisheries Monitoring Control and Surveillance (MCS) and law enforcement measures wherever appropriate. Further laws and regulations applicable to international trade should be followed in a transparent manner, which are to be reviewed from time to time.

The following four international agreements emerging out of the endorsement of the Code are relevant in this context for incorporation under the relevant laws/legislation proposed in this regard.

(i) Agreement for the implementation of the provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stock and Highly Migratory Fish Stock.

(ii) Agreement to promote compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas.

(iii) International Plan of Action to prevent, deter and eliminate, illegal, unreported and unregulated fishing.

(iv) International Plan of Action for Management of Fishing Capacity, Conservation and Management of Sharks, reducing incidental catch of Sea Birds in long line fishing.

The above agreements need effective implementation by both Indian owned fishing vessels as well as foreign fishing vessels operating in the Indian EEZ as well as in the international waters.

Inland Fisheries Legislation

The subject of legislating for the protection of freshwater fishes was opened with an inquiry made so long ago as 1869 by Dr Francis Day of the Madras Medical Services, who had been placed on special duty for that purpose. This was followed by a resolution issued in October 1871 on Dr Day's report for the North-Western Provinces, in which he recommended a Fisheries Act. Dr Day's recommendations as well as the action taken on proposals made up to 1888 by the various local governments were summarized in a note prepared for the Agricultural Conference held at Delhi in that year. The Government of India enacted the Indian Fisheries Act, which came into being in 1897. The objective of the enactment was to prohibit the use of dynamite and poison in all territorial waters and to make the provisions of the Bengal Private Fisheries Protection Act, 1889, of general application. It also empowers each State Government, with the previous sanction of the Central Government, to make rules and to apply them to any selected streams or other waters which are the property of the State, or to any other streams or other waters with the consent of the persons owning them or interested therein.

This Act also provides suitable penalties for breaches of the proposed law and of the rules made there under, and it confers on person specially empowered by the State Government, power to arrest without warrant for offences against such law or rules. This Act shall be read as supplemental to any other enactment for the time being in force relating to fisheries in the territories to which this Act extends. This is a small piece of legislation containing only seven sections. Section 1 deals with the extent of the Act while Section 2 provides that Act is a supplement to other fisheries laws. Section 3 is a defining section which defines the expressions fish, fixed engines and private water. Section 4 provides for destruction of fish by explosives in inland waters and on coasts and Section 5 deals with destruction of fish by poisoning of waters. Section 6 provides protection of fish in selected waters by rules of State Government, whereas Section 7 is a penal provision providing for arrest without warrant for offences under this Act.

There is a general impression that the Indian Fisheries Act of 1897 is an inland fisheries act. The act, of course, appears to be concerned only with inland fisheries, because the act provides that the word water includes the sea within distance of one marine league (3 nautical miles or 5.56 km) from the sea coast (Explanation No.4 (2) of the Act).

Erstwhile Punjab (before partition) was perhaps the first state to introduce legislation for conservation of fisheries. The Punjab Fisheries Act II of 1914 was passed, and later amended and revised from time to time in 1941, 1966 and 1971. For regulating fisheries in canals, separate rules were framed and notified by the Punjab Government in 1924 in the form of Rules for regulatory fishing in Government canals and rules for regulating in head waters. States of Himachal Pradesh, Haryana and the Union Territory of Delhi also follow more or less Punjab rules. The fishing rights of the notified public waters are put to open auction on or after 1st July every year and the period of lease extends from 1 September to 21 August of the next year. Some states like West Bengal, Uttar Pradesh, Andhra Pradesh, Madhya Pradesh, Karnataka, Kerala, Tamil Nadu, and Jammu and Kashmir have some rules for fisheries regulation. Rajasthan enacted fisheries legislation in 1984. The State of Uttar Pradesh put a ban on the capture and sale of juveniles (5.1 to 23.4 cm in length) from 15 July to 30 September and of spawn from 15 June to 31 July from the prohibited areas. From 1953, in Madhya Pradesh, fishing of rohu, mrigal, catla and mahseer of less than 22.9 cm length are prohibited. Many riverine areas have been declared as sanctuaries in Madhya Pradesh, Himachal Pradesh, Delhi, Jammu and Kashmir, Karnataka and Tamil Nadu. Mesh regulations are observed in many places such as Manipur, and Andaman and Nicobar Islands. Nets having a minimum mesh size of 1 inch (2.54 cm) are generally permitted for fishing in the reservoirs. The use of explosives and poisonous substances for the capture of fish is prohibited in many states like Jammu and Kashmir, Himachal Pradesh, Andhra Pradesh, Karnataka, Uttar Pradesh and Kerala.

The Government of Asom has introduced a policy on 'Fish Seed Industry' in the state in 2001 to augment quality fish seed production for advancement of aquaculture in the state and to protect the biodiversity of economically important indigenous fish species of Asom in the natural ecosystem by adoption of adequate conservation measures. In order to translate these aims and objectives into action, the State Government has proposed establishment of eco-hatcheries, standard size of brood-stock, partial replacement of broodstock with wild stock, prohibition of breeding and propagation of banned exotic fishes, registration of fish seed producers and growers and easy and unrestricted transport of fish seed in the state. Suitable regulations for river rehabilitation stock enhancement and protection of spawning grounds are also envisaged in the action plan.

The Act of 1897 has been adopted, by promulgating Rules under Section 3 of this act and through various amendments, at the state level, various states with references to the multifarious provisions pertaining to about 51 different regulatory activities, comprising mainly limited accesses, licensing of gear, gear restriction, leasing and auctioning.

The complexity of factors involved in the regulation of fisheries, domestic and international, is often underestimated. Fishing is still largely an activity to harvest wild stocks of highly ambulatory animals. These animals cannot be fenced in a limited area or with marked ownership. This makes fisheries of open water a common property resource with its related problems. Therefore, regulatory measures need to be blended with other environmental protection measures such as (*a*) limited access, (*b*) leasing and auctioning, (*c*) closed seasons, (*d*) licensing of gear, and (*e*) gear restrictions.

The Coastal Aquaculture Authority Act, 2005

The high growth rate of the economic activity of culture of shrimp in the coastal areas also led to discussions on the environmental sustainability of the aquaculture operations. Over years of discussions, The Aquaculture Authority was established and the Coastal Aquaculture Authority Act, 2005 is also in place and some of the provisions relate to preventing construction of shrimp farms in mangrove areas, other sensitive areas and in agricultural land; compulsory Environment impact assessment (EIA) for larger farms; wastewater-quality standards and effluent treatment plants; use of chemicals and drugs; licensing and mandatory application of code of conduct; provision for registration of shrimp farms valid for a period of five years which may be renewed from time to time for a similar period.

Further, the authority would make such inquiry to ascertain that registration of shrimp farms above two hectares of water spread area shall not be detrimental to coastal environment. Traditional aquaculture farms within CRZ, which have not been hither to put into use for aquaculture purposes should be registered with the Coastal Aquaculture Authority failing which such lands will not be allowed to be used for aquaculture purposes. Such registered lands should be utilized for aquaculture within one year of registration. A provision has also been made in the Bill to set up a Tribunal to decide compensation in respect of the workers of farms to be demolished. It has also been indicated in the Bill that the concept of responsible aquaculture would be followed in regulating the aquaculture activities.

At the state level also there have been some attempts to regulate shrimp farming. In this regard the Department of Fisheries, Government of Andhra Pradesh, has submitted a draft bill on regulating the quality of the shrimp seed produced in the hatcheries since at present, the hatcheries are in the private sector.

Hence, the department has proposed Enactment of Aquaculture Seed (Quality Control) Bill. The bill has been vetted by the Law Department and is pending with the Government for enactment. The salient features of the bill are:

- Ensuring the quality of the seed, brooder stock and labeling of the quality of seed.
- Stipulating norms for size, weight, purity and disease-free parameters for seed.
- Government will have powers to regulate import and export of aqua seed.
- The aqua seed testing laboratories will be set up.
- The department will have powers to register hatcheries, fish seed farms and conduct inspections.
- Notifying and regulating the varieties of seed to be used for aquaculture.
- Constitution of Aquaculture Seed Committees.
- Aquaculture seed registration and certification.
- The department will have powers to levy penalties.

Model Bill on Inland Fisheries and Aquaculture, 2005

Considering the potential of inland fishery resources and the development of fisheries sector, a Model Inland Fisheries and Aquaculture Bill has been drafted. The main objective of the Model bill is better management of the inland fishery resources so as to ensure

sustainability and increased productivity. The Government of India through Model Bill on Inland Fisheries and Aquaculture intends to ensure sustainable fish production to meet future needs of the country. The provisions of the bill are given here.

Control, regulation and ban on destructive gear

The bill stipulates that the state or any other authorized agency by the State/Union Territory shall restrict, regulate or prohibit the use of fishing crafts and gear, which are deemed as destructive in nature, so as to conserve or protect the biodiversity in general and endangered species in particular. Precautionary approach to regulate the use of fishing gear so as to protect fish species of commercial value from over-fishing or fishing at undesirable size is also recommended. The authorized fishery officer shall have the authority to control, regulate and ban destructive crafts and gears in open-water ecosystem for catching fish and imposing suitable penalty for violating the prescribed norms.

Untenable fishing practices in inland waters

Wanton killing of fish and associated fauna using poison of plant origin or synthetic, dynamite and any other destructive methods in open-waters shall be treated as cognizable act with a penalty of ₹10,000 or one year imprisonment or both. Establishment of compartments or structures of any form, such as earthen embankments, bamboo screams etc., which obstruct or restrict the movement of fish in any form within the lake or wetland or estuary or lagoon shall be deemed as cognizable offence except otherwise done in public interest.

Conservation of stock and resources

The state shall notify closed season or fishing holidays in open-waters like rivers and reservoirs make inventory of deep pools for protection and maintenance, declare biodiversity-sensitive areas as protected areas, protect the physical entity of wetlands/ floodplain lakes through check on obstruction in connectivity and encroachment. State should make provision for protection of the interest of traditional fishers.

Leasing/licensing of open-water-bodies

The leasing of open-water fisheries to be done keeping in view the long-term management perspective and lease period shall not be less than five years. Rent fixation should be based on production capacity and lease holders should regulate fishing effort, stop dumping of solid waste in water-bodies.

Certification of fish seed

The bill stipulates that all fish-seed hatcheries to be registered with State/Union Territory Department of Fisheries and recommends setting up a Fish Seed Committee to monitor and ensure supply of quality seed, restriction on breeding and propagation of banned fish. The guidelines for inter-state movement of fish seed are also prescribed.

Feed quality control and certification

Fish-feed manufacturing unit shall register with State/UT Department of Fisheries. Fish feed for aquaculture shall be certified by the competent authority and fish-feed bags shall be labeled, indicating the ingredients used, date of manufacturing, date of expiry etc.

Use of chemicals and antibiotics

The use of chemicals or antibiotics is not allowed which have the potential to affect the environment or human health.

Health monitoring and disease reporting/control

Disease diagnostic and reporting procedures shall be maintained by the State/ UT Department of Fisheries to monitor the occurrence of diseases and their containment.

Environmental and human health issues

Environment impact assessment (EIA) shall be made mandatory in all the projects which have the potential to affect the aquatic regimes including the fisheries adversely and in larger aquaculture projects. Assessment of health hazards of fish produced in waste-waters to be made.

Exotic species

Culture or breeding of prohibited exotic species shall be treated as cognizable offence. In order to protect the endemic fish germplasm, state shall ensure that no exotic species enter the open-waters.

The Model Bill also envisages that the State shall ensure that the provisions of the Code of Conduct for Responsible Fisheries (CCRF) of the FAO of the United Nations are implemented with suitable adaptations, wherever necessary.

Use of chemicals/antibiotics in shrimp aquaculture

Unscientific use of chemicals and antibiotics can have an adverse effect on human health and also the environment. Many countries importing marine products from India do not permit any residual level of banned chemicals and antibiotics. Therefore, steps are being taken to discourage the use of these chemicals and antibiotics in shrimp farming. Presently the use of 20 antibiotics and chemicals is banned in India for use in shrimp culture. The Ministry of Agriculture (Department of Animal Husbandry and Dairying) vide a notifications dated 7 July 2001 and 16 October 2001 has made it mandatory that import of all livestock products including all aquatic animals encompassing fish, crustaceans and molluscs shall be allowed only against sanitary import permits to be issued by the department. As the shrimp or fish feed may contain banned antibiotics, chemicals etc., the committee set up in this Department on Risk Analysis on sanitary imports constituted under the chairmanship of Animal Husbandry Commissioner scrutinizes the import applications and imposes the condition that feed for aquaculture should be free from any chemical residues including antibiotics. The

chemical contents of fish and shrimp feed are to be indicated in order to determine its admissibility.

A comprehensive regulatory framework for fisheries and aquaculture encompasses crucial matters such as environmental conservation, public health, legal support, economic incentives, risk insurance, information dissemination, international cooperation as well as coordination of production, marketing and management measures. Appropriate policies, legislation and regulations are required for prevention, reduction or elimination of hazards with clear-cut legal framework on property rights, water-quality protection, prevention of environmental degradation, disease spread, biodiversity conservation etc. The National Policy on Agriculture seeks to promote technically sound, economically viable, environmentally non-degrading and socially acceptable use of country's natural resources–land, water and genetic endowment– to promote sustainable development of agriculture including fisheries and aquaculture. The marine fishing policy recently released by the Union Government seeks to achieve harmonized development of marine fisheries both in the territorial and extra-territorial waters of our country through various measures suggested for different sub-sectors of marine fisheries for ensuring socio-economic security of the fishermen. Further, the Coastal Aquaculture Authority Bill, 2004 which has been recently passed by the Parliament is expected to provide necessary legal provisions for regulating the various aspects related to this sector. Model Bill on Inland Fisheries and Aquaculture which is in the pipeline is expected to provide broad guidelines to different states in regulating and managing their Inland Fisheries and Aquaculture. It is hoped that the policy guidelines and legal framework provided by the Union Government and various State Governments will go a long way in ensuring sustainable fish production and improve socio-economic conditions of fishers in India.

44. Fisheries Financing

India's fisheries development and management programmes aim at increased fish production to meet the food demand along with improve socio-economic conditions of fishermen and to tap untapped resources. Like conventional land animal production, fisheries and aquaculture are not new in the country. Though meaningful comparisons of two sectors are unreasonable, fish have significant advantages over animal growth. They are cold blooded, have three dimensional growing surfaces, mostly primary feeder, do not have to support their weight and therefore better equipped to convert food to flesh. They are also, more nutritious. Besides, the pisces have added advantage, they grow in any stagnant or flowing aquatic medium, be it marine, brackish, or freshwater.

In India, fish, as food, medicines, decoration, recreation, socio-religious events and also a factor for status in the community has existed since ancient times. However, importance of fisheries as commercial activity and scope for exploiting huge and varied marine and freshwater resources were realized in early fifties of the last century when marine and inland capture fisheries received the attention of Government of India. Gradually the aquaculture was included and the sector emerged as an area of education, development, research and extension.

Sixties and eighties showed potentiality of freshwater and brackishwater aquaculture respectively. Efforts made in upgrading technologies, adopting innovations, developing human resource and improving per unit area/effort productivity, have helped in multiplying fish production manifold.

In the last fifty-five years, the country has attained phenomenal growth. From negligible fish production of 7.5 lakh tonnes per annum to 7.64 million tonnes per annum (2008-09), the sector has shown ascending growth. Initially marine sector had higher share in total production but now in the last three decades the contribution of inland sector is increasing, overtaking the marine sector. In the last decade (as per Government of India's report), marine fisheries grew steadily at 2.32% but inland fisheries showed an average growth rate of 8.0%. Consequently, in 2008-09 inland fish production was 46.59 lakh tonnes against marine fish production of 30.04 lakh tonnes.

Fisheries is a now principle contributor to national economy as well. It has grown at a steady pace of 6% per annum during previous Five Year Plans, attaining compound growth rate of 36% in Tenth Five Year Plan, it surpassed growth rates of other agricultural sectors. Engaging 14 million people to this profession, earning ₹ 10,048 crores (2010-11) through export, sharing 1 % of total GDP and 4.56 % of agriculture and allied areas, fisheries has a significant role and cannot be ignored in any government's development and financial planning.

Quantitative expansion of fisheries activities is closely linked to the availability of adequate and timely credit. It is the most crucial input for both capture and culture fishery projects, in both cases the operations are mostly handled by credit-starved fishermen or farmers. It is in this area our financial institutions are playing pivotal role. At apex level, National Bank for Agriculture and Rural Development (NABARD), National Cooperative Development Corporation (NCDC), Small Industries Development Bank of India (SIDBI) and at ground level State Cooperative Banks (SCBs), State Cooperative and Agriculture and Rural Development Banks (SCARDBs), Regional Rural Banks (RRBs), Commetrcial Banks (CBs), Scheduled Primary Urban Cooperative Banks (SUCBs), Village Development Boards, North Eastern Development Finance Corporation Limited (NEFDC Ltd.) and other Non-banking financial companies and institutions approved by the Reserve Bank of India (RBI) have played significant role in extending credit support. The state governments, corporates, cooperative societies, NGOs, Self Help Groups (SHGs) and entrepreneurs have been the beneficiary of this support. In addition, all coordinating commercial banks in their allotted state (as per RBI guidelines) have at least an exclusive agriculture branch in each state to cater to agriculture and allied sectors including fisheries. We have 101 commercial banks, 196 regional rural banks, 49 cooperative banks, 29 state cooperative banks and 20 state cooperative agriculture and rural development banks. All these banks have 0.165 million branches in rural India. In addition, the country has about 0.101 million primary cooperative agricultural credit societies (PCACs) and 755 primary cooperative agriculture rural development banks (PCARDBs) with 689 branches. Thus, the banks have a good network all over the country.

Though fisheries has been getting formal credit from banks for the last forty years, since 1990-91 radical changes occurred in economic, social and technological environment. Signing of Dunkel draft and GATT agreement followed by WTO regime were accepted in India and elswhere. Liberalization of economy also brought attitudinal changes in entrepreneurs. In tune with changes, bankers also started supporting innovative and diversified technologies through investment credit and short-term credit portfolios.

The investment credit for agriculture and allied activities including fisheries provided by this network amounted to ₹ 90,945 crore during 2006-07, registering a growth rate of 21% over the previous year credit flow of ₹ 75,136 crore. The cumulative refinance as on 31 March 2009 stood at ₹ 118,166 crore and that to the fisheries sector at ₹ 974 crore. The NABARD has entered into agreement with 15 commercial banks for co-financing high tech/export-oriented agriculture projects involving large financial outlay/ sunrise technologies etc., thereby sharing the credit risk with partner banks.

During Ninth Five Year Plan, agriculture credit disbursement was ₹ 2,317,980 million which was up by 19.4% over Eighth Plan. Total priority sector lending percentage which also includes agriculture against net bank credit is 43.6%. If we add private sector banks' contribution say by, 40% and informal credit extended by money lenders the flow of credit in rural areas is quite impressive.

The investment credit for fisheries sector vis-à-vis the total investment credit for agriculture for the last nine years (1999-2000 to 2007-08), depicted in Table 44.1, revealed that the investment credit flow to fisheries sector constitutes only 1.36 % to

Table 44.1. Investment credit disbursements in fisheries against total disbursements

(₹ in crore)

Year	Investment credit in fisheries	Investment credit in agriculture and allied activities	% of column 2 to 3
1999-2000	404	17,303	2.33
2000-01	318	19,513	1.63
2001-02	508	21,536	2.36
2002-03	539	23,974	2.25
2003-04	1,142	32,004	3.57
2004-05	1,102	49,247	2.24
2005-06	1,019	75,136	1.36
2006-07	1,424	90,945	1.57
2007-08	1,248	73,265	1.70

Source: NABARD.

3.57 % of the total investment credit for agriculture and allied activities over the last nine years.

Compared to agriculture and livestock development credit flow in fisheries is not significant, mainly because (*i*) commercial fisheries is a new activity, (*ii*) bankers are not aware of fish technologies and its profitability, i.e. lack of orientation, (*iii*) project size is not fixed and varies, case to case basis, (*iv*) variation in production in different fishery crops, (*v*) difficulty in assessing available stock/standing crops, (*vi*) high monitoring cost in rural areas, (*vii*) poor recovery and the mounting over-dues. However, despite these handicaps, credit delivery for fisheries has been on increase as is reflected in refinance availed in the last 10 years (Fig. 44.1). It is again reiterated that the credit for the fisheries development is available from all scheduled banks with or without refinance facility from the NABARD. The farmer has to apply on prescribed application form to any bank branch of his area. The projects could be of individual or fisher group, corporates or co-operative societies. Majority of the loan proposals sanctioned so far are for fishing, aquaculture, seed hatcheries or processing.

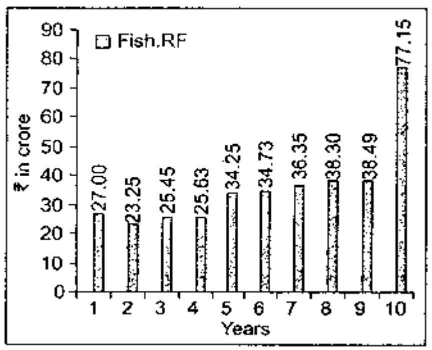


Fig. 44.1. Year-wise fisheries refinance (Fish. RF) disbursement data from 1999-2000 to 2008-09

A detailed list of sub-sector-wise fishery technologies eligible for bank financing is given in Table 44.2.

Rate of interest

The credit is extended to loan applicant with very easy norms. But the rate of interest to be charged is decided by the concerned bank and is at their discretion. Interest is also decided depending upon loan size. Softening of interest rates now a

Table 44.2. Bankable fisheries technologies

Sl No.	Sector	Sub-sector	Bankable technologies	Remarks
1	A. Marine fisheries	(i) Capture fisheries	• Traditional boats • Motorization of traditional boats • Mechanized fishing vessels • Resource specific deep-sea fishing vessels	Country crafts with Outboard engines (MFVs)
		(ii) Mariculture	• Edible oyster farming • Mussel farming • Pearl culture • Ornamental fish culture • Mud-crab farming • Cage culture of finfishes • Sea weed farming • Clam farming • Surmi production	Innovative technology still in experimental stage
		(iii) Sea-food industries	• IQF processing unit • Chitosan preparation • Ice plant • Fish feed mill plant • Refrigerated vans, transport vans • Retail fish and fish products marketing vans • Retail fish products stalls, etc.	Innovative technologies
2	B. Brackish-water fisheries	(i) Culture	• Traditional • Extensive • Semi-intensive	
		(ii) Seed production	• Shrimp hatcheries • Large-scale shrimp hatcheries	
		(iii) Ancillary activities	• Shrimp feed mills • Disease testing small-scale labs	
3	C. Fresh-water fisheries	(i) Capture	• Crafts/gears for fishing in reservoirs and rivers	
		(ii) Aquaculture	• Composite fish culture • Fish seed hatcheries • Culture of air breathing fishes • Trout farming • Ornamental fish culture and breeding • Integrated fish culture • Sewage fed fish culture • Eco hatchery • Hatcheries/rearing of fish seeds of all cultivable fishes and prawn • Monoculture/ poly culture of prawn and fish • Cage culture • Pen culture • Tilapia culture • Construction of fish farms • Reservoir development etc.	

days, has become beneficial to borrowers. The NABARD however charges interest at minimum of 8.5 % on its refinance from commercial banks. In case rate of interest charged by bank is higher, then Refinance interest to be paid by the bank is 3.5% less. In case of SCBs, ARDBs, RRBs and primary urban cooperative societies a special rate of only 8.0% on refinance is charged by the NABARD. For Agricultural Development finance Company (ADFC) however, it is still less, i.e. 7% only. In order to give boost to agriculture and allied sector in hilly region as well as eastern states even commercial banks are provided refinance at 8%. The states listed for the concession are north-eastern states, Sikkim, Bihar, Eastern part of West Bengal, Jharkhand, Odisha, Andaman and Nicobar islands, Lakshadweep, Himachal Pradesh and Jammu and Kashmir. To get clear idea of interests charged, category-wise rates are depicted in Table 44.3.

Table 44.3. Bank-wise or state-wise rate of interest and refinance interest

Sl No.	Category of banks	Rate of refinance interest	Remarks
1.	Commercial banks	Minimum 8.5%	Interest rate from borrower is decided by the concern bank. But in case any bank charges higher interest, then RF rate is 3.5% less than the final interest charged from borrower
2.	Commercial banks	8.0%	For N.E., Sikkim, Eastern part of W.B., Jharkhand, Odisha, H.P., J&K, A.N. islands, Lakshadweep
3.	SCB,RRB,SCARDB,	8.0%	All over the country
4.	ADFCs	7.0%	All over the country
5.	Rural Infrastructure Development Fund (RIDF) to state governments	Rate of refinance interest varies	Interest charged varies from state to state depending upon their deficit in priority sector and agriculture sector lending

SCB, State Cooperative Banks; RRB, Regional Rural Bank; SCARDB, State Coopertive and Agriculture and Rural Development Bank; ADFC, Agriculture Development Finance Company.

Repayment period of bank loan varies from 5 to 15 years and can be paid depending upon factors such as, project cycle, technology, harvesting schedule, life of project and cash flow analysis or quarterly, half yearly or annual basis.

Credit support so far

Bankers have substantially contributed towards development of fisheries sector in the last five decades. Though we do not have exact figures of ground-level disbursements, rough estimate can be made from refinance support extended in the last 25 years of NABARD's existence. Nearly 37 % (22,036) of mechanized boats and 39 % (73,000) of other boats of the country were introduced with refinance assistance from the NABARD. Similarly, out of 721,000 ha of freshwater aquaculture under FFDA programme of the Government of India, 57 %, i.e. 409,000 ha, developed through the NABARD/banks support. Considering that the apex bank on an average has

contributed 70% of the total credit disturbed so far, overall disbursement for fisheries is quite substantial. An estimate of year-wise refinances disbursements for fisheries vis-a vis agriculture data for the last 10 years (1999-2009) is depicted in Table 44.4. Data of investment credit disbursed by banks is not available. India has attained self-sufficiency in fish-seed production in inland fisheries. It was possible owing to setting up of large-size fish-seed hatcheries in the public sector and small fish-seed hatcheries in private sector under IDA inland fisheries project. The success in the efforts of IDA project to some extent can be attributed to banker's whole-hearted support and to the credit given under the guidance of the NABARD. Nearly 3.5 % of the 150,000 ha developed under brackishwater aquaculture since 1989-90 received refinance, in addition to some of the projects which were directly supported by a few banks. To promote exports, banks have supported large number of fish-processing units including units for value-addition in the form of IQF products and Surimi products. Any loan application with full information and with technical feasibility and financial viability is considered for bank credit. Automatic Refinance Facility (ARF) up to ₹ 15.0 lakh enables bank to process the proposal at their level but high-tech projects or projects with intensive capital cost is referred to the NABARD.

Table 44.4. Refinance disbursement in fisheries investment vis-à-vis agriculture and allied activities

(₹ in crore)

Year	Refinance disbursement for investment credit to fisheries sector	Refinance disbursement for investment credit to agriculture and allied activities	% of column 2 to 3
1999-2000	27.00	5,215.00	0.52
2000-01	34.25	6,458.10	0.53
2001-02	36.35	6,682.91	0.54
2002-03	34.73	7,418.78	0.48
2003-04	23.25	7,605.29	0.31
2004-05	25.63	8,577.46	0.30
2005-06	38.49	8,622.37	0.45
2006-07	38.30	8,795.02	0.44
2007-08	25.45	9,046.27	0.28
2008-09	77.15	10,535.29	0.73

Source: NABARD@.
@Ground-level data of disbursements from banks not available.

Direct financing and co-financing

Sixteen Scheduled Commercial Banks, two Regional Rural Banks Co-operative Banks and one Non Banking Financial Company and the NABARD have entered into agreement for co-financing hi-tech, high-value export oriental agriculture projects involving large financial outlay/sunrise technology etc., thereby sharing the credit and risks with partner banks and institutions. In addition, the NABARD is also having such co-financing on a highly selective basis with other institutions, namely NAFED, NCDC, NDDB. Three fisheries proposals have been appraised with banks on extraction of fish oil and fish-meal preparation, production of freshwater pearl under culture system and processing and value-addition of fin-fish, shrimp and other marine catches. Co-financing gives added confidence to participating bank for such ventures.

Production credit

The NABARD has opened a line of credit for production credit to the District Central Cooperative Banks (DCCBs) in October 2002 and extended the same to the Regional Rural Banks (RRBs) in March 2003. The line of credit is given for short term for raising a crop by the farmer. The period of loan varies as per the period of raising a crop. To encourage bankers to extend short-term (ST) credit NABARD provides refinance assistance. It covers both production and marking of fish. The credit for working capital is available to Primary Fisheries Cooperative Societies. Most of the State Fisheries Departments, except West Bengal, are yet to design and operationalise Management Information System (MIS), for consolidated reporting of production credit provided by the banking sector and therefore it is difficult to know state-wise disbursement under short-term credit. The progress made in West Bengal under production credit during the year 2004-05, 2005-06, 2006-07 and 2007-08, as reported by the state, is given in Table 44.5.

Table 44.5. Production credit disbursed in West Bengal between 2004-05 and 2007-08

(₹ in lakh)

Year	Sponsored to banks	Sanctioned by banks	Disbursement made by banks
2004-05	2,120	1,070	690
2005-06	3,337	1,988	1,498
2006-07	3,846	2,789	2,388
2007-08	4,354	3,235	3,035

Rural Infrastructure Development Fund

Several states initiated rural infrastructure projects but are unable to complete due to paucity of funds. For the same reason they are unable to take up new projects but since 1995-96, the NABARD, with funds/deposits of commercial banks, has initiated the Rural Infrastructure Development Fund (RIDF). This project is mainly meant for state governments and is directly funded by the NABARD. Till March 2009, a total of ₹ 88,359 crore and ₹ 56,052 crore were sanctioned and disbursed respectively. Out of the above total, 124 fisheries infrastructure projects were developed with loan amount of ₹ 14,760.16 lakh comprising Fishing harbours, Fish Landing Centers Jetty, Riverine Fisheries, Fish Market Infrastructure, Fish Farm, Cold Storages, etc. were developed in the last 12 years. States benefited are Karnataka, Kerala, Manipur, Nagaland, Odisha, Uttar Pradesh and West Bengal and UT of Puducherry. The activity-wise sanction details are depicted in the Table 44.6.

Similar projects and others like community cold storages, flood-control measures, peripheral dykes, embankments, approach roads, primary health centres or primary

Table 44.6. Activity-wise distributions of Rural Infrastructure Development Fund

(₹ in lakh)

Sl.No.	Activity	State/ UT covered	RIDF loan sanctioned
1.	Fishing harbour	West Bengal, Kerala, Puducherry	8,298.47
2.	Fishing jetty	West Bengal, Kerala, Karnataka, Odisha	2,211.83
3.	Inland fish landing centre	Manipur	52.67
4.	Fish market and food parks	West Bengal	536.84
5.	Upgradation of navigation	West Bengal	1,804.69
6.	River project	Nagaland	682.03
7.	Fish farm renovation	Uttar Pradesh	243.56
8.	Inland canals and water courses	West Bengal	930.07
	Total		14,760.16

school buildings can be taken up. Besides the state governments, other agencies could avail funds under the program are PRIs, NGOs, and SHGs.

Micro credit financing

Mostly bankers are worried for high transaction cost and poor recovery. To overcome these crucial issues, the concept of Self Help Groups (SHGs) and linking them to bank credit in rural areas was first started in 1992. The objective of the programme is to reach poorest of poor, increase credit mobilization, cultivate saving habits, improve economic level of group members and improve loan recovery. A SHG comprises 10 to 20 members and it can be registered or unregistered. Members should be from same social and financial background. In India we have adopted savings first and credit later policy. These groups can start economic activities like fish sorting, peeling, pickle making, processing, preparation of value-added products, retail marketing, net mending, seed production and rearing etc. or any small-scale activity in freshwater, brackishwater or marine fishery sector. Continuous efforts made by the ICAR, NCDC, MPEDA, FSI, state fisheries departments and state agricultural universities have made fisheries a commercially viable activity. The sector is capable to increase fish production. Diversification of agricultural activities has become a necessity due to ever-increasing demand for food. Fisheries, having vast potential in India and is an answer to the requirement and could fulfill the gap between demand and supply. Bank credit is now available on easy terms and through number of financing programmes. It is therefore possible for entrepreneurs to expand fisheries horizontally, vertically and not only improve their economic status but also create employment opportunities both in rural and urban areas.

45. Development Initiatives in Fisheries and Aquaculture

Indian fisheries with diverse aquatic resources, inland, brackishwater and marine is blessed with about 10% of the global biodiversity in terms of fish and shell-fish species. The sector contributed ₹ 10,000 crore in terms of value of the agricultural exports and 4.56% of the agricultural GDP. The sector provides employment to more than 14 million people in different activities. Though the Indian fisheries and aquaculture over the years has shown continuous and sustainable growth in terms of fish production since independence from 0.752 million tonnes (I Five Year Plan) to 8.00 million tonnes up to 2009-10 (XI Five Year Plan), yet the fisheries and aquaculture development of the country has witnessed paradigm shift in terms of increasing contributions from inland fisheries sector, stagnation of marine fish production, the boom burst and the sustainable production from the brackishwater aquaculture. The freshwater aquaculture has been a major contributor overtaking the freshwater capture fisheries production through aquaculture and culture-cum-capture fisheries production from tanks and reservoirs. The marine fisheries though showing declining or stagnating production trends is largely supporting the livelihood options of huge fisher population of the maritime states in the country.

The fishery resources of the country are vast and varied with large untapped potential which can contribute considerably to improve nutritional security, livelihood, as also women empowerment. The inland fisheries has about 6.1 million ha of reservoirs, ponds and tanks, flood plains and derelict water-bodies with huge untapped potential. These resources offer a vast opportunity to enhance the fish production through proper management, species diversification and adoption of diverse aquaculture technologies. The rivers and canals which run over 195,000 km though offer a huge potential, the production and productivity has decreased over the years due to pollution, urbanization, encroachment and various other reasons. The area under brackishwater is about 1.24 million ha, of which only about 15% of the area is currently utilized for brackishwater aquaculture. The shrimp culture in the coastal regions has become unsustainable due to continued outbreak of viral diseases, unscientific management practices, environmental problems, unstable export markets and other social problems which calls for diversification of aquaculture species and practices, introduction of fin-fish in coastal aquaculture, improvement of species by bringing specific pathogen-free (SPF) stocks, encouragement of domestic marketing and various other aspects.

The marine fisheries, with a coast line of 8,118 km, has been the traditional vocation of the huge coastal fishing population. Due to over-capacity of fishing fleets, over-exploitation of coastal fishery resources, lack of on-board processing, improper utilization of low-value species, lack of infrastructure at the fishing harbours or landing centres for hygienic handling and processing leading to poor disposal of landed fish have led to more than 20% loss in utilization of fish as food. In order to enhance the

coastal fisheries, measures addressing issues related to sea ranching, open-sea cage culture of commercially important species, installation of artificial reefs and fish aggregating devices (FADs), seaweed cultivation, coastal aquaculture in bays/ lagoons, saline waters etc. need to be promoted for enhancing the coastal fish production.

There is ample opportunity to harness the deep-sea fishery resource, under-exploited resources of the Indian exclusive economic zone (EEZ), particularly that of tuna and bill fish resources of the country. The existing tuna-fishing crafts have to be better equipped with on-board processing and storage facility and there is also a need to enhance the fishing fleets by either modifying the trawlers into tuna long liners or bringing in new fishing fleets specifically for tuna.Diversification and high-value produce could add new dimensions to the sector. Simultaneously, effective marketing arrangements through establishment or modernization of wholesale and retail markets, fish dressing or processing centres at production sites or landing centres, establishment of cold chains for proper distribution of fish and fish products and proper awareness building about importance of fish as nutritious food to the general public needs focused attention.

For coordinating the various development initiatives, the National Fisheries Development Board (NFDB), an autonomous organization under the administrative control of the Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Government of India, was established at Hyderabad as a nodal agency to work towards Blue Revolution with a focused attention aimed at (*i*) increasing the fish production of the country, (*ii*) double the exports and (*iii*) to create direct employment for additional 3.5 million people by extending assistance to the various agencies for implementation of activities under inland, brackishwater and marine sectors. Thus, the NFDB was envisaged to serve as a platform for coordination of different agencies and public-private partnerships for fisheries development with an end-end approach.

Objectives of NFDB

- To bring major activities relating to fisheries and aquaculture for focused attention and professional management;
- To coordinate activities pertaining to fisheries undertaken by different ministries/ departments in the Central Government and also coordinate with the State/ Union Territory Governments;
- To improve production, processing, storage, transport and marketing of the products of capture and culture fisheries;
- To achieve sustainable management and conservation of natural aquatic resources including the fish stocks;
- To apply modern tools of research and development including biotechnology for optimizing production and productivity from fisheries;
- To provide modern infrastructure mechanisms for fisheries and ensure their effective management and optimum utilization;
- To generate substantial employment;

- To train and empower women in the fisheries sector; and
- To enhance contribution of fish towards food and nutritional security.

Strategies for promotion of fisheries development and sustainability

In recent times, sustainability of fisheries is being bestowed lot of importance due to gradual depletion of natural fishery wealth because of over-exploitation with no equivalent replenishment of natural stocks. For addressing issues related to production enhancement through sustainable approach, the NFDB has broadly formulated the activities that have a direct bearing on enhancement of production, consumption and domestic marketing. These activities are: intensive aquaculture in ponds and tanks, fisheries development in reservoirs, coastal aquaculture, mariculture, seaweed cultivation, infrastructure: fishing harbours and landing centres, fish-dressing centres and solar drying of fish, domestic marketing, technology upgradation, deep-sea fishing and tuna processing, and other activities.

Various schemes of the NFDB that are implemented through various state fisheries departments, fisheries corporations/ federations/ cooperatives, ICAR institutes, fisheries colleges, KVKs, NGOs etc. are detailed in the Table 45.1.

Table 45.1. Various developmental schemes of National Fisheries Development Board

Activity	Components
Intensive aquaculture in ponds and tanks	• Carp polyculture • New species culture • Freshwater prawn farming • Coldwater fisheries • Broodstock banks • Integrated fish farming • Running water fish culture • Hatcheries • Feed production units • Demonstration centres • Farmers' training • Capacity building in state fisheries departments • Publications and learning material • Funds for technology upgradation • Broodstock development • Ornamental fisheries
Fisheries development in reservoirs	• Fish seed rearing units • Reservoir stocking with fish fingerlings • Cage culture • Pen culture • Training and demonstration • Funds for technology upgradation
Coastal aquaculture	• Shrimp, finfish aquaculture • Cage culture • Broodstock development • Aquatic quarantine • Capacity building in state fisheries departments

(Continued...)

(Table 45.1 concluded)

Activity	Components
	• Development of diagnostic kits • Pathogen-free nauplii production centres • Electrification of aquaculture projects • Funds for technology upgradation
Mariculture	• Diversified finfish/shellfish seed production • Farming of mussels and oysters • Cage culture in open seas and coastal waters • Marine ornamental fish culture • Training and demonstration • Funds for technology upgradation
Seaweed cultivation	• Establishment of seaweed-processing units • Training and demonstration
Infrastructure: fishing harbours and landing centres	• Modernization of existing facilities in fishing harbours • Modernization of existing facilities in fish-landing centres • On-board training in hygienic handling of fish • Processing and cold chain
Fish-dressing centres and solar drying of fish	• Setting up of model fish-dressing centres in coastal states • Setting up of solar fish-drying units and sun-drying platforms • Training of fisherwomen • Demonstration units • Funds for technology upgradation
Domestic marketing	• Modernization of wholesale fish markets • Cold chains of varying levels • Hygienic retail outlets • Institutional support to develop hygienic/ whole retail markets • Developing working models/branding/bench marking/ certification • Designing of modern state-of-art outlets and technology upgradation
Deep-sea fishing and tuna processing	• Value-addition and processing of tuna • Training and demonstration • Funds for technology upgradation • Construction of indigenous deep-sea fishing fleet • Packaging and processing units • Development of technologies in fishing gear, resource assessment etc.
Technology upgradation	• Proposals addressing the yield gap between on-station trials and farmers ponds • Upgrading older technologies being adopted by farmers • Dissemination of new technologies
Human resource development in fisheries sector	• Continuous training programmes to functionaries of fisheries departments, fisheries corporations/federations/cooperatives

Approaches of NFDB to increase fish production

Realizing the gaps, resources, potentials and constraints in adoption of various activities, the following approaches are devised for enhancement of fish production in the country.

Intensive aquaculture in ponds and tanks

Ponds and tanks are the most important freshwater aquaculture resources of the country, accounting for 24.14 lakh ha where extensive and semi-intensive aquaculture is practised using Indian major carps and exotic carps. Most of these areas come under tropical conditions and is amenable for increasing the production and productivity levels to about 5 tonnes/ha/annum. Out of the total area, the NFDB proposes to bring in at least 8 lakh ha under intensive aquaculture by extending technical and financial support. It is aimed to support development of 2 lakh ha by renovating the ponds and tanks and also providing subsidy for desired inputs. To develop remaining 6 lakh ha as envisaged in the plan, the farmers and other related stakeholders will be suitably trained regarding scientific fish-farming practices to enhance the production from the present level of 2.6 tonnes/ha to 5 tonnes/ha. Through this activity, an additional production of about 2.4 million tonnes is expected to be generated. Besides, it is also planned to bring about 50,000 ha of new area under intensive aquaculture by extending financial support for pond construction and inputs to achieve a production target of 5 tonnes/ha. This additional area would provide another 2.5 lakh tonnes to the total fish production.

Setting up of fish seed hatcheries and rearing centres

Quality fish seed is the critical input for increasing the fish production. At present, there are many seed deficit states or areas in the country. The total fish seed (fry) required for optimal stocking in the existing ponds, new ponds and reservoirs is about 48,000 million fry. As against this, the current seed production is 31,688 million fry. Thus, there is a gap of 16,312 million fry. In order to meet the additional seed requirement, state-wise seed action plans have to be prepared to set up new hatcheries, new nurseries in diverse resources utilizing different technologies to meet this increased demand for fish seed. With a view to diversify the seed production, there is a need to bring in new technology for setting up of hatcheries for magur, *Pangasius*, chitala, murrels, seabass and other commercially important species within inland and brackishwaters whose fish seed-production technology has been standardized. The technology for seed production of commercially important marine fish species such as *Cobia*, groupers, snappers, mullets, milk fish, *Etoplus* etc. needs to be upgraded/imported. Required support is provided by the NFDB for setting up and renovation of fish-seed hatcheries, fish seed-rearing farms both by state governments and entrepreneurs.

Setting up of feed mills: Formulated feed is a key to scientific aquaculture, as the feeds are formulated keeping in view the nutritional requirements of the targeted cultivable fish species. Formulated pelleted feeds are of great value for fish species which are gulpers. Though Indian major carps are basically filter feeder, species like rohu do accept the artificial formulated feeds and grow much faster. Traditionally, fish culture in India mainly depends on loose mixtures of rice bran, wheat bran and various oil-cakes mixed in different proportions. Heavy loss of feed due to dispersion in the water led to very high feed conversion ratio and eutrophication due to higher organic matter accumulation at the pond bottom leading to heavy parasitic infestation and diseases in many instances. With pelleted feed, though cost of production works out to be slightly higher, the pond life is extended without much of soil bottom and water-quality problems. For culturing fish species like common carps, *Pangasius*, tilapia, murrels, cat fishes, trout etc., formulated pelleted feeds are beneficial with great advantages. Hence, popularization of feed mills of various capacities suitable for big entrepreneurs, farmers and Government departments is being supported by the NFDB.

Coldwater fisheries

Trout farming is a low-volume, high-value aquaculture activity with greater potentials in the hill areas of the country. Two potential candidate species are rainbow and brown trout. Due to low temperature, slow growth and high cost of feed, the cost of trout production is quite high. There is a good scope for trout farming in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh, Sikkim, Nagaland and other hilly regions of Himalayas. Establishment of trout-breeding centres, race ways, feed mills, marketing infrastructure is proposed to be supported by the NFDB. It is planned to achieve a target production of 1,000 tonnes by the end of XI Five Year Plan. Capacity building of various farmers and other stakeholders is also prioritized.

Reservoir fisheries

The area under reservoir fisheries in the country has been estimated to be about 3 million ha and with the constant addition of new reservoirs, this area is likely to increase further in the coming years. In spite of huge water area available under reservoirs, utilization of these water-bodies from the fisheries point of view is poor. It is expected that through sustained supplementary stocking by quality fingerlings, augmenting the fish stocks through auto stocking, adoption of appropriate mesh sizes for harvesting, optimum fishing efforts and enforcement of closed areas and closed seasons, the average productivity can be increased to a level of 500 kg/ha/year for small reservoirs, 200 kg/ha/year for medium reservoirs and 100 to 150 kg/ha/year for larger reservoirs from the present average production of 20 kg/ha/year. Thus the success of this management practices would address issues related to livelihood, socio-economic benefits, employment opportunities, creation of new vocations such as marketing etc. The main aim of the NFDB's intervention in reservoir development is to ensure adequate stocking of reservoirs with right size and quality fingerlings at right time. Even if 50% of the total area is brought under reservoir-development programme, within the span of 5 years, it would provide an additional production of more than one million tonnes.

Coastal aquaculture

The area under coastal aquaculture has come down from 214,000 ha during 1995-

96 to about 87,686 ha during 2007-08, mainly due to outbreak of viral diseases as well as bad-quality seed, poor-quality brooders, bad management practices and inadequate capacity building. There is a need to revive shrimp aquaculture in the country by addressing the issues related to shrimp seed quality, better management practices, feeds and feeding strategies, disease management and suitable tie up to the marketing network. It is planned to revive shrimp farming in an area of about 50,000 ha by extending financial and technical support for capacity building. Further, for introduction and farming of new species like *Litopenaeus vannamei*, better incentives are provided for pond renovation, inputs, creation of effluent treatment system (ETS). With the introduction of *L. vannamei*, additional 5,000 ha are expected to be brought under shrimp aquaculture. With a view to provide quality specific pathogen-free seed of *Penaeus monodon*, the NFDB in collaboration with Hawaii based shrimp selective breeding organization, proposes to establish a Multiplication Centre (MC) for large-scale (3 billion post-larvae per year) production of post-larvae for reviving the *P. monodon* culture in India. With these activities, an additional production of about 50,000 tonnes is expected to come from brackishwater aquaculture. The NFDB is also trying to popularize the existing hatchery technology of seabass, *Lates calcarifer* in brackishwater ponds, in Tamil Nadu, Andhra Pradesh and Maharashtra with the help of the Central Institute of Brackishwater Aquaculture (CIBA), Chennai. Further diversification of coastal aquaculture in the form of mullets, milk fish, pearl spot and other commercially important species also need to be promoted.

Marine fisheries

Mariculture: The scope for enhancement of fish production from inshore waters up to 12 nautical miles lies in enhancement of fish stocks through sea-ranching programmes and adoption of region-specific, resource-specific and species-specific mariculture activities besides implementing the regulations with regard to fishing capacity, type of fishing activities, mesh-size regulations, enforcement of closed seasons etc. The regulations being the state subject, a suitable policy developed by Tamil Nadu may be implemented by enforcing suitable policies by other maritime states of the country. The NFDB proposes to promote open-sea cage culture of some of the commercially important fish species such as seabass, cobia, shrimp, lobster, groupers etc., through the Central Marine Fisheries Research Institute (CMFRI), Kochi, with its technology support. However, the NFDB also desires to invite global tenders for establishing suitable and commercially viable cages in the Indian waters. Open-water leasing policy needs to be developed by the maritime states for adoption of this technology.

To promote livelihood options of coastal fisherwomen and Self Help Groups, the Board mandated to support culture of sea weeds, mussel and oyster culture with suitable financial support.

In order to improve the facilities for hygienic fish handling and to reduce post-harvest losses (both on-board and at landing centres), the NFDB desires to suitably support the creation of handing facilities at fish-landing centres and fishing harbours, modernization

of existing facilities in the fishing harbours and landing centres. Establishment of cold chains and development of value-added products etc., are given impetus and these programmes could be implemented through the State Fisheries Departments.

Deep-sea fishing and tuna processing

In order to tap the tuna potential resources of the exclusive economic zone (EEZ) (approximately 278,000 tonnes of tuna and tuna-like fishes) and to improve the post-harvest processing and value-addition, the Board has come up with a scheme of assistance for construction of indigenous deep-sea fishing fleets for enhancing capture of tuna which stands at about 30,000 tonnes at present. Lakshadweep and Andaman and Nicobar Islands are supposed to be harnessing huge tuna resources. Assistance is also provided for on-board training of interested entrepreneurs or fishermen to build awareness about the technique of tuna fishing, post-harvest on-board processing and to promote sashmi-grade tuna processing which is in great demand in China, Japan and other countries.

Fish marketing

India is traditionally a fish-eating country where more than 90% of the produce is consumed in fresh condition. However, hygiene in handling and transportation of fish has been an important concern due to substantial post-harvest losses as well as reduction in quality. In order to promote domestic marketing and make available quality fish to the consumers, the NFDB proposes to establish fish-dressing centres and or solar drying of fish, establishment of cold chain, establishment of model wholesale and retail markets, empowering fisherfolk by providing financial assistance for better mode of transportation with icing facility for fish hawking, establishment of fish-food courts and restaurants, processing and marketing of value-added products.

In order to build public awareness and to promote fish as health food besides showcasing various fish production, processing, value-addition and marketing technologies, the NFDB plans to organizes fish festivals all over the country to promote fish consumption and to create business opportunities for small, medium and large entrepreneurs. Series of campaigns are organized for showcasing through print and visual media to build greater awareness among the general public about the NFDB, its schemes and opportunities besides promoting fish as health food.

New initiatives of the Board

Following major activities have been initiated by the Board keeping in view the requirement of the industry and need for upgradation of technology in terms of species, new technologies and quarantining to enhanced fish production from freshwater, brackishwater and marine ecosystems.

Establishment of specific pathogen-free *P. monodon* multiplication centre

With a view to produce and supply specific pathogen-free (SPF) shrimp seeds to the farmers of the country, the NFDB is in the process of establishment of SPF tiger prawn multiplication centre to produce 3 billion post-larval of SPF *monodon* seed per year. This is taken up in collaboration with M/s Moana Technologies, Hong Kong, and the multiplication centre will be established in Srikakulam district of Andhra Pradesh. As a prelude to the multiplication centre, jump start programme has been initiated to demonstrate the advantages of culture of SPF tiger prawn and also as learning school to understand the intricacies, the problems and possible remedies for large-scale adoption of tiger prawn farming in India.

Demonstration of pond culture of Asian seabass

The technology for pond-based culture of Asian seabass (*Lates calcarifer*) is taken up in collaboration with the CIBA, Chennai, in Tamil Nadu, Andhra Pradesh and Maharashtra using the feed developed by the research institute. The farmers are being trained on seed rearing in hapas, periodic size grading and scientific culture of seabass in ponds.

Cage culture of seabass and other species in open sea

The NFDB in collaboration with the CMFRI, Kochi, has set up 14 units of open-sea cages for demonstration in Gujarat (Veraval), Maharashtra (Mumbai), Karnataka (Mangalore), Kerala (Kochi), Tamil Nadu (Chennai), Andhra Pradesh and Odisha. In addition to seabass, other fishes/shell fish of commercial importance such as marine ornamental fishes, lobsters, mullets, pearl spot, pomfret and shrimp are also tried for their culture possibilities in cages.

Aquatic quarantine facility for *Litopenaeus vannamei*

The Ministry of Agriculture, Government of India has permitted the culture of exotic shrimp *Litopenaeus vannamei* in India under strict biosecurity regulations. To import the broodstock of specific pathogen-free *L. vannamei* list of suppliers and shrimp hatcheries were approved by the Coastal Aquaculture Authority of India. The NFDB has extended funding support to establish an Aquatic Quarantine Facility at Chennai exclusively for import of *L. vannamei* into the country.

Tuna processing

In order to promote processing sashmi-grade tuna and to train the interested entrepreneurs, the NFDB in collaboration with National Institute for Fisheries Post-Harvest Technology and Training (NIFPHATT), Kochi, has undertaken upgradation of processing facilities at Vishakhapatnam in Andhra Pradesh.

Domestic marketing

The National Centre for Agricultural Research and Policy (NCAP), New Delhi, completed a study on present status of fish markets in India, fish supply and demand scenario and strategies for development of domestic fish-marketing network in the country. Some of recommendations of the study are:

- Promotion of producer companies, fishermen, societies, SHG's

- Training on responsible fisheries, good harvest and management practices to the fishermen
- Subsidies for ice boxes to the fishermen, especially in the marine sector
- The traders, both wholesale and retailers, should be given electronic balances
- Provision of sufficient ice, boxes, cutting equipment and boards to the traders both wholesale and retailers
- Training on good hygienic practices to traders
- Implementation of entrepreneurship-development programmes in fisheries
- Advertizements through professional agencies in print and electronic media about the nutritional qualities of fish
- Modernization of wholesale markets in the metros
- Establishment of modern small- and medium-scale fish markets
- Approach roads, infrastructure like cold storages at major collection centres
- Better subsidy component for starting modern retail outlets
- Establishment of fish-drying yards and waste-disposal mechanisms in major production centres and fish markets
- Adoption of suitable domestic quality standards for fishery products
- Efforts to rope in the big retail giants/MNC's in hygienic marketing

Other initiatives

To promote fish-seed rearing in cages or pens to meet the huge demand for fish seed to stock in the reservoirs, an action plan has been prepared in consultation with the concerned states and the Central Inland Fisheries Research Institute, Barrackpore, West Bengal. This would help in reducing the transportation cost and release of well-acclimatized fish fingerlings of large size into the reservoir. A training programme was also conducted in this regard to train the officers of different states on fabrication and installation of cages for fish-seed rearing.

District development plan

In order to understand the aquaculture resources, potentials, creation of new resources, fish seed, capacity building of fish farmers, establishment of processing and marketing networks etc., the NFDB is proposing to prepare model district fisheries development plan. This would help to bring in a comprehensive fisheries development in selected districts of various states of the country, besides enhancing fish production, thereby production of huge employment opportunity will be created for diverse stake holders.

Human resource development

Human resource development (HRD) is one of the major tasks of the Board, besides training large number of farmers and entrepreneurs for undertaking various development activities; the Board has also prepared HRD plan involving various research institutes, fisheries colleges, development agencies and others to plan and implement trainers training on diversified and important issues in the country.

46. Scenario of Fishery Cooperatives

The growth of the fishery cooperative movement in India can be traced to 1913 when the first fishermen's society was organized under the name of 'Karla Machhimar (Fishermen) Cooperative Society' in Maharashtra. The state of West Bengal was the next to organize cooperative societies in the fishery sector in 1918. In the same year another state, Tamil Nadu, also organized one cooperative society. The structure continued to grow over years into multifunctional units at the primary level, federations at district/regional, state and national levels.

There has been a perceptible improvement in the fishery cooperative sector of the country and the structure as it exists today consists of national level federation, 1; state level federations, 21; central (district/regional) level, 125; and primary societies, 18,145 (approx.).

The membership at the primary level is around 2.3 million (Table 46.1).

It may be added that in some of the states, the fishery cooperative movement is working very effectively and a number of studies and evaluation reports have confirmed the efficiency of these organizations. One evaluation report confirmed that arrangements of marketing made by the fishery cooperatives in Maharashtra saved the members from exploitation. A number of fishery cooperatives in the country are helping their members and their family members to the extent of providing complete marketing infrastructure for the sale of the catch at remunerative prices.

National Federation of Fishermen's Cooperatives Ltd.

The National Federation of Fishermen's Cooperatives Ltd. (FISHCOPFED) is comparatively of recent origin. Registered in 1980, the federation started its operation in 1982. The objectives of the federation is to facilitate the fishing industry in India. The membership of the federation stood at 78 including Government of India. Within a short period of its active functioning, the FISHCOPFED has entered a number of activities.

Activities

The activities of the FISHCOPFED are:

(*i*) to undertake or promote own or on behalf of its member institutions, inter-state and the international trade and commerce in fish products and undertake, whatever necessary, sale, purchase, import, export and distribution of fish and fish products and other articles and goods from various sources for pushing up its business activities and to act as the agency for canalization of export and import and inter-state trade of fish and other commodities or articles and to facilitate these activities, wherever necessary, and to open branches/sub-offices and appoint agents at any place within the country and abroad;

(*ii*) to undertake purchase, sale and supply of fish and fish products, marketing and

Table 46.1. Structure of Fisheries Cooperatives in India (State-wise Position)

(Apex Level National Cooperative Federation –
National Federation of Fishemen's Cooperatives Ltd., New Delhi)

S. No.	State/UTs	State federation	Central societies	Primary societies	Membership
1	Andhra Pradesh	01	22	5,013	411,433
2	Arunachal Pradesh	-	-	5	324
3	Asom	01	-	456	49,624
4	Bihar	01	5	532	40,000
5	Delhi	-	-	02	640
6	Goa	01	-	10	1,000
7	Gujarat	01	03	620	88,483
8	Haryana	-	-	45	504
9	Himachal Pradesh	-	-	39	5,994
10	Jammu and Kashmir	-	-	-	-
11	Karnataka	03	-	504	168,216
12	Kerala	01	16	653	200,000
13	Madhya Pradesh	01	-	1,749	60,612
14	Maharashtra	01	21	2,024	208,273
15	Manipur	01	-	181	9,182
16	Meghalaya	-	-	73	10,751
17	Mizoram	-	-	36	808
18	Nagaland	-	-	168	4,285
19	Odisha	01	05	1,003	203,464
20	Punjab	-	-	04	60
21	Rajasthan	01	-	107	4,624
22	Sikkim	-	-	01	
23	Tamil Nadu	01	11	1,376	607,014
24	Tripura	01	-	129	14,225
25	Uttar Pradesh	01	19	966	53,040
26	West Bengal	01	20	1,072	160,000
27	Andaman and Nicobar	-	-	45	3,812
28	Chandigarh	-	-	01	-
29	Dadra and Nagar Haveli	-	-	-	-
30	Daman and Diu	-	-	06	2,993
31	Lakshadweep	-	-	02	-
32	Puducherry	01	02	36	28,754
33	Chhattisgarh	01	01	916	28,768
34	Jharkhand	01	-	362	18,000
35	Uttarakhand	-	-	9	236
	Total	21	125	18,145	2,385,119

processing requisites such as machinery, spare parts and other fisheries requisites;

(*iii*) to act as an insurance agent and to undertake all such work which is incidental to the same;

(*iv*) to organize consultancy work in various fields for the benefit of the member cooperative institutions;

(*v*) to undertake manufacture of fishing vessels, marine engines and other fishery requisites by setting up manufacturing units either directly or in collaboration with or as a joint venture with any other agency, including import and distribution of spare parts and components for upkeep of the fishing vessels and gears, etc.;

(*vi*) to set up storage units including cold storage for storing various commodities and goods by itself or in collaboration with any other agency in India or abroad;
(*vii*) to maintain transport units of its own or in collaboration with any other organization in India or abroad for movement of goods on land, sea, air etc.;
(*viii*) to undertake marketing, research and dissemination of market intelligence;
(*ix*) to subscribe to the share capital of other cooperative institutions as well as other public and joint sector enterprises, if and when considered necessary for fulfilling the objectives of FISHCOPFED;
(*x*) to arrange for training of employees of the fishery cooperative societies, State Fishery Departments and State Cooperative Departments;
(*xi*) to establish processing units for processing and preservation of fish and fish products;
(*xii*) to undertake grading, packing and standardization of fish and fish products;
(*xiii*) to acquire, take on lease or hire lands, buildings, fixtures and vehicles and to sell/give on lease or hire them for the business of FISHCOPFED;
(*xiv*) to advance loans to its members and other cooperative institutions on the security of goods or otherwise; and
(*xxv*) to do all such things or undertake such other business or other activities as may be incidental or conducive to the attainment of any or all of the above objects.

Activities of the FISHCOPFED can be divided into three broad categories, namely (*i*) developmental or promotional, (*ii*) welfare and (*iii*) commercial.

Developmental or promotional activities: Under developmental or promotional activities, the FISHCOPFED organizes National Fisheries Cooperative Congress a perennial highest forum of fishermen and fisheries cooperatives, seminars on different need-based on related subjects, conferences, workshops and meetings.

Organization of educational programmes for non-official leaders, prospective leaders and office bearers in collaboration with the National Centre for Cooperative Education of National Cooperative Union of India, and training programmes for members, prospective members and active fishers.

Transfer of technology to fishers through cooperatives is an effective way to ameliorate the efficiency and capability of fishers and their cooperatives in providing appropriate coordination between man and machine.

Development of fisherwomen through cooperatives has been an on-board agenda of the FISHCOPFED. Emphasis is laid on development of fisherwomen by imparting cooperative education and engaging them in the process of net making and transfer of technology. Imparting of knowledge and skill development on the subjects related to health-care awareness against AIDS and family-welfare awareness on different aspects of cleanliness, hygiene and nutrition, was the integral part of the programme of the Union Ministry of Health and Family Welfare, implemented by the FISHCOPFED.

Conducting studies and their publication on relevant subjects from time to time include *Impact of Centrally Sponsored Group Accident Insurance Scheme, Leasing Systems of Inland Waters, Manual on Export of Fish and Fish Products* besides collection, compilation of data on fisheries and publishing statistical bulletin.

Besides the above, the FISHCOPFED brings out a bi-lingual quarterly journal, namely *FISHCOOPS*, that contains very useful articles on different subjects of fishery, management and cooperatives and organizational news and views, fish in kitchen, etc.

Networking of fishery cooperatives and fish landing centres: There are more than 15,000 primary fishery cooperatives in the country. Ministry of Agriculture, in close conjunction with the National Informatics Centre (NIC), is going to launch a fisheries information system network FISHnet, an e-governance initiative to provide a continuously updated and authentic fishery data in regard to prices of different fish at different locations of the country and other important fishery data for all the stakeholders, scholars and fishery universities or institutions and the fishers at the lowest level. The FISHCOPFED has been considered as a nodal agency for FISHNET project.

A proposal has been submitted to NIC for providing 1,000 computers to the primary fishery cooperatives to link them with 220 fish-landing centres, National Informatics Centre, Ministry and FISHCOPFED to enable successive planning and sustainable development.

Research and development: The FISHCOPFED conducts survey/research in various fishery-related areas. The FISHCOPFED has initiated a survey on the total number of fishery cooperatives along with the details of their members and facilities available with these cooperatives, so as to have authentic data on inland fisheries that will facilitate the implementation of various projects in various states of the country besides making all the data available through FISHnet for all the stakeholders, researchers, scholars, universities and institutions. Development schemes taken up by the FISHCOPFED are as follows:

Welfare of fishers and their cooperatives: Under welfare activities, the FISHCOPFED implements the most acclaimed Centrally Sponsored Group Accident Insurance Scheme for Active Fishermen throughout the country. To provide a link to the progress of scheme and an interactive page for information about the accidental death/disability to insured under the scheme has been added. The scheme provides for 24-hours accident cover amounting to ₹ 50,000 against death or permanent disability and ₹ 25,000 against permanent (partial) disability to the insured as a result of accident against an annual premium of ₹ 14 per insured. The insured does not pay anything towards the premium for the cover which is paid by the Central as well as the State Governments concerned on 50:50 basis. Around 25 lakh fishers are covered under the scheme covering 19 states and 4 union territories in 2008-09. The FISHCOPFED has settled more than 13,000 claims over the years– a record by any cooperative in the world. The Government of India has enhanced the cover to ₹ 1.0 lakh against death or permanent disability in the current year.

Promotion of aqua-culture and fish marketing: In order to demonstrate fish culture in inland waters, it has taken a water-body from fisheries department of Chhattisgarh and established its inland fish production-cum-demonstration centre at Raipur in Chhattisgarh, whereas the process in other potential states is under consideration. Marketing of fish and fish products of the Integrated Fishery Projects (IFP) are among the commercial or business activities of the FISHCOPFED. The FISHCOPFED has started a cold chain of its own with the assistance of the Department of Animal Husbandry, Dairying and Fisheries (DAHD&F), Government of India under Post Harvest Infrastructure in the metropolitan cities in India where fish and fishery products are marketed in controlled and proper hygienic conditions, in order to provide remunerative price to fish farmers and quality fresh fish to consumers. The federation has been running a fish retail shop at the Community Centre at Yusuf Sarai, New Delhi. The network of fish retail shops will soon be expanded to other areas, subject to availability of suitable sites at Delhi as well as in surrounding cities of the National Capital Region.The federation also caters to requirement of fish of the Delhi-based hotels of the Indian Tourism Development Corporation (ITDC).

Inter-state marketing: To provide remunerative price to producer fishers, the FISHCOPFED arranges inter-state fish trade from fish-surplus to fish-deficient areas by procuring fish right from landing centres, transport through refrigerated trucks to fish-deficient areas. A few unit offices have also been established by it in different states, to begin with at Warangal in Andhra Pradesh, Bhubaneshwar in Odisha and Guwahati in Asom and the process to increase the number of units is under consideration.

Export promotion: In order to eliminate middlemen and traders from international fish trade and take up direct exports through cooperatives, the FISHCOPFED has acquired Import-Export Code Number from the Ministry of Commerce, Government of India. Members of the FISHCOPFED can avail of these facilities through the federation.

A manual on *Export of Fish and Fish Products* has been published by the federation, explaining details of documentation and quality standards for export to different countries.

International relations: The FISHCOPFED has been maintaining good relations with fishery cooperative movements all over the world. It is a member of the International Cooperative Alliance (ICA) Fisheries Committee. The federation has received a lot of support from the International Cooperative Alliance and ICA Fisheries Committee. The FISHCOPFED hosted meeting of ICA Regional Fisheries Committee and ICA Main Fisheries Committee at New Delhi. Besides, it has organized three ODA Seminars on Leadership Development in India.

Publicity and public relations: The FISHCOPFED publishes bilingual quarterly journal carrying up-to-date information on fishery technology as well as trends. The journal is a source of knowledge about technology and the scheme of the Central as well as State governments oriented to the development, promotion and welfare of fishers, besides several allied subjects, news on fisheries cooperatives, fish for health, fish delicacies, etc. The journal has a Hindi section too for the benefit of generally Hindi-speaking segment, an effective means of publicity among its readers. The FISHCOPFED circulates the journal free of charge among its members and the concerned departments of Central and State Governments. The FISHCOPFED also publishes a statistical bulletin on the fishery cooperatives.

Projects: The FISHCOPFED has following projects or programmes in operation at present:

- Aquaculture development and pisciculture project at Khushrangi Reservoir at Raipur in Chhattisgarh,
- Inter-state Fish Marketing and Procurement Centre at Bhubaneshwar (Odisha) and Warangal (Andhra Pradesh),
- Project unit at Guwahati (Asom) for the benefit of north-eastern states,
- Local fish retail outlet at Yusuf Sarai Community Centre at New Delhi,
- Promotion of export of fish and fish products,
- Education and training programmes in the states funded by the Government of India and the National Fisheries Development Board.

Future approach: The FISHCOPFED is making efforts to carry out following programmes in near future:

- Implementation of Aquaculture Development Scheme in fishery cooperative sector
- Enhancement of cover under the Centrally Sponsored Group Accident Insurance Scheme for Active Fishermen an additional schemes.
- Creation and management of data/information management through World Wide Web Overseas Fishery Trade Development through partnership.
- Human resource development and management.
- Project formulation, implementation and control.
- Broadbasing of activities with member fishery cooperatives.
- Database of fishery cooperative members.
- Online interaction/communication.
- Online information about insurance claims.
- Networking of fisheries co-operatives through National Information Centre (NIC).

A study conducted by the Council for Social Development confirmed the suitability of fishery cooperatives as a tool for promoting the interests of fishermen. It also emphasized the need for strengthening and encouraging the fishermen cooperative societies for performance of multipurpose functions and social interests of their members. Cooperatives have distinct advantages than any other sector of the economy. Members' strength and their cohesiveness make them more powerful backed by cooperative principles and philosophies. Fishery cooperatives in India have taken the full advantages of the cooperative systems. The success story of the FISHCOPFED could very well be emulated by other cooperatives to sustain.

47. Sea Safety and Disaster Management

Marine capture fishery is one of the riskiest occupations known to civilization. However, concern over safety of the fishers at sea is of quite recent origin in the history of navigation. This new dimension, concern over safety seems to stem from two different institutions of complimentary nature – Marine insurance and Establishment of labour rights. On-going efforts of the United Nations, International Labour Organization (ILO) and International Maritime Organization (IMO) resulted in setting of global safety standard in sea-voyages. However, these efforts have gotten much diluted during their application in fishing especially small-scale fisheries (e.g. from shipping to fishing vessels above 24 m of length and to fishing vessels below 24 m length) and from developed countries to developing countries. In the context of marine fisheries, lack of information is a major constraint to develop interventions. However, data from developed countries show fishing is much riskier than any average occupation. A series of reasons ranging from inadequate implementation of laws to poor quality of fishing vessels and lack of safety concern among the boat owners and fishers is responsible for poor safety practices. The fishers being poor and living in isolated coastal zones in India are also vulnerable to natural disasters. However, a natural hazard does not necessarily become a disaster, through suitable policies and practices it is possible to build capacity to control the magnitude and scale of a natural hazard. The best possible way to improve the safety and reduce vulnerability of the fishers is inclusive development policies. The fisher's opinion should be considered while designing safety intervention or coastal area development. The government is running various welfare schemes for fishers. It is also necessary to ensure the quality of products of such schemes.

Marine fisheries

An ILO Report (May 1999) on Safety and Health in the Fishing Industry shows that compared to other industries, fatality rate (number of incidents per 100,000 fishers per year) in fishing is much higher. For example, in Australia, between 1982 and 1984, the fatality rate for fishermen was 18 times higher than the national average; in Denmark, from 1989 to 1996, the rate was 25-30 times higher than the rate for those employed on land, and in the United States of America (USA) in 1996, the death rate in fisheries was estimated at eight times that of persons operating motor vehicles for a living, and over 40 times the national average. As per the ILO estimates, the fatality rate in fishing at the global level is about 77 that is 24,000 fatalities per year. This is likely to be the best possible scenario as the information is collected from the countries where safety measures of highest level are employed. If we consider the developing countries, this estimated rate of fatality is expected to go much higher. For example, a study carried out by Bay of Bengal Programme in Sri Lanka in 1990s showed that fatality rate in Sri Lanka's offshore fisheries are 10 times higher than that in Norway. Studies carried out by the Food and Agriculture Organization (FAO) of the United Nations and the FISH Safety Foundation, an independent international organization, revealed that in a number of countries along the West African coast, the artisanal canoe fatality rates appeared to be in the range of 300 to 1,000 and in South Africa there are about 585 fatalities in capture fisheries.

In India, mechanism for data on fishing-related accidents is yet to be fully established and specific information are scantily available. However, some information is available in police and hospital records, and at the national level one of the major source of information on status of sea safety is Group Accident Insurance Scheme for Active Fishermen of Ministry of Agriculture implemented by the FISHCOPFED and Oriental Insurance Company. There are some recent initiatives to tap these sources of information to establish the extent and cause of fishing-related accidents in India.

A study carried out by the South Indian Federation of Fishermen Societies (SIFFS) in Tamil Nadu for the period 2000-07 estimated about 1,210 accidents during the period excluding the death due to December 2004 Tsunami. Given an active fisher population of 206,908 (as per the Marine Fisheries Census of 2005), the fatality rate for Tamil Nadu during 2000-07 is about 84 per 100,000 fishers per year. This is slightly more than the global average of 77 suggested by the ILO. However, since the study was based on recollection of historic events by the victims or next to victims, there are possibilities of under-reporting.

Another recent study (2004-09) carried out by the Bay of Bengal Programme Inter-Governmental Organization (BOBP-IGO) and National Institute of Occupational Safety and Health (NIOSH), USA, based on the all insurance claims approved or received by the FISHCOPFED, New Delhi, and the Oriental Insurance Company Limited, New Delhi, from the Department of Fisheries of the coastal States/ Union Territories (Total 513 claims). The objective of the study was to found the causes of fishing-related accidents during 2004-09. The study indicated that in 62% of the cases death was due to drowning. From the SIFFS study, it can be inferred that the major causes of drowning are capsizing, engine failure and surf crossing mostly during returning from fishing.

Factor affecting safety in marine fisheries

The inherent risk in fishing comes from the fact that evolution of mankind has made man suitable for living in the land. Unlike some other animals, humans are not natural swimmers and even using the swimming pool can sometime turn fatal! Compared to this, long hours of working in a moving, exposed and slippery platform on-board of a vessel is much strenuous causing fatigue and physical injuries.

Given this threshold level, risk profile of marine fisheries gets magnified or filtered based on the action taken by the main players, namely the fisher, the asset owner and the government. Leaving aside the debate on fisher's attitude towards risk (As per an IMO report 80% of the accidents are caused by human error by ignoring existing measures.), their action on board get modified by the governmental policies, internal arrangement, market conditions, etc. That is, the risk profile of a fisher engaged in fishing in the sea can be expressed as:

Total risk	=	Policy-induced risks	+	Internal arrangements (IA) induced risks	+	Market-induced risks	+	Behavioural risks	+	External (natural) risks

For example, specifying standards during registration and licensing of a fishing vessel also modifies risk profile (policy-induced risks). In the same vein, subsidy for motorization of an artisanal craft changes the risk profile of the fishers using it. On the other hand, relationship between asset (boat) owner and the fishers, experience and training also modifies the risk profiles faced by a fisher Internal arrangement (IA), induced risks. Market conditionalities, like need to land catch before sunrise or expecting a lower price results in competition for catch. Manipulation by the middlemen often increases the stress of the fishers, namely if the demands are high, fishers often venture into the sea without taking enough rest, resulting in increased fatigue. As can be seen, market-induced risks go hand-in-hand with internal arrangement ones and in the process magnifying each other. Behavioural risks include habits like drinking, ignoring training, not carrying First Aid box, etc.

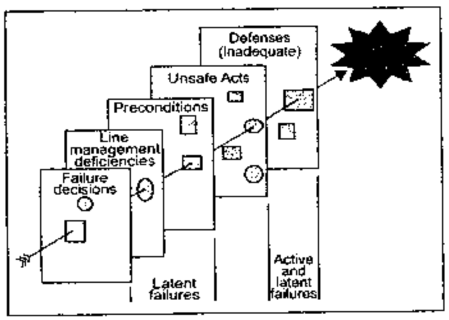


Fig 47.1. Reason's Accident Causation Model

The process, through which these risks lead an accident, is summarized in the Reason's Accident Causation Model. In the model (Fig. 47.1), the first layer (defences) represents defences that should mitigate the results of the unsafe act. The second layer (unsafe acts) and third layer (preconditions) include such conditions as fatigue, stress, operating practices, etc. (behaviour, market conditionalities and IA). The fourth layer (line management) includes aspects such as training, maintenance, etc (IA). The fifth layer depicts all high-level decision-makers such as regulators, owners, designers, manufacturers, trade unions, etc (IA + policy-induced risks).

The following case study reported in the SIFFS study shows how these failures can end up taking life of a fisher. On 22 February 2007, Thursday, 1600 hours two men, Mr Amalraj (45) and Mr Lustin (37), set out to sea in a FRP Catamaran from Kodimunai, Kanyakumari, Tamil Nadu. At 2000 hr they reached the fishing ground (23 fathoms) and laid out their gill net (Valiyavala). They were carrying a hand-held GPS, a knife, a flashing light for the net and a compass. The sea turned rough soon after they had laid out the net and the men decided to haul in the net and head back. During return, a merchant ship passed very closely and the combined effect of the rough sea and the ship's displacement flipped the boat over, throwing the men into the water. After the ship had passed, the men swam to the capsized boat. They tried in vain to draw attention

from ships and fishing vessels in the vicinity for 2 days. By nightfall of the second day, Mr Amalraj, exhausted and dehydrated because of diarrhoea, Mr Amalraj died. Mr Lustin somehow managed to keep himself alive throughout the ordeal and using the jerry cans used as floats for the net, swim in the direction of rising sun. He was later rescued by another fishing vessel.

The development of the event shows: (*i*) the sea turned rough (pre-condition); (*ii*) the fishers were not aware of any weather warning and ventured into the sea (decision); (*iii*) they possibly did not inform their voyage plan to their family or village head who could call for a Search and Rescue Operation (SAR) and they crossed into a shipping route possibly due to lack of navigational training (decision and line management), (*iv*) the fishers ventured in to the sea without any personal protection equipment (PPE) like life jacket or buoy (unsafe act) and (v) they were not having any communication equipment except the flashlight and even the flashlight was not secured (a possible defence). That is, Mr Amalraj lost his life not only due to his own action but also due to action or lack of action of other actors beyond his control and all the holes in the model were aligned.

The lesson is that prevention of accidents needs coordination of many factors and should be implemented at various levels.

Measures for ensuring safety at sea

Safety at sea can be defined as a set of measures including policies, technologies, training, which if properly implemented can reduce risk associated with marine fisheries.

Information: The first and foremost necessity is to set up a proper accident-reporting mechanism. As mentioned above, the available data on fishing-related accident is inadequate and not sufficient to establish the causality of the accident, it is not possible to pinpoint the intervention measures needed to prevent such accidents.

Currently, the BOBP-IGO is working with NIOSH to formulate an effective accident-reporting mechanism. The mechanism once finalized is expected to be implemented in the claim format of the Group Insurance Scheme for fishers. Common type of accidents in Indian waters and their reasons are given in Table 47.1.

Policies: In Indian context fishing is a state subject for inland waters and waters up to 12 nautical miles. Beyond 12 nautical miles to the extent of Exclusive Economic Zone (EEZ) fishing comes under the central government. Marine Fishing Regulation

Table 47.1. Common types of accidents and their reason

Type of accident	Possible reasons
Capsizing	Poor stability/heavy loads on deck/water trapped on deck
Sinking	Bad construction/ bad maintenance
Drifting	Bad engine installation/bad maintenance of engine/lack of fuel/lack of trouble-shooting experience
Collision	Lack of navigation lights/tired crew
Fire	Bad engine installation/bad installation of cooking stove
Work accidents	Slippery decks/unprotected machinery/tired crew

Act (MFRAs) as enacted by different coastal states and Union Territories is the governing law for the fisheries. For fishing in the EEZ, at present there is no such law to regulate domestic fishing vessels.

Regarding registration of the fishing vessels, the Merchant Shipping (MS) Act 1958 is the governing Act. The registration is carried out by the Marine Mercantile Department (MMD) under the Director General of Shipping. As a pre-condition for registration, the fishing vessel should be sea worthy and should carry necessary communication and PPEs. However, due to limited field presence of the MMD not much progress was made in this regard.

After the Mumbai incidents of 26 November 2008, the Central Government has decided that all the fishing/non-fishing boats plying in Indian waters need to get registered under a uniform system. The Department of Shipping is the nodal department in this regard. Two notifications, one for amending the MS (Registration of Fishing Vessels) rules along with a revised format for registration and another for notifying the list of registrars, were issued by the Ministry of Shipping in consultation with the Ministry of Law in June 2009. The government has also decided that all types of boats would be fitted or provided with navigational and communication equipment to facilitate vessel identification and tracking. The DG, Shipping, has issued two circulars to ensure that all types of vessels including fishing vessels other than those of less than 20 m are installed with Automatic Identification System (AIS) type B transponders for the purpose of identification and tracking. In addition to this, a Committee under the D G, Coast Guard, has been constituted to suggest type of transponders on vessels of less than 20 m of length.

The MFRAs also provides for registration and licensing of fishing vessels by the Department of Fisheries of the state government/union territories. The MFRAs also provided for zonation of fishing ground. However, the basic objective of zonation is to mitigate conflict among different gear users and not sea-worthiness of fishing vessels as such. Further as per both the Acts (MS Act and MFRAs), the fishing vessels are classified based on their length and use of engine.

Along with the vessels it is also necessary to register the boat yard and ensuring the quality of the fishing vessels. Fishing vessels are the last resort to a fisher struggling in the sea. If they are not up to the standard, fisher's chance of survival gets reduced greatly.

However, Department of Fisheries does not have the capacity at present to monitor activities of the fishing vessels at sea or to coordinate/execute any search and rescue operation. The search and rescue is carried out by the Coast Guard and again there is little coordination among the agencies of state government, coast guard and fisheries associations. Improving coordination and proper implementation of existing rules and regulation is necessary to reduce fishing-related fatalities.

Also, the government should take measures to provide basic navigational and sea-safety training to the fishers. Since fishers are unlikely to attend such a programme away from their villages, it is needed that these programmes are organized at the village level during the off-season (e.g. monsoon ban).

Considering design of the vessels to designate their area of operation: Fishing

vessels meet different sea conditions. The International Standards Organization ISO 12215-5 regulations for boats under 24 m uses four different design categories to characterize the maximum wave-height and wind speed [measured in Beaufort Wind Force Scale (BWFS)] that a boat should be suitable for. The ISO uses the term significant wave height (SWH) which is the average of the 1/3 highest waves. These categories are: Oceanic (SWH > 4 m); offshore (SWH $\leq$ 4 m; BWFS $\leq$ 8); inshore (SWH $\leq$ 2 m; BWFS $\leq$ 6) and sheltered water (SWH $\leq$ 0.3 m).

Individual fisher community actions

At their level, the fishers and the fisher community or association can take several measures to reduce fatalities. The first step is preparation of a voyage plan and sticking to that voyage plan. The fishers also need to inform their families or association about the voyage plan. As per coast guard reports, their search and rescue operation are often hampered by lack of information on possible location of the fishing vessels. A simple voyage plan can address this issue effectively and saves life.

The next step is pre-voyage check up of fishing vessels. This should include checking condition of the craft, hull and engine, carrying enough fuel, water, food and medicines; insisting on carrying PPEs on-board, carrying communication equipment and signals, etc. Since an individual fisher might not be in a position to raise such issues with the boat owner, movement by the community or association or both is necessary. The fisherwomen should be made a part of such effort as ultimately the onus fall upon them. In addition, the fisherwomen can provide moral strength to their male member to abstain from drinking or use of other behaviour modifying products during fishing.

The community can also organize local search and rescue team and carry out mock drills in association with the coast guard. The coast guard provides such services through its outreach programme. The fisher association can maintain roaster to discourage race to fishing ground among the fishers. Declining resource base is one of the main reasons for worsening safety at sea.

These measures are a part of setting up of an effective monitoring, control and surveillance (MCS) mechanism in marine fisheries.

Disaster management

A disaster is, "the occurrence of a sudden or major misfortune which disrupts the basic fabric and normal functioning of a society or a community. An event or a series of events which give rise to casualties and/or damage or loss of property, infrastructure, essential services or means of livelihood on a scale which is beyond the normal capacity of the affected communities to cope with unaided" (*Source:* FAO, 1998). Disasters can be natural or man-made. Natural disaster includes cyclone, flood, draught; earthquake and tsunami; land slide, volcanic eruption, etc. That is the events triggered by natural forces. On the other hand, man-made disasters are the event either caused by human activities or as a result of human activities. These are nuclear leaks, chemical leaks, oil spills, war, etc. Flood is also often caused by human activities like building of a faulty dam, destruction of forest cover, etc. However, natural phenomena, such as earthquakes, floods and cyclones – referred to as natural hazards – are not disasters in themselves. A natural or other hazard only becomes a disaster when people are affected or losses are incurred.

India has been traditionally vulnerable to natural disasters on account of its unique geo-climatic conditions. As per the Status Report on disaster management in India, about 60% of the landmass is prone to earthquakes of various intensities; over 40 million ha is prone to floods; about 8% of the total area is prone to cyclones and 68% of the area is susceptible to drought. In the decade 1990-2000, an average of about 4,344 people lost their lives and about 30 million people were affected by disasters every year in India.

As the definition of 'disaster' suggests that there are linkages which turn a hazard into disaster (Fig. 47.2). Therefore, it is possible to manage disaster successfully if proper policies, planning and implementation are in place.

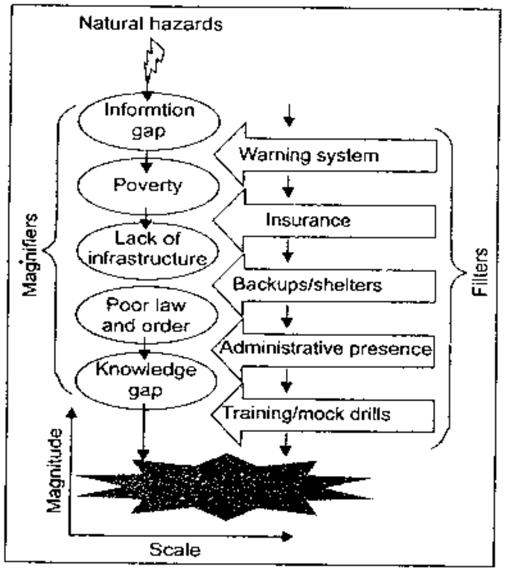


Fig 47.2. From hazard to disaster and its management

The main reasons that converse a hazard into a disaster are: information gap, lack of capability (poverty); poor infrastructure, law and order and knowledge gap. For example, lack of early warning for a cyclone is likely to increase its destructive effect. Even if there is a warning, people may lack the capability of dealing with it, for example; arranging transportation to move to a safer zone. Poor infrastructure, namely absence of cyclone shelter, lack of road connectivity etc. increases the vulnerability of the population. Law and order is also a major issue, i.e. if people fear that their property will be stolen in case they move out of their home to go to a safer place, then they may delay their departure and thus fall victim. Knowledge gap is another major magnifier of hazards. Usually people of a particular region over a period of time get accustomed to the type of natural hazards prevailing in the region and act accordingly–traditional houses in the earthquake-prone north-eastern India are built of light and durable material like bamboo. However, such shared knowledge and skills are missing in present day. Further, since these events have very low probability of happening, people do not have the mental preparation of dealing with them.

Vulnerability of fisheries sector

Disasters affect the fisheries sector in many different ways. Natural disasters often lead to large numbers of casualties and cause tangible losses in the form of damaged and lost boats, gear, fish cages, aquaculture broodstock and other productive assets like destruction of infrastructure such as landing facilities and loss of production, e.g. fish escaping from aquaculture ponds. Environmental damage through accidents, such as oil spill may cause the closing of a fishery. As opposed to sudden natural disasters, other hazards build up over time. Outbreaks of disease and other threats to farmed fish in particular cause production losses.

In Indian context, marine fishers live along the coastline and are quite vulnerable to the disasters, as has been observed during the December 2004 t-sunami, wherein due to lack of any mangrove cover, the coastal villages became highly susceptible to strong wind wave. Further, as per the Marine Fisheries Census of 2005, about 38% fishers live in a *kutcha* house. In states of West Bengal and Odisha nearly all of the fishers stay in the *kutcha* house. Although remaining 62% of the fishers stays in semi-*pucca* or *pucca* house, adaptability of these houses to natural calamities is questionable. In addition, about 20% of marine fishing villages had no road connection in 2005.

Mitigation strategies

Subsequent to Bhuj earthquake in 2001, the Government of India drew up a roadmap to tackle with such disaster effectively. These include setting up institutional mechanism and mainstreaming disaster management into development process. As mentioned earlier, considerable amount of resources is required to tackle with disasters, however, given their low probability it is not possible to commit such amount of resources only for disaster management. Hence mainstreaming disaster with development is necessary. Side-by-side skills should be developed to tackle emergencies within the administrative system and the community through training, education and mock drills.

The possible steps which can control the scale and magnitude of hazard, particularly in coastal areas are setting up, efficient weather-warning system; insurance of assets; building infrastructure like cyclone shelters, sea wall, etc.; ensuring administrative presence in the coastal villages by involving panchayat and the community to maintain law and order and training to bridge the knowledge gap.

As was evident during the post December 2004 tsunami, the coastal population especially the fishers and small-scale aqua farmers did not have resources to rebuild their livelihoods. These issues were addressed to a large extent by international charity. However, depending upon donor funding is an uncertain way of dealing such issues, hence insurance of assets is quite necessary.

In this regard, it is also necessary to monitor and coordinate the effort of various voluntary agencies with that of government. Lack of coordination may lead to duplication of effort and poor quality of service.

At the end of the day, fishers are a set of entrepreneurs engaged in one of the riskiest occupation of the world and creating livelihoods for millions of people in the downstream. Therefore, the ultimate objective of fisheries policy tools should not be just to protect the resource but also to minimize occupational hazard and reduce vulnerability of this community. Mobilization of policy measures and training can be the most important step for improving overall safety in fisheries sector.

48. Information and Communication Technology in Fisheries

, fish, fish-farmer, fishing and fish consumer are the main components of the ies sector, which are spread from a small pond to vast ocean. Fisherman, fish-r, small-scale as well as fishery entrepreneur needs information on every aspect ter, fish, fishing tools, market and weather reports to make fisheries a profitable rise. A single example is enough to explain the role of information in fisheries – 26 December 2004 and 16 March 2011, when the tsunami struck the Indian l areas and Japan respectively. Fishing villages that received the information tsunami in time survived, otherwise thousands of fishermen and their equipment wiped out in a stroke of this natural disaster. An information became the life-line heries sector. The terms, information systems and information technology, are times used interchangeably, but these two are distinct concepts. The term nation system describes all the components and resources necessary to deliver formation and related functions to the organization. The term information ology refers to the software, networking, data management and hardware onents necessary for the system to operate. The software technologies include ting system software, web browser, software productivity suites, software drives, ase-management systems, and other software-based components and modules. etworking of fisheries include processors, telecommunication media, and software d to provide wire-based and wireless access and support for the internet and te internet-based networking, namely intranets and extranets. Data-resource ologies include management system software for development, access and enance of the fisheries sector.

agement information system

e pioneer research in fisheries has made a major breakthrough during Blue lution that generated information for which a system was to be developed so that ld reach to its end-users. The system would access, organize, summarize, and ay information for supporting routine decision making in the functional areas. system is called functional management information system. It is to be put in to ensure that fish breeding to fish selling business information activities are in an efficient manner.

anagement information system report might also include summary reports for the nt period or for any number of previous periods. Management information system ed for monitoring, planning and control. For instance, the fisheries department t produce a weekly report on the status of delinquent accounts receivable. Or, a forecast could help the marketing manager make better decisions regarding rtising and pricing of products. Besides being useful in making routine decisions, system also enables managers to detect possible problems at an early stage.

Decision support system: The basic objective of decision support system is to provide computerized support to complex, sometimes non-routine decisions. This system expands in two directions, namely (*i*) executive information system, and (*ii*) group support system. The executive information systems were designed to support senior executives like managers, scientists etc. These are expanded later to support all levels of manager around the business organizations. The second direction is the support system of working groups. The group support system initially supports people working in a special decision-making situation. As the network computing develops, this group support system is able to support the decision makers working in different locations. The various commercial software products that support people working in groups are called groupware. It is designed for use with all types of networks, since it supports employees involved in fish-farming, technicians, scientists working in different locations.

Intelligent system: A new intelligent system emerged in the end of 20^{th} century in which systems with learning capabilities enable computers to incorporate new information or feedback and update their knowledge. This type of artificial intelligence excels at processing vague or incomplete information, recognize subtle patterns in data regarding weather, cyclone, fish-farming and to make predictions or recognize patterns or profiles in situations where the logic or rules are not known.

Developing successful information system solutions to fish-farming problems is a major challenge for professionals of this field and to the scientists today. A system manager is responsible for proposing or developing new or improved uses of information technologies for the research organization related to fisheries sector.

Almost computer-based information systems are conceived, designed and implemented using some form of systematic development process. In this development process, end-users and information specialists design information system application based on an analysis of the fishery business requirements of an organization. The other activities include investigating the economic or technical feasibility of a proposed application, acquiring and learning how to use any software necessary to implement the new system, and making improvements to sustain the research in fishery. The other functions include project identification on fisheries, investigation and feasibility study at the research place/fishery institute/fish-farming field, systems analysis and system design, programming, implementation, operation, and review and maintenance.

Communication media

Media bridge the information gap between research laboratories and fish-farmers, and play a vital role in increasing public awareness about natural calamity, i.e. it alarms in advance so that fish-farmers can save themselves; it prepares the communities for the ensuing disaster and covers real story about the facts and situations during and after the disaster without making them a sensational issue.

The communication strengthens the operational efficiency of disaster management plans, and strategies are implemented to achieve goal timely. The establishment of a channel on television as well as a radio frequency would be an effective path to alarm ie fish-farmers in anticipation. A key to have a strengthened information system is to ivest in mechanisms and capacity for monitoring, surveillance and evaluation. An ptimum level vulnerability analysis could lead to risk mapping of the zone and ommunity. Thus media play pivotal role in fish farming.

For data to be communicated from *taluka*/block level to scientific community, some orm of pathways or medium must be used. These pathways are called communication hannels, and they include twisted-pair, coaxle cable, fibre optic cable, microwave ransmission and satellite transmission.

Cable media: It includes physical wires or cables to transmit data with information.

Microwave: It is widely used for high-volume, long-distance point-to-point ommunication. Microwave towers should usually not be spaced more than 48.3 km 30 miles) apart because the earth's curvature would interrupt the line of sight from ower to tower.

Satellite: A major advancement in communications in recent years is the use of ommunication satellites for digital transmissions. These are of 3 types:

Geostationary earth orbit: The orbit of these satellites is 35,888.28 km (22,300 niles) directly above the equator, and they maintain a fixed position above the earth's urface. These satellites are excellent for sending television programme to cable operators and broadcasting directly homes.

Medium earth orbit: The orbit of this satellite is within the range of a few hundred ilometres to a few thousand kilometres above the earth's surface.

Low earth orbit: These satellites are located from 643.74 to 1,609.34 km (400 miles to 1,000 miles) above the earth's surface. These satellites are closer to earth, reducing or eliminating apparent propagation delay. They can pick up signals from weak transmitters. They consume less power and cost less to be launched than geostationary earth orbit and medium earth orbit satellite.

Role of remote sensing

The compilation of information about the object without physical contact is called remote sensing. The Indian Space Research Organization (ISRO) has developed some methodologies to use remote-sensing technologies to aid locators of fishery resources. The remote sensing technology is useful in the study of natural processes taking place in the area to which human beings have no easy access; digital format that enables using such data for processing or interpretation through computers.

Global positioning system: Marine fishing needs a special type of wireless information system like global positioning system. This system uses satellites to enable user to determine their position anywhere on the earth. This is used for navigation by commercial airlines and fishing vessels. This system is supported by 24 satellites that are shared world-wide. Each satellite orbits the earth once in 12 hr, on a precise path at an altitude of 17,541.8 km (10,900 miles). At any point of time, the exact position of each satellite is known because the satellite broadcasts its position and a time signal from its on-board atomic clock, accurate to 1 billion of a second. Receivers also have accurate clocks that are synchronized with those of the satellites.

Radio: It is an electromagnetic data communication system that keeps fishermen informed about the forecast of weather or alarming situations. It is being used increasingly to connect computers and local-area networks. For data communications, the greatest advantage of radio is that no metallic wires are needed. Radio waves tend to propagate easily through normal office wall.

Television/video-cassette recorders: The remote control unit of TV and VCR is the application of infrared light which can be modulated or pulsed for conveying information. With computers infrared transmitters and receivers are being used for short-distance connection between computers and peripheral equipment, or between computers and local-area network. Communication networks are usually defined by their size and complexity. These are of mainly three types:

Local-area network. These networks connect computer equipment and other terminals distributed in a localized area, e.g. with office, organization, sea port, cargo etc.

Metropolitan area network. These networks are used to interconnect local-area networks that are spread around the particular area in which progressive fish-farmers work. It is a high-speed network using optical fibre connections.

Wide area network. These networks connect computers and other terminals over long distances. They often require multiple communication connections, including microwave radio link and satellite.

E-agriculture

(a) Ensure the systematic dissemination of information using information and communication technology (ICTs) on agriculture, animal husbandry, fisheries, forestry and food, in order to provide ready access to comprehensive, up-to-date and detailed knowledge and information, particularly in rural areas.
(b) Public-Private Partnerships should seek to maximize the use of ICTs as an instrument to improve production (quantity and quality).
(c) With the approval of the Open Access Policy in ICAR, the ICAR publications, viz. *The Indian Journal of Agricultural Sciences*, *The Indian Journal of Animal Sciences*, *ICAR Reporter*, *ICAR News* etc. are globally read (i.e. 178 countries as on 21 June 2011) and a single research paper is down-loaded between 20 and 100 times from our research journals. This has become possible through a project, namely, 'E-Publishing and Knowledge System in Agricultural Research, under NAIP.

Network fish handling centre

FISHNET-ReAL Craft is an e-governance Portal-cum-web-based workflow-based application developed by the NIC Kerala State Centre for the Fisheries Department using LAPP (Linux, Apache, Postgres and PHP) technology. FISHNET- Real Craft project has been successfully implemented in all the marine districts of Kerala. A decision has been taken to roll out the same in all the remaining coastal states/union territories. Accordingly, FISHNET coordinators of these states have had preliminary sions with the concerned officials of the state fisheries departments. FISHNET- Craft will facilitate On-line Licensing and Registration System for Fishing s and a database on Fishing Vessels and their movement in all the coastal states nion territories. The coastal security has become an important issue and this t assumes greater significance because of this also.

establish a network of about 1,500 Fish Landing Centres, along the coastal lines country, for speedy collection and dissemination of information on Fish Landing sh Price. The project will have the components - Networking of Fish Landing s and Fish Catch Volume and Fish Price Data. FISHNET-FLCIS will network h Landing Centres using AGMARKNET software to be customized for this e. This will facilitate Fisheries Informatics for Decision Support and Information s for Fisheries Development in India.

t of ICT on small-scale fishing enterprises in South India

ormation and Communication Technology (ICT) as a cost-effective and tive mechanism for delivering relevant information and knowledge to the olders. More than 70 % of adults in Kerala eat fish at least once a day, and more million people work in the fishing industry. Fishing is done primarily by small izes, working near home markets and traditionally selling their catches to a c market. This causes large geographical disparities in market prices, according l conditions of supply and demand. These disparities were so great that it was common for fish in some markets to be discarded because they could not be hile there was an active trade going on in neighbouring towns. Mobile phone s were introduced in Kerala in 1997 and expanded progressively along the nd outwards from the major urban areas. Network coverage also extends 20– out to sea, allowing fishermen to find out the prices in different markets along st, decide where to land their catches, and agree on prices before landing their fectively conducting auctions by phone.

effects were significant. Since mobile phones were introduced, 30-40% of nen began selling fish outside their home markets–compared with almost none and. Within a few weeks this significantly reduced the dispersion in fish prices n markets. Prices on any given day now rarely differ by more than a few rupees compared with up to ₹ 10 before. Moreover, there are almost no cases of wastage. phones have resulted in an increase in fishermen's incomes. On average, daily es were risen by ₹ 205, while costs (including the cost of buying the phones) have ed by ₹ 72. Thus the profits of fishermen have jumped by ₹ 133/day, i.e. 9% e. The introduction of mobile phones has also had a modest benefit for customers, e average price of sardines falling by ₹ 0.39/kg, or just under 4%.

***gu* (e-cultivation) system:** The e-*Sagu* is a ICT-based agro-advisory system. means cultivation, in Telugu). It aims to improve farm productivity by ng high-quality personalized (farm-specific) agro-expert advice in a timely to each farm at the farmer's door-steps. The advice is provided on regular om sowing to harvesting which reduces the cost of cultivation and increases

the farm productivity as well as quality of agri-commodities. In e-*Sagu*, the developments in ICT such as database, internet, and digital photography are extended to improve the performance of agricultural extension services. The project is providing personalized advice in 6 districts of Andhra Pradesh. The major crops covered under the project are cotton (*Gossipium hirsutum*), chilli (*Capsicum annum*), rice (*Oryza sativa*), groundnut (*Arachis hypogaea*), castor (*Ricinus communis*), pigeonpea (*Cajanus cajan*) and fish.

AQUAa project: AQUAa (almost all questions answered) is a multilingual online question and answer forum – which provides online answers to questions asked by farmers and agri-professionals over the internet. It allows users to create, view and manage content in their native language. It provides easy and fast retrieval of contextual information, documents and images using various keyword search strategies with the held of query expansion and indexing techniques. Using this, a farmer can ask a question on AQUAa from a kiosk (cyber-café); experts view the question and answer back, providing solutions to the problem. It is available in English, Hindi and Marathi. Being Unicode compliant system, it can support other languages also.

Information and communications technologies in the fisheries sector

Digital and other electronic technologies are transforming our economies, societies and people's lives. Technology has had an especially profound impact on the information and communications activities that have always been central to sustainable development. Information and communications technologies (ICTs) refers to technologies that facilitate communication and the processing of information by electronic means and includes everything from radio and television to telephones (fixed and mobile), computers and the internet.

In fisheries, new ICTs are being used across the sector, from resource assessment, capture or culture to processing and commercialization. Some are specialist applications such as sonar for locating fish. Others are general-purpose applications such as Global Positioning Systems (GPS) used for navigation and location finding, mobile phones for trading, information exchange and emergencies, radio programming with fishing communities and web-based information and networking resources. A wide range of technologies can be adopted and introduced in all but the most remote communities and once appropriated by users, can have positive impacts on their lives.

ICT for development

The uses of ICT for development go beyond direct support for income-generating activities. The ICT for pro-poor development can be a powerful means of reducing people's vulnerability, of fostering equity and social inclusion and in mobilizing communities to take charge of their own development. In conjunction with traditional communication activities such as meetings and theatre, community radio, video for television, mobile phones, telecentres and print publications can be used to share information, especially marketing information (checking fish prices), and knowledge, as well as raise awareness and stimulate discussion of issues such as gender, health, education, local development and diversification of income generation. The ICTs (particularly mobile phones and the internet or telecentres) also have an important role to play in connecting migrants with their home communities.

Information sharing – a fundamental need

Food and livelihoods security issues and the lack of extension support for fishers and fish-farmers can be addressed through information networks. New opportunities can emerge from combining mobile and newer networking technologies. Programmes and policies supporting further development of ICTs in fishing communities and across the sector must link effectively between relevant stakeholders from local to international levels, be designed to cater truly for the needs of the poor and lead towards more responsible fisheries.

Information and communications technologies are a fundamental development tool to support information sharing, collaboration and dialogue leading to increased participation and ownership. The world is undergoing an ICT revolution, a revolution that has enormous socio-economic implications for the developed and developing countries.

ICT plays a vital role for the development of the status of agriculture and allied areas in our country. ICTs range from advanced modern technologies, such as GPS navigation, satellite communication, and wireless connectivity, to older technologies such as radio and television. The latest innovations of ICTs in fisheries sector have brought about a tremendous change in the life styles of the fish-farmers. Different initiatives in ICTs have been taken up which would also help in expanding and developing the fisheries technologies to the farmers.

Computer software for fisheries

Aquaculture is one of the world's fastest growing industries, with an average growth rate of over 8% per year for the past 10 years. Over half of all the aquatic species consumed are now produced from aquaculture, and it is estimated that a further 40 million tonnes of aquatic food will be required by 2030 to supply the increasing demand. The aquaculture industry will face many challenges over the next few years to be economically, socially and environmentally sustainable. The industry will require trained and experienced staff to successfully address these issues and to meet anticipated future growth. In 2009 the University of St Andrews teamed up with *TheFishSite.com* to launch an e-learning certificate level course in sustainable aquaculture. This course started in May 2010. The course is aimed at those who wish to develop their skills and knowledge of the aquaculture industry, particularly for those looking to focus on the rapidly growing Asian and South American markets. The course is also suitable for those looking to enter the aquaculture industry who wish to gain a greater knowledge and a recognized qualification to promote their career prospects.

ARTFISH – Approaches, Rules and Techniques for Fisheries Statistical Monitoring: ARTFISH is developed as a standardized tool adaptable to most fisheries in the developing countries. Its design was driven by the need to provide users with robust, user-friendly and error-free approaches and computer software, and achieve the implementation of cost-effective fishery statistical systems with minimal external assistance.

BEAM 1 and 2: Bioeconomic Modeling of Artisanal and Industrial Sequential Shrimp Fisheries – Software packages for bioeconomic modeling of artisanal and industrial sequential shrimp fisheries based on an age structured Thompson and Bell yield per recruit biological model and a simple input output microeconomic model. BEAM1 gives its simulated results by age groups. BEAM2 gives them by standard commercial categories as used in the shrimp fishing industry.

BEAM 3: A Bioeconomic Simulation Model of Tropical Shrimp Fisheries Using Fixed or Random Recruitment – BEAM3– is a stochastic model that aims at determining the optimum size, in the long-term, of the level of fishing capacity corresponding to the management goals.

BEAM 4: Analytical Bioeconomic Simulation of Space structured Multispecies and Multifleets Fisheries – BEAM4– is a versatile tool for the rational management of exploited living aquatic resources. It can deal with a fishery system of several stocks, fleets, areas (fishing grounds) and processing plants, and can account for migration of the animals as well as seasonality of recruitment.

CLIMPROD: Experimental Interative software for choosing and fitting surplus production models including environmental variable – various equations allow for the introduction of an environmental variable into surplus production models. CLIMPROD helps the user select the most appropriate model for a particular case, according to objective criteria. It resembles a simple expert system and uses artificial intelligence language (PROLOG) to converse with the user.

CLIMPROD-PLUS: Experimental Interactive software for choosing and fitting surplus production models including environmental variable - various equations allowing for the introduction of an environmental variable into surplus production models are available. CLIMPROD-PLUS helps the user to select the model corresponding to a particular case according to objective criteria. It looks like a simple expert system and uses artificial intelligence to converse with the user.

FAST: The Fishing Activity Simulation Tool, called FAST was developed as an extension for the ESRI ArcView GIS Software (v.3.1) in combination with the Spatial Analyst v. 1.0 extension. It is based on two models focussing on the analysis of the spatial components of the fishing effort distribution.

FISAT II : Stock Assessment Tools - The FAO-ICLARM Stock Assessment Tools (FISAT) is a programme package consisting of robust methodologies for use with micro-computers, enabling users to formulate management options for fisheries, especially in data-sparse, tropical contexts.

FISHSTAT-PLUS: This is Universal Software for Fishery Statistical Time Series. The system provides users with access to Fishery Statistics of various sorts. Any data having time series structure can potentially be stored and processed by FishStat Plus. The system consists of the main module and the datasets. Each dataset can be installed and uninstalled separately.

ITBASE 1.1: The Model of Trophodynamics of Black, Azov Ecosystem, an ogy software package for the study of the impact of exotic species introduction on stocks: Mnemiopsis-Anchovy relationships case (MTBASE 1.1).

ANSIS: Software for Fishery Survey Data Logging and Analysis, NANSIS, is a ey Information System for logging, editing and analysis of scientific trawl survey (trawl/catch data and length/frequency data).

HOMPSON AND BELL YIELD ANALYSIS: Introduction to Thompson and Yield Analysis Using Excel Spreadsheets application refers to the use of a group odels loosely based on the work of Thompson and Bell. The models are essentially ematical depictions of fisheries, or parts of fisheries.

ONBIT 2005: VONBIT stands for von Bertalanffy Iterative Approach and it is a uter software designed to run under Windows. The presented linear regression od for fitting the von Bertalanffy growth function to data on size at age is also ly applicable to tag and recapture data, thus offering a more integrated approach ther similar methods. Several comparison tests revealed that the present approach s lower error and bias and more flexibility of action than other commonly used ls and systems.

munication softwares

en system interconnection (OSI) is a standard reference model for communication en 2 end-users in a network. The open system interconnection reference model bes 7 layers of related functions that are needed at each end when a message is om one party to other in a network.

plication layer: All the capabilities of networking begin in the application layer. ansfer, messaging, web browsing, and other application are in this layer. Each pplication will appropriately invoke processing of data for transmission through efined interfaces to layers below this one.

sentation layer: This is responsible for data formating. It takes care of such as bit and byte ordering and floating point representation. For instance, external epresentation (XDR) and abstract syntax notation (ASN).

sion layer: This handles the exchange of data through dialogue procedures or chat versation protocols. This layer is largely designed for mainframe and terminal unications. It has no relevance with respect to TCP/internet protocol networking.

nsport layer: This is responsible for communication between 2 systems. It es the communication session including flow control, ordering of information, etection and recovery of data.

work layer: This owns the responsibility of delivering data between different s in different interconnecting networks.

a link layer: This provides rules for sending and receiving data between 2 ted nodes overall particular physical medium.

sical layer: This defines the required hardware, namely cables, and interfaces ven media of communication like electrical, radio frequency and light based. In y, methods for transmitting and receiving bit-streams of informations are defined.

Internet

The inter-connected network exchanges information seamlessly by rising the same open non-proprietary standards and protocols. It is called internet. The internet forms massive electronic communication network among different information users, e.g. progressive fish-farmers, consumers, scientists, government agencies, other organizations world-wide, etc. Internet has opened up exciting new possibilities that challenge traditional ways of interacting, communicating and doing business of fisheries etc.

Addresses on the internet: Each computer on the internet has an assigned address, called the internet protocol address that uniquely identifies it from other computers. The internet protocol numbers have 4 parts separated by dots. For example, the internet protocol address of one computer may be 421.20.195.11. Most computers also have names which are easier for people to remember that internet protocol addresses. These names are derived from a system called the domain name system. Domain name consists of multiple parts, separated by dots, and are translated from right to left. The right most part of an internet name is its top-level specification. 'com' indicates that this is a commercial site, and org (www.icar.org) indicates it is an organization. For instance

- *Chfish@vsnl.com* (Chennai Research Centre of CMFRI) — .com commercial site
- *nbfgrcochin@eth.net* (NBFGR Kochi Unit) — .net networking oragnizations
- *Cift@ceftmail.org* (Central Institute of Fisheries Technology) — .org organizations

Accessing the internet: There are three main ways to connect the internet. These methods include connecting via a LAN/server or connecting via SLIP (serial line internet protocol), PPP (point-to-point protocol).

Connect via LAN server. This approach requires that user computer should have specialized software called a communication stack, which provides a set of communication protocols that perform the complete functions of the seen layer of the OSI communications model. LAN servers are typically connected to the internet at 56 kbps or faster.

Connect via serial line internet protocol (SLIP)/point-to-point protocol (PPP). This approach requires that users have a modem and specialized software that allows them dialling into a SLIP/PPP servers.

Internet – a useful tool

The internet provides three major types of services, namely communication, information retrieval, and the world-wide web.

Communication services

These include electronic mail (e-mail), USENET newsgroups, LISTSERVS, chating, telnet, internet telephony, and internet fax.

E-mail: Electronic mail, also known as computer-based message systems (CBMS), rovides a variety of facilities to assist human communication between locations. It ffers the following basic services:

Message creation by the originator: The range of information types (text, graphic, tc.) used into the messages will depend on the workstation available and the capability f the communications network. A secret password should be given as a security check efore the system allows a user access to the network.

Routing of messages to the recipients. The network controls the information about where the recipient is located and transmission channels available to deliver the communication to the appropriate workstations in the most efficient and reliable manner.

Storing incoming mail until the recipients is ready to receive it. After transmission, the message stays in computer storage which is accessible to the recipient, known as an electronic mailbox, from where it is extracted at the recipients convenience. This is called a stored and forward system.

Applications of e-mail. It is useful in education, and research, business and medicine.

(i) Academic information as well as information related to fisheries research etc. can be spontaneously shared between many experts from all over the world. E-mail addresses of some important fisheries institutions are given here.

- Bay of Bengal Programme (BOBP), Chennai, Tamil Nadu
  info@bobpigo.org
- Central Inland Fisheries Research Institute, Barrackpore (West Bengal)
  cifri@vsnl.com
- Central Institute of Brackishwater Aquaculture, Chennai (Tamil Nadu)
  director@ciba.res.in
- Central Institute of Fisheries Education, Mumbai (Maharashtra)
  director@cife.edu.in
- Central Institute of Fisheries Technology, Kochi (Kerala)
  en-ciftaris@sancharnet.in
- Central Institute of Freshwater Aquaculture, Bhubaneshwar (Odisha)
  cifa@ori.nic.in
- Central Marine Fisheries Research Institute, Kochi (Kerala)
  director@cmfri.org.in
- National Bureau of Fish Genetic Resources, Lucknow (Uttar Pradesh)
  nbfgr@sancharnet.in
- Directorate of Coldwater Fisheries Research, Bhimtal (Uttarakhand)
  dcfrin@gmail.com
- Central Institute of Fisheries Nautical and Engineering Training, Kochi (Kerala)
  cifnet@nic.in
- National Institute of Fisheries Post-harvest Technology and Training, Kochi (Kerala)
  ifpchn@nic.in
- Fishery Survey of India, Mumbai (Maharashtra)
  dg@fsi.gov.in

- Central Institute of Coastal Engineering for Fishery, Bengaluru (Karnataka)
  cicef@dataone.in
- Centre for Marine Living Resources and Ecology, Kochi (Kerala)
  sagarsampada@gmail.com
- The Marine Products Export Development Authority, Kochi (Kerala)
  mpeda@mpeda.nic.in
- National Institute of Oceanography, Dona Paula (Goa)
  ocean@nio.org
- National Fisheries Development Board, Hyderabad (Andhra Pradesh)
  info.nfdb@nic.in
- Coastal Aquaculture Authority, Chennai (Tamil Nadu)
  aquaauth@vsnl.net
- National Federation of Fishermen Cooperatives Ltd (FISHCOPFED)
  nfc@fishcopfed.in New Delhi
- Rajiv Gandhi Centre for Aquaculture (RGCA), Sirkazhi, Tamil Nadu
  rgcaho@gmail.com
- Zoological Survey of India (ZSI), Kolkata
  zsi@envis.nic.in

(ii) Fish marketing and sales information can be quickly sent to regional offices, distributors etc. within country and abroad. Dispatch reports, interaction with scientists, processing of routine purchase orders directly without human intervention can be made possible. Financial upgrade can be sent to regional offices.

(iii) Meteorologists, scientists of fisheries sector, and progressive fish-farmers can consult each other anywhere in the world rapidly.

USENET Newsgroups: USENET is a protocol that delineates how groups of message can be stored and sent between 2 computers. Following the USENET protocol, users may send e-mail messages on a specific topic, namely capture fisheries, marine sector, inland sector, culture fisheries, coldwater fisheries, brackishwater and aquaculture, fish genetics, fish harvest and post-harvest technology, and island-development programme etc. to the USENET server machine, which accesses this information. Users can log onto the server to read messages or have the computer automatically download messages to be read at the users convenience.

USENET provides forum for interested users on the internet. This forum is divided into newsgroups, namely comp, news, rec, sci, soc, biz., alt etc. These disseminate information of computer hardware or software, informative documents, recreational subject discussion on the problems of fishermen, business on fisheries-related groups, alternative groups of discussions etc. respectively.

LISTER V: It is a type of public forum that allows discussion to be conducted through pre-defined groups. For instance *e-choupals* are being organized on it. The difference is that USTER V uses e-mail mailing list servers instead of bulletin boards for communications. If users find a LISTER V topic in which they are interested, they may subscribe. Later they will receive all messages, through e-mail, sent by all others icerned with that topic. If users post-messages to the LISTER V, these messages l be sent to all others on the USTER V.

ua gyan choupals

The Government of India is in the process of establishment of low-interest loans, iture capital funds, agri-business centres and facilities for establishing *gyan choupals* village knowledge centres. In the field of fisheries aqua *gyan choupals* have duly n established. There is need for a National Alliance in the penninsular states or stal areas for facilitating self-employment. Such an alliance brings together all the eholders private and public institutions, commercial and cooperative banks etc. ough information and communication technologies.

Chatting: It is the second most-used internet application besides e-mail. Chatting ws 2 or more people, who are simultaneously connected to the internet, to hold (real-time), interactive, written conversations. For instance if one farmer wants to w about new feed for fish or about fish pathology, he or she may directly approach orresponding expert and know its details through chatting.

Telnet: It is a protocol that establishes an error-free link between 2 computers. rs can log on and use third party computers that have been made accessible to the lic, i.e. using the catalogue of the US library of congress.

nternet telephone: This technology is helpful to talk abroad for price of only the net connection. In it internet vendors are providing products that emulate traditional ic switched telephone network (ISTN) applications.

nternet fax: Fax service from an internet service connects desktop computers and dard fax machines to a fax server located within the ISP's network. The same ice can also be connected with desktop e-mail to the ISP's servers, so that faxes be originated as easily as sending an e-mail. This application is useful because s can be sent long distances at local telephone rates, and delivery can be guaranteed ugh store and forward mechanisms.

treaming audio and video: Technology is advancing day-by-day and to carry technology from laboratory to remote areas the streaming audio-and-video nology was developed. Streaming allows internet users to see and hear data h are transmitted from the host server. Streaming audio and video are being to deliver market-sensitive news and other live status reports to stock trader, to sales people on new products, and to deliver significant results of research to le.

net

is an access-restricted network used internally in an organization. It uses the concepts and technologies as the world-wide web and internet. This includes browsers and servers running on the internet protocol suite and using internet cols, namely ftp, TCP/IP, HTML and e-mail. Internets are generally used for munication and collaboration, web publishing, business operation and management ntranet for portal management.

It is useful because it is easy to use, inexpensive to use, if once it is set up, initial set up cost of hardware and software moderate, useful throughout the whole enterprise, reduces employee training costs. Besides, it reduces printing, distribution and paper costs especially on policy manuals, newsletters on fishery, products catalogues of fishery sector, technical drawings, e.g. fish catch-up, training material etc. Intranet also reduces sales and marketing costs, reduces office administration and accounting costs, and cases of access results in an integrated company, e.g. at seashore or in fish market, with employees communicating and collaborating more freely and more productively.

World-wide web

The web is a system with universally accepted standards for storing, retrieving, formatting and displaying information via client or server architecture. The web handles all types of digital information, including text, hypermedia, graphics and sound. It uses graphical user interfaces, so it is very easy to use. The technology underlying global network of hypertext documents that would allow scientific researchers to work together.

Offering information through the web requires establishing a home page, e.g. *http.//www.icar.org.in* which is a text and graphical screen display that welcomes the users and explains the organization that has established the page. The home page will lead users to other pages. All the pages of a particular company or individual are known as website. Web pages provide information to contact the organization or the individual. Some important web sites related to fisheries sector are:

- *http://babalfish.altavista.com/translate.dyn*
- *www.fao.org*
- *www.cgiar.org/ilri*
- *http://www.nic.in/ciba*
- *www.cabi.org*
- *http://biodiversity.bio.unoedu/fungi*
- *http://www. aqualink.com/disease/disease.html*
- *http://www.fishbase.org*

Web pages: With the increased popularity and availability of the web, more and more people are putting up their own web page. Especially in the field of fishery people are presenting their information in a clear and accessible manner that gives a pleasant experience. An *e-news journal* has been launched by the CIFE, Mumbai. People are getting web page or webs-ites created to increase their own business world-wide. Some of the web sites are given here.

www.fishforall.org; www.fordfound.org; www.hrdc.gc.ca;
www.Ittechnologycentre.com; www.simtelnet; www.eric.ed.gow; www.mapinfo.co.th
http://www.blackseaweb.net/general/enviprog.htm#tabel2
http://www.blackseaweb.net/maps/content.htm
http://www.esri.com/;http://www.gis.com/index.html; http://igras.geonet.ru/

Developing fisheries information system

Fisheries data and information collection, along with their compilation, is not an end in itself. Information should be used to support and/or influence fisheries policy and management decisions. Significant amounts of data and information are being collected, but are not effectively utilized due to insufficient analysis, ineffective packaging and communication, poor reliability or quality, relevance and timeliness.

The existing data and information systems have not only to focus on the processes of data collection, but also on the overall purpose and goals of the exercise, *i.e.* service and utilization. Collection of data and information is an undertaking that requires tremendous resources from the agencies involved.

Information needs for policy-making, planning and management expand as concerns over sustainable fisheries, support of disadvantaged rural communities in a market-oriented economies and protection of natural resources grow. A concerted and persistent effort to collect useful information and data is necessary to overcome the existing deficiencies.

The primary role of regional organizations or institutions is to support and facilitate national efforts. Thus, formulation of regional actions should be based on national commitment and interests. While collection and analysis of fisheries data and information for national policies and management are primarily national responsibilities, the country will derive substantial benefits from regional efforts. Additionally, regional collaboration strengthens political will, which reinforces the synergy required for national actions.

Information system will require certain policies for its proper development and effective utilization.

- Data and information collection should be done as per the objective, which has to be decided after detailed dialogue with users. This would help filling knowledge gaps.
- Improve accessibility of database and individual farmer confidentiality to increase utilization of data and information collected. Spreading the awareness of benefits from use of accurate and reliable data, especially for fisheries planning and management, would attract the fish-farmers towards database. Compilation and exchange of information on fisheries including lessons learned and successful policy and management interventions, based on data and information availability or unavailability will encourage others to utilize information.
- National and regional directories of existing data and information resources should be prepared, and database should be made available to planners and fisheries experts.
- Appropriate communication mechanisms are required to disseminate results to all users (e.g. annual reports, statistics, proceedings of workshops and meetings). Training should be given for effective communication of data and information analyses to promote understanding of their applications for fisheries. Training is also to be given to collectors, and compilers of data and information, so that data information are treated in a consistent manner, including regular verification processes.

- National methodologies for fisheries data and information handling need to be developed separately for marine, estuarine, inland, shellfish, finfish sectors; and cross checked with international standards to ensure continued compatibility with fisheries policy, planning and management goals.
- Strong and consistent national data and information collection as well as analyses have to be promoted. Strong communication link has to be established between policy-makers, planners and those collecting data and information for a better future of fisheries in India.

GEOINFORMATICS IN FISH FARMING

Geoinformatics Information System (GIS) and remote-sensing tasks are mutually interlinked and division of software to GIS software and remote-sensing software means that GIS software is able to work with remote-sensing data and to perform simple tasks with them. On the contrary, GIS functions are embedded in remote sensing software. This duality is a result of close relation between these regions. Looking for the GIS free software, four groups of them can be found:

- *Viewers of commercial software*: ArcReader 9, ArcExplorer 4.0 of ESRI, GeoMedia® Viewer of INTERGRAPH, FreeLook 3.1 for ENVI, etc.
- *Software tools for certain tasks:* GDAL 1.1.5, libgeotiff, MB-System for bathymetry and backscatter imagery data derived from multibeam, interferometry, and sidescan sonars, MITAB MITAB a C++ library for reading and writing MapInfo .TAB (binary) and .MIF/MID files.
- *Complete GIS software:* GRASS, ILWIS, FMaps covering GIS together with remote sensing.
- *Software for image processing:* Intel, Image Analyzer 1.27

The Open Source GIS brings a list of more than 150 free GIS software available for users. The *webpage remotesensing.org* is a source of many free software for remote sensing including the link to Remote Sensing Tutorial prepared by William J. Campbell from the NASA.The GIS is made up of the following maps: geography, chemical oceanography, biology and fish resources. By pushing a button the user makes the corresponding subject section of the GIS appear on the screen. Aided by the menu in this section the user chooses the appropriate maps and analyses them separately or jointly, compares them with other maps, computes the final parameters on any spot they choose on the water surface. Data can be obtained touching all layers at once. There is a possibility of building arbitrary layers (calculating temperature gradients or drawing correlation maps). Thus the users working with the Black Sea GIS on their own are given a new kind of information, which can be created with the use of geo information technologies only, and the opportunity of receiving a new sort of library service.

Foreign GIS in the libraries

Arc Atlas: The Atlas contains a sizeable volume of reference information on the nature of the Earth and provides the user with possibility of editing the maps. There are several factors, which prevent from implementation GIS in the libraries. Those

GISs that are of most value are developed mostly by research and industrial organizations. These systems are either rather expensive or are created for a single purpose to meet the specific needs of the organization. In a number of cases working with GIS requires special rather complicated software and accordingly high capacity computers and that is scarcely ever available to libraries. One of the ways to improve the situation is the organization of digital access to a GIS via internet (organization of corporate access).

ELECTRONIC GOVERNANCE IN FISHERIES

In simple terms e-Governance can be defined as giving citizens the choice of when and where they access government information and services. While e-Governance entails the processes used to provide services to the public, e-Government is the tool to accomplish e-Governance. Putting the citizen at the centre of government means taking a delivery channel view. This would mean using more and more of Electronics and Information Technology in many of the government functions. There are three aspects to the e-Governance:

(a) IT enabling the government functions – something similar to back-office automation,

(b) Web-enabling the government functions so that the citizens will have a direct access, and

(c) Improving government processes so that openness, accountability, accuracy, speed of operations, effectiveness and efficiency may be achieved.

Typically, this would mean web-enabled applications, but e-Governance would also cater to automated applications for the government sector, which helps in achieving SMART governance which some define as: Speed, Moral, Accountable/Accurate, Responsive and Transparent Governance. According to one school of thought, e-Governance is not just about government website and e-mail. It is not just about service delivery over the Internet. It is not just about digital access to government information or electronic payments. It will change how citizens relate to governments as much as it changes how citizens relate to each other. It will bring forth, new concepts of citizenship, both in terms of needs and responsibilities.

e-Governance provides three basic change potentials for good governance for development:

Automation: replacing current human-executed processes, which involve accepting, storing, processing, outputting or transmitting information. For example, the automation of existing clerical functions.

Informatization: supporting current human-executed information processes. For example, supporting current processes of decision-making, communication, and decision implementation.

Transformation: supporting new human-executed information processes. For example, creating new methods of public service delivery.

These change potentials, in turn, can bring – singly or in combination – five main benefits to governance for development:

Efficiency gains

(i) Governance that is low-priced: producing the same outputs at lower total cost.

(ii) Governance that does more: producing more outputs at the same total cost.

(iii) Governance that is quicker: producing the same outputs at the same total cost in less time.

Effectiveness gains

(i) Governance that works better – producing the same outputs at the same total cost in the same time, but to a higher quality standard.

(ii) Governance that is innovative – producing new outputs.

Hence, with e-Governance, a reinvigorated, digital-era government is at hand. When governments, citizens, and private sector partners redefine and reengage their roles, better government–better governance–will be the result.

SCIENTOMETRICS IN FISHERIES

An analysis of 16,891 publications published by Indian scientists during 1993-2002 and indexed by *Science Citation Index Expanded* (Web of Science) indicates that the publication output in the agricultural sciences is on the decline since 1998 onwards. 'Dairy and animal sciences' followed by 'veterinary sciences' constitute the largest component of the Indian agricultural research output. Agricultural universities and institutes under the aegis of Indian Council of Agricultural Research (ICAR) are the major producers of research output. Most of the papers have been published in domestic journals and in low normalized impact factor journals with a low rate of citation per paper. Most of the highly productive institutions are either agricultural universities or the institutes under the aegis of the ICAR. Most of the prolific authors are from the highly productive institutions. However, only a few highly cited authors are from highly productive institutions.

IMPORTANCE OF ICT IN FISHERIES

New information and communication technologies (ICTs) are being used across the fisheries sector, from resource assessment, capture or culture to processing and commercialization. Some are specialist applications such as sonar for locating fish. Others are general purpose applications such as Global Positioning Systems (GPS) used for navigation and location finding; mobile phones for trading, information exchange and emergencies; radio programming with fishing communities and web-based information and networking resources. Introduction of mobile phones in India has brought about a tremendous change in fisheries sector. One result was a significant improvement in the efficiency and profitability of the fishing industry. As mobile phone service spread, it allowed fishermen to land their catches where there were wholesalers ready to purchase them. This reduced waste from between 5 and 8% of total catch to close to zero and increased average profitability by around 8%. At the same time, consumer prices fell by 4%. Different communication technologies have been used by the fishermen, entrepreneurs, aquaculturists, extension workers, etc. Of all these, radio has been found to be most widely used by farmers. Information on various innovations of fisheries technologies are being disseminated among the farmers.

The internet is emerging as a tool with potential to contribute to rural development. nternet enables rural communities to receive information and assistance from other levelopment organizations: offers opportunities for two-way and horizontal communication and for opening up communication channels for rural communities and development organizations.

It can facilitate dialogue among communities and with government planners, levelopment agencies, researchers, and technical experts: encourage community articipation in decision-making; coordinating local, regional and national development fforts for increased effectiveness; and help agricultural researchers, technicians, armers and others in sharing information. Internet can also give a vast global nformation resource. The internet has proven valuable for the development of fisheries n developing countries like India.

Initiatives in fisheries sector ATIC: It is not enough to generate information alone ut it is also necessary to ensure that the required information is delivered to the end-sers at the earliest and with the least dissemination loss. The establishment of gricultural technology information centres (ATIC) can forge a better interaction etween researchers and technology users.

This acts as a single window system with an objective to help farmers and other akeholders to provide solutions to their agriculture-related problems. This also helps providing technological information along with technology inputs and products. uch information is useful for farmers, entrepreneurs, extension workers, NGOs and rivate sector organizations.

Kisan Call Centre: The Department of Agriculture and Cooperation (DAC), linistry of Agriculture, Government of India, launched Kisan Call Centres across the ountry to deliver extension services to the farming community. A Kisan Call Centre onsists of a complex of telecommunication infrastructure, computer support and ıman resources organized to respond the queries raised by farmers in their local nguages. Subject Matter Specialists (SMS) using telephone and computers, interact ith farmers directly to understand the problems and answer the queries at the call ntres. There are call centres for every state that are expected to handle traffic from ıy part of the country.

elpline

Leveraging on the IT revolution in India and the increasing penetration of telephones villages, many State Agricultural Universities and ICAR institutes have started lpline services. The helplines address queries related at specific hours. The helpline mber is advertized through mass media, namely radio and press.

Aqua service centres: Many unemployed educated youths have started operating

aqua service centres in the line of agri-clinics. These centres offer services like soil and water testing, feed analysis, seed quality testing (PCR test), disease diagnosis and market intelligence. They also sell inputs such as feed, fertilizers, pesticides, other therapeutics etc. In Andhra Pradesh, several such centres can be found in Kolleru lake area of West Godavari district. Farmers need to pay for availing services of these centres.

One stop aqua shop

One of the major recommendations of DFID funded project "Investigating improved policy on aquaculture service provision to poor people" was to establish one stop aqua shop (OAS). It is intended that OAS would provide better access to farmers regarding appropriate aquaculture technology as well as information on government schemes and rural banking and micro finance. It was also envisaged that OAS would sell fish seed and other inputs. The shop is a single outlet for all inputs that a farmer may require in the cultivation of fish. The inputs include fish seed, fertilizers, chemicals etc. The OAS is also helping farmers in providing information on fish farming through information brochures supplied by state departments and research institutes.

Aqua *choupal*

Aqua *choupal*, the unique web-based initiative of ITC Ltd offers the farmers of Andhra Pradesh all the information, products and services they need to enhance productivity, improve farm gate prize realization and cut transaction cost. Farmers can access information on weather, scientific farming practices and market prices through a web portal. Aqua *choupal* also facilitates the supply of high-quality farm inputs as well as purchase of shrimps at their doorstep.

Rural Knowledge Centre

Rural Knowledge Centre is a part of a nationwide plan and has been set in motion in July 2004 by the Centre in collaboration with the states, National Association of Software and Services Companies, United Nations Development Programme and a host of NGOs. Its primary aim is to set up multipurpose resource centres at the villages of the country. Each Knowledge centre is run by local self-help groups, and cater to knowledge based livelihoods and create income avenues for rural people, farming communities and disadvantaged people.

Cyber extension

The internet is emerging as a tool with potential to contribute to rural development. Internet enables rural communities to receive information and assistance from other development organizations–offer opportunities for two-way and horizontal communication and for opening up communication channels for rural communities and development organizations.

It can facilitate dialogue among communities and with government planners, development agencies, researchers, and technical experts: encourage community participation in decision-making; coordinating local, regional and national development ts for increased effectiveness; and help agricultural researchers, technicians, farmers others in sharing information. Intern can also give a vast global information resource.

vards sustainable development

he aquaculture sector of developing countries are under tremendous pressure due e increasing market orientation of aquaculture of trade, the emergence of global kets and competition and increasing concern about food and environment.

iversification and intensification are some of the key factors for sustainable culture development and therefore the regular information flow among farming munities, technical and marketing resources and other supplying institutions is a t for steady growth in the farm economy. Small-holder farm families comprising majority of farming families are facing increased pressure to respond changing ket demands and to adopt latest technological innovations. The agricultural sions and transactions in the developed world are now manipulated through digital vorks. The internet and mobile telephones in particular, are used by governments rovide services to citizens (e-government) and to provide a platform for citizens to ract with fellow citizens as well as experts.

-governence can make governance more efficient and more effective by improving ernmental process (e-administration), connecting citizens (e-citizens and e-services) building external interactions (e-society). E-citizens, e-services and e-society are tively new inclusions within the e-governance, as they rely on the new Information Communication Technologies (ICT). Access to information is clearly a key erminant for maintaining a successful farming business .

ublic extension systems require a paradigm shift from top-down, blanket semination of technological packages, towards providing producers with the owledge and understanding with which they solve their own location-specific blems. Aquaculture is one of the fastest developing industries and there is an reasing need in proper information, technologies, and farming techniques semination, such as the Code of Good Management Conduct in Aquaculture. Lack communication facilities in communities inhibits the social political and economic powerment of the majority of the population.

Extension today has to assume multiple roles of providing information about hnologies, prices and market, policies; organizing farmers for exchange of ormation, facilitating learning from experiences; provide problem solving nsultancy in serve the farming community.

Farmers now need quality information about technological options in farming to duce and participate better in markets. They need to know not only market prices also trends about market prices to plan cultivation. To make information transfer re effective, greater use will need to be made of modern information technology d communication among researchers, extensionists and farmers.

APPENDIX I

ICAR Institutes, National bureaux, Project directorates and National research centres

NATIONAL INSTITUTES

- Indian Agricultural Research Institute
Pusa, New Delhi 110 012
- Indian Veterinary Research Institute
Izatnagar (Uttar Pradesh) 243 122
- National Dairy Research Institute
Karnal (Haryana) 132 001
- Central Institute of Fisheries Education
Off Yari Road, Andheri (West)
Mumbai (Maharashtra) 400 061
- National Academy of Agricultural Research and Management
Rajendranagar, Hyderabad
(Andhra Pradesh) 500 030

OTHER INSTITUTES

Agricultural Sciences

- Central Agricultural Research Institute
PB 181, Port Blair
(Andaman and Nicobar Islands) 744 101
- Central Arid Zone Research Institute
Jodhpur (Rajasthan) 342 003
- Central Institute of Agricultural Engineering
Berasia Road, Nabi Bagh
Bhopal (Madhya Pradesh) 462 038
- Central Institute of Arid Horticulture
Bikaner (Rajasthan) 334 006
- Central Institute for Cotton Research
Shankar Nagar, Nagpur (Maharashtra) 440 010
- Central Institute for Sub-tropical Horticulture, Rehmankhera, PO Kakori
Lucknow (Uttar Pradesh) 227 107
- Central Institute of Temperate Horticulture
Old Air Field, Rangreth (Jammu and Kashmir) 190 007
- Central Institute of Post-harvest Engineering and Technology
Ludhiana (Punjab) 141 004
- Central Institute for Research on Cotton Technology
PB 16640, Adenwala Road, Matunga
Mumbai (Maharashtra) 400 019
- Central Plantation Crops Research Institute
Kasaragod (Kerala) 671 124
- Central Potato Research Institute
Shimla (Himachal Pradesh) 171 001
- Central Research Institute for Dryland Agriculture
Santoshnagar, P O Saidabad
Hyderabad (Andhra Pradesh) 500 059
- Central Research Institute for Jute and Allied Fibres
Barrackpore, 24 Paraganas
(West Bengal) 700 120
- Central Rice Research Institute
Cuttack (Odisha) 753 006
- Central Soil Salinity Research Institute
Zarifa Farm, Kachwa Road, Karnal
(Haryana) 132 001
- Central Soil and Water Conservation Research and Training Institute
218 Kaulagarh Road, Dehra Dun
(Uttarakhand) 248 195
- Central Tobacco Research Institute
Rajahmundry (Andhra Pradesh) 533 105
- Central Tuber Crops Research Institute
PB 3502, Sreekariyam
Thiruvananthapuram (Kerala) 695 017
- ICAR Research Complex for Goa
Ela, Old Goa (Goa) 403 402
- ICAR Research Complex for Eastern Region, Patna (Bihar) 800 014
- ICAR Research Complex for North-Eastern Hill Region
Umiam (Meghalaya) 793 103
- Indian Agricultural Statistics Research Institute, Library Avenue, Pusa Campus
New Delhi 110 012
- Indian Grassland and Fodder Research Institute, Pahuj Dam, Jhansi
(Uttar Pradesh) 284 003
- Indian Institute of Horticultural Research
P O Hessaraghatta Lake
Bengaluru (Karnataka) 560 089
- Indian Institute of Pulses Research
Kanpur (Uttar Pradesh) 208 024
- Indian Institute of Soil Science
Nabi Bagh, Bhopal (Madhya Pradesh) 462 038
- Indian Institute of Spices Research
P B 1701, P O Marikunnu
Kozhikode (Kerala) 673 012
- Indian Institute of Sugarcane Research
P O Dilkusha, Lucknow (Uttar Pradesh) 226 002
- Indian Institute of Natural Resins and Gums
Namkum, Ranchi (Jharkhand) 834 010
- Indian Institute of Vegetable Research
P.B. 01, P.O. Jakhini, Varanasi (Uttar Pradesh) 221 305

ational Institute of Research on Jute and
lied Fibre Technology
Reagent Park, Kolkata (West Bengal)
0 040
ational Institute of Abiotic Stress
anagement
alegaon, Baramati, Pune (Maharashtra)
3 115
ugarcane Breeding Institute
oimbatore (Tamil Nadu) 641 007
vekananda Parvatiya Krishi Anusandhan
ansthan
mora (Uttar Pradesh) 263 601

al Sciences

entral Avian Research Institute, Izatnagar
ttar Pradesh) 243 122
entral Institute for Research on Buffaloes
rsa Road, Hisar (Haryana) 125 001
entral Institute for Research on Goats
akhdoom, Mathura (Uttar Pradesh)
31 122
entral Sheep and Wool Research Institute
vikanagar, District Tonk
a Jaipur (Rajasthan) 304 501
ational Institute of Animal Nutrition and
hysiology
dugodi, Bengaluru (Karnataka) 560 030

eries

entral Inland Fisheries Research Institute
arrackpore (West Bengal) 743 101
entral Institute of Brackishwater
quaculture
A Puram, Chennai (Tamil Nadu)
00 028
entral Institute of Fisheries Technology
Villingdon Island, P O Matsyapuri
Kochi (Kerala) 682 029
entral Institute of Freshwater Aquaculture
Kausalyaganga, Bhubaneshwar (Odisha)
51 002
entral Marine Fisheries Research Institute
B 1603, Kochi (Kerala) 682 018

IONAL BUREAUX

cultural Sciences

National Bureau of Agriculturally
mportant Insects
PB 2491, H A Farm, Hebbal
Bengaluru (Karnataka) 560 024
National Bureau of Agriculturally
mportant Micro-organisms, P B No. 6
Kusmaur
Mau Nath Bhanjan (Uttar Pradesh)
275 101

- National Bureau of Plant Genetic Resources
  Pusa Campus, New Delhi 110 012
- National Bureau of Soil Survey and Land
  Use Planning
  Shankar Nagar, Nagpur
  (Maharashtra) 440 010

Animal Sciences

- National Bureau of Animal Genetic
  Resources
  P B 129, Karnal (Haryana) 132 001

Fisheries

- National Bureau of Fish Genetic Resources
  P O Dilkusha, Lucknow
  (Uttar Pradesh) 226 002

**PROJECT DIRECTORATES/
DIRECTORATES**

Agricultural Sciences

- Project Directorate of Farming Systems
  Research
  Modipuram, Meerut
  (Uttar Pradesh) 250 110
- Directorate of Groundnut Research
  P B 5, Junagadh (Gujarat) 362 001
- Directorate of Knowledge Management in
  Agriculture
  KAB I, Pusa, New Delhi 110 012
- Directorate of Maize Research
  Pusa Campus, New Delhi 110 012
- Directorate of Oilpalm Research
  Pedavegi (Andhra Pradesh) 534 450
- Directorate of Oilseeds Research
  Hyderabad (Andhra Pradesh) 500 030
- Directorate of Rapeseed-Mustard Research
  P B 41, Bharatpur (Rajasthan) 321 303
- Directorate of Rice Research
  Hyderabad (Andhra Pradesh) 500 030
- Directorate of Seed Research
  Kusmaur, Mau Nath Bhanjan (Uttar
  Pradesh) 275 101
- Directorate of Sorghum Research
  Rajendranagar, Hyderabad (Andhra
  Pradesh) 500 030
- Directorate of Soybean Research
  Bhawerkua Farm, Khandwa Road
  Indore (Madhya Pradesh) 452 001
- Directorate of Wheat Research
  P B 158, Kunjpura Road, Karnal
  (Haryana) 132 001
- Directorate of Weed Science Research
  Maharajpur, Adhartal
  Jabalpur (Madhya Pradesh) 482 004
- Directorate of Water Management
  Chandrasekharpur, Bhubaneshwar
  (Odisha) 751 023

- Directorate of Research on Women in
  Agriculture
  Baramunda
  Bhubaneshwar (Odisha) 751 003
- Directorate of Cashew Research
  Kamminje, Puttur (Karnataka) 574 202
- Directorate of Floricultural Research
  IARI Campus, Pusa, New Delhi 110 012
- Directorate of Medicinal and Aromatic
  Plants Research
  Boriavi, Anand (Gujarat) 387 310
- Project Directorate of Mushroom Research
  Chambaghat, Solan (Himachal Pradesh)
  173 213
- Project Directorate on Onion and Garlic
  Research
  Rajguru Nagar, Pune (Maharashtra)
  410 505

Animal Sciences

- Project Directorate on Animal Disease
  Monitoring and Surveillance
  Hebbal, Bengaluru (Karnataka) 560 024
- Project Directorate on Cattle
  Grass Farm Road, PB 17
  Meerut (Uttar Pradesh) 250 001
- Project Directorate on Foot and Mouth
  Disease
  IVRI Campus, Mukteshwar
  Kumaon (Uttarakhand) 263 138
- Project Directorate on Poultry
  Rajendranagar, Hyderabad (Andhra
  Pradesh) 500 030

Fisheries

- Directorate of Coldwater Fisheries
  Research
  Bhimtal (Uttarakhand) 263 136

NATIONAL RESEARCH CENTRES

Agricultural Sciences

- National Centre for Agricultural
  Economics and Policy Research
  DPS Marg, Pusa, New Delhi 110 012
- National Research Centre for Agroforestry
  IGFRI Campus, Pahuj Dam
  Jhansi (Uttar Pradesh) 284 003
- National Research Centre for Banana
  Thiruchirapalli (Tamil Nadu) 620 102
- National Research Centre for Citrus
  P B 464, P O Shankar Nagar
  Nagpur (Maharashtra) 440 010
- National Research Centre for Grapes
  P B No. 3, Manjri Farm Post
  Pune (Maharashtra) 412 307
- National Research Centre for Integrated
  Pest Management
  Lal Bahadur Shastri Building
  IARI Campus, Pusa, New Delhi 110 012
- National Research Centre for Litchi
  Manchi House, Muzaffarpur (Bihar)
  842 002
- National Research Centre for Orchids
  Pakyang (Sikkim) 737 106
- National Research Centre for Plant
  Biotechnology
  Indian Agricultural Research Institute
  Pusa, New Delhi 110 012
- National Research Centre on Pomegranate
  Shelgi, Solapur (Maharashtra) 413 006
- National Research Centre for Seed Spices
  Tabiji, Ajmer (Rajasthan) 305 206

Animal Sciences

- National Research Centre on Camel
  Jorbeer, P B 07, Bikaner (Rajasthan)
  334 001
- National Research Centre for Equines
  Sirsa Road, Hisar (Haryana) 125 001
- National Research Centre on Meat
  Hyderabad (Andhra Pradesh) 500 039
- National Research Centre for Mithun
  Jharnapani, Medziphema
  (Nagaland) 797 106
- National Research Centre for Pigs
  Panjabari Road, 6th Mile, Guwahati
  (Asom) 785 037
- National Research Centre on Yak
  West Kemeng, Dirang
  (Arunachal Pradesh) 790 101

APPENDIX II

icultural/Horticultural/Veterinary and Animal Sciences/Fisheries Universities and Central Universities with agriculture faculty

ultural Universities

harya N G Ranga Agricultural
versity
jendranagar
derabad (Andhra Pradesh) 500 030
and Agricultural University
and (Gujarat) 388 110
sam Agricultural University
hat (Asom) 785 013
han Chandra Krishi Vishwavidyalaya
hanpur, Nadia (West Bengal) 741 252
ar Agricultural University
pour, Bhagalpur (Bihar) 813 210
sa Agricultural University
nchi (Jharkhand) 834 006
andra Shekhar Azad University of
riculture and Technology, Kanpur (Uttar
desh) 208 002
audhary Charan Singh Haryana
ricultural University, Hisar (Haryana)
5 004
Sarwan Kumar Krishi Vishwavidyalaya
ampur (Himachal Pradesh) 176 062
Balasahib Sawant Konkan Krishi
yapeeth
poli (Maharashtra) 415 712
Panjabrao Deshmukh Krishi
yapeeth
ola (Maharashtra) 444 104
vind Ballabh Pant University of
riculture and Technology, Pantnagar
tarakhand) 263 145
ira Gandhi Krishi Vishwavidyalaya
pur (Chhattisgarh) 492 012
waharlal Nehru Krishi Vishwa Vidyalaya
balpur (Madhya Pradesh) 482 004
nagadh Agricultural University
nagadh (Gujarat) 362 001
rala Agricultural University
lanikkara, Thrissur (Kerala) 680 656
harana Pratap University of Agriculture
d Technology, Udaipur (Rajasthan)
3 001
hatma Phule Krishi Vidyapeeth
huri (Maharashtra) 413 722
rathwada Agricultural University
rbhani (Maharashtra) 431 402
rendra Deva University of Agriculture
d Technology, Faizabad
ttar Pradesh) 224 229

- Navsari Agricultural University
  Navsari (Gujarat) 396 450
- Orissa University of Agriculture and Technology
  Bhubaneshwar (Odisha) 751 003
- Punjab Agricultural University
  Ludhiana (Punjab) 141 004
- Rajamata Vijayaraje Scindia Krishi Vishwa Vidyalaya
  Gwalior (Madhya Pradesh) 474 002
- Rajendra Agricultural University
  Samastipur, Pusa (Bihar) 848 125
- Sardarkrushinagar-Dantiwada Agricultural University
  Dantiwada (Gujarat) 385 506
- Sardar Ballabh Bhai Patel University of Agriculture and Technology, Modipuram
  Meerut (Uttar Pradesh) 250 110
- Sher-e-Kashmir University of Agricultural Sciences and Technology, Srinagar
  (Jammu and Kashmir) 191 121
- Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, PB 37, Jammu
  (Jammu and Kashmir) 180 009
- Swami Keshavanand Rajasthan Agriculture University, Bikaner
  (Rajasthan) 334 006
- Tamil Nadu Agricultural University
  Coimbatore (Tamil Nadu) 641 003
- University of Agricultural Sciences
  GKVK, Bengaluru (Karnataka) 560 065
- University of Agricultural Sciences
  Dharwad (Karnataka) 580 005
- University of Agricultural Sciences
  Raichur (Karnataka) 584 101
- Uttar Banga Krishi Vishwavidyalaya
  Pundibari, Cooch Bihar
  (West Bengal) 736 165

Horticultural Universities

- Andhra Pradesh Horticulture University
  Tadepalligudam
  (Andhra Pradesh) 534 101
- Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Distt Solan (Himachal Pradesh) 173 230
- University of Horticultural Sciences
  Bagalkot (Karnataka) 587 102

Veterinary and Animal Sciences/Fisheries Universities

- Guru Angad Dev Veterinary and Animal Sciences University, Firozepur Road
  Ludhiana (Punjab) 141 004
- Karnataka Veterinary, Animal and Fisheries Sciences University
  Bidar (Karnataka) 585 401
- Kerala Veterinary and Animal Sciences University
  Pookot, Wayanad (Kerala) 673 576
- Madhya Pradesh Pashu Chikitsa Vigyan Vishwavidyalaya, Jabalpur
  (Madhya Pradesh) 482 004
- Maharashtra Animal Sciences and Fisheries University, Nagpur (Maharashtra) 440 006
- Rajasthan University of Veterinary and Animal Sciences,
  Bikaner (Rajasthan) 334 006
- Sri Venkateswara Veterinary University
  Tirupati (Andhra Pradesh) 517 502
- Tamil Nadu Veterinary and Animal Sciences University, Chennai (Tamil Nadu) 600 051
- UP Deen Dayal Upadhyaya Veterinary and Animal Sciences University, Mathura
  (Uttar Pradesh) 281 001
- West Bengal University of Animal and Fishery Sciences, Kolkata
  (West Bengal) 700 037
- Kerala University of Fisheries and Ocean Studies
  Panangad, Kochi (Kerala) 682 506

Central Agricultural University

- Central Agricultural University
  Imphal (Manipur) 795 004

Central Universities (with Agriculture Faculty)

- Aligarh Muslim University
  Aligarh (Uttar Pradesh) 202 002
- Banaras Hindu University
  Varanasi (Uttar Pradesh) 221 005
- Visva Bharati University
  Shantiniketan (West Bengal) 731 236
- Nagaland University
  Medziphema (Nagaland) 797 106

Deemed-to-be Universities

- Indian Agricultural Research Institute
  Pusa, New Delhi 110 012
- Indian Veterinary Research Institute
  Izatnagar (Uttar Pradesh) 243 122
- National Dairy Research Institute
  Karnal (Haryana) 132 001
- Central Institute of Fisheries Education
  Andheri (West), Mumbai
  (Maharashtra) 400 061
- Sam Higginbottom Institute of Agriculture, Technology and Sciences (formerly Allahabad Agricultural Institute), Rewa Road, Naini, Allahabad
  (Uttar Pradesh) 211 007

APPENDIX III

Fisheries colleges and institutions under the National Agricultural Research System

Sl No.	Name of the college / institute	Annual intake capacity		
		Bachelor's	Master's	Doctoral
	College of Fishery Science (Sri Venkateswara Veterinary University),Muthukur 524 344, Nellore District, Andhra PradeshTel: 0861-2377477; Fax: 0877-2242786	30	10	-
	College of Fisheries (Assam Agricultural University) Raha 782 103, Nagaon District, Asom Tel: 03672-285719; Fax: 03672-285719	20	-	-
	College of Fisheries (Rajendra Agricultural University) Dholi, Muzaffarpur 843 121, Bihar Tel: 0621-229318	13	-	-
	College of Fisheries (Indira Gandhi Krishi Vishwavidyalaya), Kawardha 491 995, Chhattisgarh Tel: 07741-232066	38	08	-
	College of Fisheries (Junagadh Agricultural University) Rajendra Bhavan Road, Veraval 362 265, Gujarat Tel : 02876-221053; Fax: 02876-242052	24	-	-
	College of Fisheries (Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir), P.O. Box:1079 GPO, Srinagar 191 212, Jammu and Kashmir Tel & Fax: 0194-2262214	20	09	03
	College of Fisheries (Karnataka Veterinary, Animal and Fisheries Sciences University), Matsyanagar, Kankanady (P.O), Mangalore 575 002, Karnataka Tel: 0824-2248936; Fax: 0824-2248336	40	20	14
	College of Fisheries [Kerala University of Fisheries and Ocean Studies (KUFOS, Kochi)], Panangad, Kochi 682 506, Kerala Tel: 0484-2700598/2703781; Fax: 0484-2700337	50	14	04
	College of Fisheries (Dr Balasaheb Sawant Konkan Krishi Vidyapeeth), Shirgaon, Ratnagiri 415 629, Maharashtra Tel: 02352-232241, 232678, 232987; Fax: 02352-232241	40	28	05
	College of Fishery Sciences (Maharashtra Animal and Fishery Sciences University), Telangkhedi, Nagpur 440 001, Maharashtra Tel: 0712-2511784; Fax: 0712-2511282	32	-	-
	College of Fisheries (Maharashtra Animal and Fisheries Science University), Latur 413 517, Udgir, Maharashtra	32	-	-
	College of Fisheries (Orissa University of Agriculture and Technology), Rangailunda, Berhampur, Ganjam 760 007, Odisha Tel: 0680-2242235	48	10	02
13.	College of Fisheries (Guru Angad Dev Veterinary and Animal Sciences University), Ludhiana 141 004, Punjab Tel: 0161-2414061; Fax: 0161-2414054	18	05	02
14.	College of Fisheries (Maharana Pratap University of Agriculture and Technology), P.O.Box 171, Udaipur 313 001, Rajasthan Tel: 0294-2471101; Fax: 0294-2470682	30	10	03
15.	Fisheries College and Research Institute (Tamil Nadu Veterinary and Animal Sciences University) Thoothukudi 628 008, Tamil Nadu Tel: 0461 – 2340154; Fax: 0461-2340574	30	21	15
16.	College of Fisheries (Central Agricultural University), P.O. Box 120, Lembucherra, Agartala 799 210, Tripura Tel: 0381-2865264, 2865291; Fax: 0381-2865291	33	10	-
17.	College of Fishery Science (Govind Ballabh Pant University of Agriculture and Technology), Udham Singh Nagar, Pantanagar 263 145, Uttarakhand Tel: 05944-233376; Fax: 05944-233377	25	12	03
18.	College of Fisheries (Narendra Deva University of Agriculture and Technology), Kumarganj, Narendra Nagar, Faizabad 224 229, Uttar Pradesh Tel: 05270-262117	15	-	-
19.	College of Fisheries Science (West Bengal University of Animal and Fishery Sciences), Mohanpur Campus P.O. 741 252, West Bengal Telefax: 033-24328763	32	20	03
20.	Central Institute of Fisheries Education (Deemed University), Mumbai 400 061, Maharashtra Tel: 022-26363404, Fax: 022-26361656	-	69	39
	Total Seats	570	250	93

APPENDIX IV

Important websites related to fisheries and aquaculture

ian Fisheries Society
p://www.asianfisheriessociety.org

rcode of Life Data Systems (BOLD)
vw.boldsystems.org

y of Bengal Programme (BoBP), Chennai
p://www.bobpigo.org

lifomia Academy of Science (for Catalog of the Species of fishes by William N. Eschmeyer *et*
)
p://www.calacademy.org/research/ichthyology/species/

mmonwealth Scientific and Industrial Research Organization (CSIRO), Australia
p://www.csiro.au/

nsortium for the Barcode of Life (cBOL/iBOL)
p://www.barcodeoflife.org/, http://ibol.org

partment of Biotechnology (DBT), Government of India
p://www.dbtindia.nic.in/

nistry of Earth Sciences (MoES), Government of India
o://dod.nic.in/

h Barcode of Life Initiative (FISH-BOL)
vw.fishbol.org

h Base
o://www.fishbase.org/

hery Survey of India
o://fsi.gov.in

od and Agriculture Organization of the United Nations (FAO)
o://www.fao.org/

ian Council of Agricultural Research (ICAR)
o://www.icar.org.in/

ernational Coral Reef Action Network (ICRAN)
o://www.icran.org/

rine Products Export Development Authority (MPEDA), Government of India
o://www.mpeda.com/

tional Bank for Agriculture and Rural Development (NABARD)
o://www.nabard.org/

tional Centre for Biotechnology Information
o://www.ncbi.nlm.nih.gov/

National Centre for Cold Chain Development (NCCD), Gurgaon, Haryana
http://nhb.gov.in

National Centre for Sustainable Coastal Management (NCSCM)
http://ncscm.org

National Institute of Oceanography, Goa
http://www.nio.org/

National Marine Fisheries Service (NMFS), USA
http://www.nmfs.noaa.gov/

Network of Aquaculture Centres in Asia-Pacific (NACA)
http://www.enaca.org/

Rajiv Gandhi Centre for Aquaculture (RGCA)
rgcaho@gmail.com

ReefBase
http://www.reefbase.org/

Society of Integrated Coastal Management (SICOM), New Delhi
http://sicommoef.in

Southeast Asian Fisheries Development Centre (SEAFDEC)
http://www.seafdec.org/

World Aquaculture Society
http://www.was.org/

World Fish Centre
http://www.worldfishcenter.org/

Zoological Survey of India (ZSI), Kolkata
http://zsi.gov.in

APPENDIX V

Important journals in fisheries and aquaculture

vances in Marine Biology
mal Genetics
plied and Environmental Microbiology
uaculture
uaculture and Fisheries Management
uaculture Engineering
uaculture International
uaculture Nutrition
uaculture Research
uatic Biology
uatic Botany
uatic Conservation: Marine and Freshwater Ecosystems
uatic Living Resources
uatic Microbial Ecology
uatic Sciences
uatic Toxicology
an Fisheries Science
C Biotechnology
C Genetics
C Genomics
chemical Genetics
chemical Systematics and Ecology
diversity and Conservation
logical Journal of the Linnaean Society
nadian Journal of Botany
nadian Journal of Fisheries and Aquatic Sciences
nadian Journal of Microbiology
mate Research
matic Change
mparative Biochemistry and Physiology – A, B, C
astal Aquaculture
nservation Biology
nservation Genetics
nservation Genetics Resources
peia
ral Reefs
tical Reviews in Biochemistry and Molecular Biology
Crustaceana
Crustacean Research
Cryobiology
Cryogenics
Cryoletters
Current Biology
Current Science
DNA Sequence
Ecological Monograph
Ecological Research
Ecology
Environment Biology of Fishes
Estuaries
Estuarine Coastal and Shelf Science
European Journal of Phycology
Fish and Fisheries Research
Fish and Shellfish Immunology
Fish Pathology
Fish Physiology and Biochemistry
Fisheries Management
Fisheries Management and Ecology
Fisheries Oceanography
Fisheries Research
Fisheries Science
Fishery Technology
Genetica
Genome
Hydrobiologia
Ichthyological Exploration of Freshwaters
Indian Journal of Animal Nutrition
The Indian Journal of Animal Sciences
Indian Journal of Biotechnology
Indian Journal of Ecology
Indian Journal of Experimental Biology
Indian Journal of Fisheries
Indian Journal of Geo-Marine Sciences
Indian Journal of Microbiology
International Journal of Ecology and Environment Sciences
International Journal of Food Microbiology
International Journal of Food Science and Nutrition
Israeli Journal of Aquaculture - Bamidgeh
Journal of Applied Aquaculture
Journal of Applied Ichthyology
Journal of Applied Microbiology
Journal of Applied Phycology
Journal of Aquaculture
Journal of Aquatic Animal Health
Journal of Biotechnology
Journal of Bombay Natural History Society
Journal of Coastal Research
Journal of Crustacean Biology
Journal of Environmental Biology
Journal of Experimental Marine Biology and Ecology
Journal of Fish Biology
Journal of Fish Diseases
Journal of Fisheries Economics and Development
Journal of Genetics
Journal of Inland Fisheries Society of India
Journal of Marine Biological Association of India
Journal of Marine Biological Association, UK
Journal of Marine Systems
Journal of Plankton Research
Journal of Phycology
Journal of Shellfish Research
Journal of Threatened Taxa
Journal of Tropical Aquaculture
Journal of World Aquaculture Society
Lakes and Reservoirs and Management
Limnology and Oceanography
Marine and Freshwater Research
Marine Biology
Marine Biology Research
Marine Biotechnology
Marine Ecology Progressive Series
Marine Environmental Research
Marine Pollution Bulletin
Molecular Biology Reports
Molecular Ecology
Molecular Ecology Resources
Molecular Evolution and Phylogenetics
New Zealand Journal of Marine and Freshwater Research
North American Journal of Fisheries Management
Ocean and Coastal Management
Oceanography and Marine Biology
Oceanologia
Ocean Science Journal
Phycological Research
Proceedings of National Academy of Sciences, USA
Raffles Bulletin of Zoology
Reviews in Fish Biology and Fisheries
Transactions of American Fisheries Society
Trends in Ecology and Evolution
Zoological Studies
Zootaxa

APPENDIX VI

Marine fisheries resources – coastal states and union territories

e	Approximate length of coast line (km)	Continental shelf ('000 km²)	Number of landing centres	Number of fishing villages
ra Pradesh	974	33	508	508
	104	10	88	72
rat	1,600	184	286	851
ataka	300	27	29	221
la	590	40	226	222
arashtra	720	112	184	395
ha	480	26	63	329
il Nadu	1,076	41	362	446
t Bengal	158	17	65	652
aman and cobar Islands	1,912	35	57	45
an and Diu	27	–	7	31
shadweep	132	4	11	10
ucherry	45	1	28	45
tal	8,118	530	1,914	3,827

APPENDIX VII

Growth in export of Indian marine products during 1961-62 to 2010-11

Year	Quantity (tonnes)	Value (₹ crore)
1961–62	15,732	3.92
1962–63	11,161	4.20
1963–64	19,057	6.09
1964–65	21,122	7.14
1965–66	15,295	7.06
1966–67	21,116	17.37
1967–68	21,907	19.72
1968–69	26,811	24.70
1969–70	31,695	33.46
1970–71	35,883	35.07
1971–72	35,523	44.55
1972–73	38,903	59.72
1973–74	52,279	89.51
1974–75	45,099	68.41
1975–76	54,463	124.53
1976–77	66,750	189.12
1977–78	56,967	180.12
1978–79	86,894	234.62
1979–80	86,401	248.82
1980–81	75,591	234.84
1981–82	70,105	286.01
1982–83	78,175	361.36
1983–84	92,187	373.02
1984–85	86,187	384.29
1985–86	83,651	398.00
1986–87	85,843	460.67
1987–88	97,179	531.20
1988–89	99,777	597.85
1989–90	110,843	634.99
1990–91	139,419	893.37
1991–92	171,820	1,375.89
1992–93	209,025	1,768.56
1993–94	243,960	2,503.62
1994–95	307,337	3,575.27
1995–96	296,277	3,501.11
1996–97	378,199	4,121.36
1997–98	385,818	4,697.48
1998–99	302,934	4,626.87
1999–00	343,031	5,116.67
2000–01	440,473	6,443.89
2001–02	424,470	5,957.05
2002–03	467,297	6,881.31
2003–04	412,017	6,091.95
2004–05	461,329	6,646.69
2005–06	512,164	7,245.30
2006–07	612,641	8,363.53
2007–08	541,701	7,620.92
2008–09	602,835	8,607.94
2009–10	678,436	10,048.52
2010–11	802,861	12,755.02

Source: MPEDA, Kochi.

APPENDIX VIII

Inland fisheries resources—states and union territories

State/Union Territory	Rivers and canals (km)	Reservoirs (lakh ha)	Tanks and ponds (lakh ha)	Floodplain lakes and derelict waters (lakh ha)	Brackish-water (lakh ha)	Total water-bodies (lakh ha)
Andhra Pradesh	11,514	2.34	5.17	–	0.60	8.11
Arunachal Pradesh	2,000	–	2.76	0.42	–	3.18
Asom	4,820	0.022	0.23	1.10	–	1.35
Bihar	3,200	0.60	0.95	0.05	–	1.60
Goa	250	0.03	0.03	–	–	0.06
Gujarat	3,865	2.43	0.71	0.02	1.00	4.26
Haryana	5,000	Neg.	0.10	0.10	–	0.20
Himachal Pradesh	3,000	0.42	0.01	–	–	0.43
Jammu and Kashmir	27,781	0.07	0.17	0.06	–	0.30
Karnataka	9,000	4.40	2.90	–	0.10	7.40
Kerala	3,092	0.30	0.30	2.43	2.40	5.43
Madhya Pradesh	17,088	2.27	0.60	–	–	2.87
Maharashtra	16,000	2.79	0.59	–	0.10	3.48
Manipur	3,360	0.01	0.05	0.04	–	0.10
Meghalaya	5,600	0.08	0.02	–	–	0.10
Mizoram	1,395	–	0.02	–	–	0.02
Nagaland	1,600	0.17	0.50	–	–	0.67
Odisha	4,500	2.56	1.14	1.80	4.30	9.80
Punjab	15,270	Neg.	0.07	–	–	0.07
Rajasthan	5,290	1.20	1.80	–	–	3.00
Sikkim	900	–	–	0.03	–	0.03
Tamil Nadu	7,420	5.70	0.56	0.07	0.60	6.93
Tripura	1,200	0.05	0.13	–	–	0.18
Uttar Pradesh	28,500	1.38	1.61	1.33	–	4.32
West Bengal	2,526	0.17	2.76	0.42	2.10	5.45
A and N Islands	115	0.01	0.03	–	1.20	1.24
Chandigarh	2	–	–	–	–	–
Dadra and Nagar Haveli	54	0.05	–	–	–	0.05
Daman and Diu	12	–	–	–	–	–
Delhi	150	0.04	–	–	–	0.04
Lakshadweep	–	–	–	–	–	–
Puducherry	247	–	–	0.01	–	0.01
Chhattisgarh	3,573	0.84	0.63	–	–	1.47
Uttarakhand	2,686	0.20	0.01	–	–	0.21
Jharkhand	4,200	0.94	0.29	–	–	1.23
Total	195,210	29.07	24.14	7.98	12.40	73.59

APPENDIX IX

Fish production in India for the period 1950–51 to 2009–10 ('000 tonnes)

Year	Marine	Inland	Total
1950-51	534	218	752
1955-56	596	243	839
1960-61	880	280	1,160
1965-66	824	507	1,331
1970-71	1,086	670	1,756
1973-74	1,210	748	1,958
1980-81	1,555	887	2,442
1981-82	1,445	999	2,444
1982-83	1,427	940	2,367
1983-84	1,519	987	2,506
1984-85	1,698	1,103	2,801
1985-86	1,716	1,160	2,876
1986-87	1,713	1,229	2,942
1987-88	1,658	1,301	2,959
1988-89	1,817	1,335	3,152
1989-90	2,275	1,402	3,677
1990-91	2,300	1,536	3,836
1991-92	2,447	1,710	4,157
1992-93	2,576	1,789	4,365
1993-94	2,649	1,995	4,644
1994-95	2,692	2,097	4,789
1995-96	2,707	2,242	4,949
1996-97	2,967	2,381	5,348
1997-98	2,950	2,438	5,388
1998-99	2,696	2,602	5,298
1999-00	2,852	2,823	5,675
2000-01	2,811	2,845	5,656
2001-02	2,830	3,126	5,956
2002-03	2,990	3,210	6,200
2003-04	2,941	3,458	6,399
2004-05	2,778	3,526	6,304
2005-06	2,816	3,756	6,572
2006-07	3,024	3,845	6,869
2007-08	2,920	4,207	7,127
2008-09	2,978	4,659	7,637
2009-10	3,070	4,930	8,000

APPENDIX X

State-wise fish production during 2008–09 ('000 tonnes)

State/Union Territory	Marine	Inland	Total
Andhra Pradesh	291.16	961.62	1,252.78
Arunachal Pradesh	–	2.88	2.88
Asom	–	206.15	206.15
Bihar	–	300.65	300.65
Goa	82.95	2.28	85.23
Gujarat	623.05	142.85	765.90
Haryana	–	76.28	76.28
Himachal Pradesh	–	7.79	7.79
Jammu and Kashmir	–	19.27	19.27
Karnataka	218.14	143.00	361.14
Kerala	583.58	82.57	666.15
Madhya Pradesh	–	68.46	68.46
Maharashtra	395.96	127.14	523.10
Manipur	–	18.80	18.80
Meghalaya	–	3.96	3.96
Mizoram	–	3.76	3.76
Nagaland	–	6.17	6.17
Odisha	135.49	235.97	371.46
Punjab	–	104.77	104.77
Rajasthan	–	25.70	25.70
Sikkim	–	0.17	0.17
Tamil Nadu	365.28	168.88	534.16
Tripura	–	36.00	36.00
Uttar Pradesh	–	349.27	349.27
West Bengal	186.79	1,323.12	1,509.91
A and N Islands	32.79	0.16	32.95
Chandigarh	–	0.24	0.24
Dadra and Nagar Haveli	–	0.05	0.05
Daman and Diu	14.06	0.08	14.14
Delhi	–	0.51	0.51
Lakshadweep	11.59	–	11.59
Puducherry	36.55	3.30	39.85
Chhattisgarh	–	158.70	158.70
Uttarakhand	–	3.16	3.16
Jharkhand	–	75.82	75.82
Total	2,977.38	4,659.59	7,636.97

APPENDIX VIII

Inland fisheries resources–states and union territories

State/Union Territory	Rivers and canals (km)	Reservoirs (lakh ha)	Tanks and ponds (lakh ha)	Floodplain lakes and derelict waters (lakh ha)	Brackish-water (lakh ha)	Total water-bodies (lakh ha)
Andhra Pradesh	11,514	2.34	5.17	–	0.60	8.11
Arunachal Pradesh	2,000	–	2.76	0.42	–	3.18
Asom	4,820	0.022	0.23	1.10	–	1.35
Bihar	3,200	0.60	0.95	0.05	–	1.60
Goa	250	0.03	0.03	–	–	0.06
Gujarat	3,865	2.43	0.71	0.02	1.00	4.26
Haryana	5,000	Neg.	0.10	0.10	–	0.20
Himachal Pradesh	3,000	0.42	0.01	–	–	0.43
Jammu and Kashmir	27,781	0.07	0.17	0.06	–	0.30
Karnataka	9,000	4.40	2.90	–	0.10	7.40
Kerala	3,092	0.30	0.30	2.43	2.40	5.43
Madhya Pradesh	17,088	2.27	0.60	–	–	2.87
Maharashtra	16,000	2.79	0.59	–	0.10	3.48
Manipur	3,360	0.01	0.05	0.04	–	0.10
Meghalaya	5,600	0.08	0.02	–	–	0.10
Mizoram	1,395	–	0.02	–	–	0.02
Nagaland	1,600	0.17	0.50	–	–	0.67
Odisha	4,500	2.56	1.14	1.80	4.30	9.80
Punjab	15,270	Neg.	0.07	–	–	0.07
Rajasthan	5,290	1.20	1.80	–	–	3.00
Sikkim	900	–	–	0.03	–	0.03
Tamil Nadu	7,420	5.70	0.56	0.07	0.60	6.93
Tripura	1,200	0.05	0.13	–	–	0.18
Uttar Pradesh	28,500	1.38	1.61	1.33	–	4.32
West Bengal	2,526	0.17	2.76	0.42	2.10	5.45
A and N Islands	115	0.01	0.03	–	1.20	1.24
Chandigarh	2	–	–	–	–	–
Dadra and Nagar Haveli	54	0.05	–	–	–	0.05
Daman and Diu	12	–	–	–	–	–
Delhi	150	0.04	–	–	–	0.04
Lakshadweep	–	–	–	–	–	–
Puducherry	247	–	–	0.01	–	0.01
Chhattisgarh	3,573	0.84	0.63	–	–	1.47
Uttarakhand	2,686	0.20	0.01	–	–	0.21
Jharkhand	4,200	0.94	0.29	–	–	1.23
Total	195,210	29.07	24.14	7.98	12.40	73.59

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1982-83	1,427	940	2,367
1983-84	1,519	987	2,506
1984-85	1,698	1,103	2,801
1985-86	1,716	1,160	2,876
1986-87	1,713	1,229	2,942
1987-88	1,658	1,301	2,959
1988-89	1,817	1,335	3,152
1989-90	2,275	1,402	3,677
1990-91	2,300	1,536	3,836
1991-92	2,447	1,710	4,157
1992-93	2,576	1,789	4,365
1993-94	2,649	1,995	4,644
1994-95	2,692	2,097	4,789
1995-96	2,707	2,242	4,949
1996-97	2,967	2,381	5,348
1997-98	2,950	2,438	5,388
1998-99	2,696	2,602	5,298
1999-00	2,852	2,823	5,675
2000-01	2,811	2,845	5,656
2001-02	2,830	3,126	5,956
2002-03	2,990	3,210	6,200
2003-04	2,941	3,458	6,399
2004-05	2,778	3,526	6,304
2005-06	2,816	3,756	6,572
2006-07	3,024	3,845	6,869
2007-08	2,920	4,207	7,127
2008-09	2,978	4,659	7,637
2009-10	3,070	4,930	8,000

APPENDIX X

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State/Union Territory	Marine	Inland	Total
Andhra Pradesh	291.16	961.62	1,252.78
Arunachal Pradesh	–	2.88	2.88
Asom	–	206.15	206.15
Bihar	–	300.65	300.65
Goa	82.95	2.28	85.23
Gujarat	623.05	142.85	765.90
Haryana	–	76.28	76.28
Himachal Pradesh	–	7.79	7.79
Jammu and Kashmir	–	19.27	19.27
Karnataka	218.14	143.00	361.14
Kerala	583.58	82.57	666.15
Madhya Pradesh	–	68.46	68.46
Maharashtra	395.96	127.14	523.10
Manipur	–	18.80	18.80
Meghalaya	–	3.96	3.96
Mizoram	–	3.76	3.76
Nagaland	–	6.17	6.17
Odisha	135.49	235.97	371.46
Punjab	–	104.77	104.77
Rajasthan	–	25.70	25.70
Sikkim	–	0.17	0.17
Tamil Nadu	365.28	168.88	534.16
Tripura	–	36.00	36.00
Uttar Pradesh	–	349.27	349.27
West Bengal	186.79	1,323.12	1,509.91
A and N Islands	32.79	0.16	32.95
Chandigarh	–	0.24	0.24
Dadra and Nagar Haveli	–	0.05	0.05
Daman and Diu	14.06	0.08	14.14
Delhi	–	0.51	0.51
Lakshadweep	11.59	–	11.59
Puducherry	36.55	3.30	39.85
Chhattisgarh	–	158.70	158.70
Uttarakhand	–	3.16	3.16
Jharkhand	–	75.82	75.82
Total	2,977.38	4,659.59	7,636.97

APPENDIX XI

State-wise details of shrimp production during 2009-10

ate	Area developed (ha)	Area utilized (ha)	Production (tonnes)	Productivity (MT/ha/year)
est Bengal	51,659.00	47,488.00	33,685.00	0.71
disha	13,843.00	4,769.00	6,149.00	1.29
ndhra Pradesh	58,145.20	33,754.00	39,537.00	1.17
amil Nadu	6,109.33	2,381.49	2,702.38	1.13
erala	15,099.39	9,544.84	1,581.00	1.07
arnataka	3,708.84	1,484.00	1,581.00	0.74
oa	867.00	272.00	319.00	1.17
aharashtra	1,329.56	650.86	1,243.79	1.91
ujarat	2,214.48	1,915.79	3,605.72	1.88
Total	152,975.48	102,359.98	95,918.89	0.94

APPENDIX XII

State-wise details of scampi production during 2009-10

tate	Area developed (ha)	Area utilized (ha)	Production (tonnes)	Productivity (tonnes/ha/year)
Vest Bengal	4,825.00	3,325.00	1,725.00	0.52
Odisha	3,786.00	447.61	1,724.07	3.85
ndhra Pradesh	10,913.00	2,823.00	1,759.14	0.62
amil Nadu	465.60	161.98	111.97	0.69
erala	2,594.17	1,378.83	398.74	0.29
arnataka	285.00	0.00	0.00	0.00
Goa	0.00	0.00	0.00	0.00
Maharashtra	86.49	16.58	531.00	NA
Gujarat	34.00	0.00	318.00	NA
Total	22,989.26	8,153.00	6,567.92	0.81

Source: MPEDA and Seafood Export Association of India.

APPENDIX XIII

Conversion table

	Linear measures		
1 Nautical Mile (NM)	= 1.852 Kilometres (KM)	= 1.50779 Miles	
1 Mile (mi)	= 1.60934 Kilometres	= 1760 Yards	
1 Fathom (fm)	= 1.8288 Metres	= 6 Feet	= 2 Yards
1 Yard (yd)	= 0.9144 Metre	= 36 Inches	= 3 Feet
1 Foot (ft)	= 30.48 Centimetres	= 12 Inches	
	Square measures		
1 Acre (ac)	= 4046.856 Square Metres	= 100 Cents	
1 Hectare (Ha)	= 10,000 Square Metres	= 0.01 Square Kilometre	
	Volume measures		
1 Pound (lb)	= 0.45359 Kilogram		
1 Gallon Imperial (gal)	= 4.54609 Litres		
1 Ounce (oz)	= 28.34952 Gram	= 0.0284131 Litres	
	Mass measure		
1 Metric Tonne or Tonne (t)	= 1,000 Kilogram		
	Speed measure		
1 Knot (kn)	= 1 Nautical Mile/hour	= 1.852 km/hr	
	Number systems		
1 Crore	= 100 Lakh	= 10 Million	
1 Million	= 10 Lakh	= 0.1 Crore	
1 Billion	= 100 Crore	= 1000 Million	
1 Trillion	= 1000 Billion	= 1000000 Million	

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Scientific names

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