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Aquaculture Development and the Blue Revolution

Role of Aquaculture

India is blessed with huge open-water resources – seas, rivers, lakes, reservoirs and wetlands. Aquaculture in freshwater ponds and tanks covering 2.43 million ha contributes a large share of the total fish production of 11.4 million t (approx. 60%). The country has a coastline of 8118 km and nearly 2 million sq. km of exclusive economic zone (EEZ), and 500,000 sq. km of continental shelf (IASRI, 2016). From these marine resources, India has an estimated fisheries potential of 4.21 million t. It has an extensive river and canal system consisting of 14 major rivers, 44 medium rivers and numerous small rivers and streams. India experienced a 14-fold increase in fish production in the past six-and-a-half decades.

Indian fisheries and aquaculture is an important sector of food production, providing nutritional security to the food basket, contributing to agricultural exports and engaging about 14 million people in different activities. With diverse resources ranging from deep seas to lakes in the mountains, and more than 10% of the global biodiversity in terms of fish and shellfish species, the country has shown continuous and sustained increments in fish production since its independence. Constituting about 6.3% of global fish production, the sector contributes 0.9% of GDP and 5.43% of agricultural GDP. Paradigm shifts in terms of increasing contributions from the inland sector and from aquaculture have been significant over the years. With high growth rates, the different facets of marine fisheries, coastal aquaculture, inland fisheries, freshwater aquaculture and coldwater fisheries contribute greatly to the food, health, economy, exports, employment and tourism of the country.

The 429 Fish Farmers Development Agencies (FFDAs) and 39 Brackishwater Fish Farmers Development Agencies (BFDAs) are promoting freshwater and coastal aquaculture. With annual carp seed production of 45 billion and shrimp seed of about 14 billion, the country has been largely able to satisfy the increasing demand for seed for aquaculture of carp in freshwater and shrimps in land-based coastal aquaculture. With increasing emphasis on species diversification in the recent past, there has been greater focus on development of technologies for breeding and mass-scale seed production of several freshwater, brackishwater and marine finfish and shellfish species for aquaculture in ponds and cages (Ayyappan *et al.*, 2011). Along with food-fish culture, ornamental fish culture and high-value fish farming are gaining importance.

With over 240,000 fishing craft operating around the coast, six major fishing harbours, 62 minor fishing harbours and 1511 landing centres, the needs of over 3.9 million fisherfolk are being met. Fish and fish products have emerged as the largest group in India's agricultural exports, with 1.05 million t and Rs 378.7 billion in value.

This accounts for around 10% of the total exports of the country and nearly 20% of agricultural exports. More than 50 different types of fish and shellfish products are exported to 75 countries around the world.

The aquaculture sector is recognized as the 'sunshine' sector of Indian agriculture. It helps in increasing food supply, generating adequate employment and raising nutritional levels. It has huge export potential and is a major source of foreign exchange earnings for the country. Freshwater aquaculture in India has evolved from confinement to the east-Indian states during the 1950s to the present vibrant industry that has spread over the entire country. Total fish production has experienced phenomenal increase, from 0.75 million t in 1950–51 to 10.79 million t in 2015–16. Dominance of marine-capture fishery, with 60% share of total fish production in 1990–91, has been reversed, with 7.21 million t (66.8%) now coming from inland fisheries (2015–16), of which more than 80% is from aquaculture.

The Blue Revolution

India is now predominant in aquaculture production, globally, occupying second position only after China. This quantity is almost fully consumed in the domestic market, except for shrimps and freshwater prawns, which are mainly exported. Specifically, freshwater aquaculture experienced a 15-fold growth in the past three-and-a-half decades, i.e. 0.37 million t in 1980 to about 5.7 million t at present. About 40% of the population does not eat fish, since they are vegetarian, and the remaining 60% consume fish. It has been estimated that the inland fishery resources have production potential of about 15 million t. Against this potential, the actual production was 6.58 million t in 2014–15, thus suggesting considerable scope for inland aquaculture.

The Blue Revolution, encompassing multidimensional activities, focuses mainly on increasing production from aquaculture and other fisheries resources, both inland and marine. The vast fishery resources (Table 6.1) offer immense opportunities to enhance fish production through aquaculture-system diversification, species diversification, proper management, introduction of new and advanced technologies in both the marine and inland sectors, adoption of scientific practices and application of suitable fish-health management strategies. In marine fisheries and capture fisheries, growth has proved elusive for many reasons. One reason is that marine fishing activity remains confined to coastal waters, leaving most of the EEZ, measuring 2.02 million sq. km, underexplored. The narrow coastal belt of up to 50 m depth, is being over-exploited by traditional fishermen (Ayyappan *et al.*, 2011), causing considerable depletion of fish stocks. Motorized fishing vessels are responsible for about 85% of the total marine catch, yet deep-sea fishing activity remains at low levels owing to the inadequacy of the fishing vessels.

The potential of inland aquaculture is still untapped in India, despite the fact that of the current 11.4 million t of total fish production, the inland fisheries account for two thirds of

Table 6.1. Details of fishery resources in India. (From: DAH and DF, 2016–17)

Fisheries sector	
Global position	3rd in fisheries, 2nd in aquaculture
Contribution of fisheries to GDP	0.90%
Contribution to agricultural GDP	5.43%
Per capita fish availability	9 kg
Annual export earnings	Rs 378.7 billion (US$5.78 billion)
Employment in the sector	14.5 million
Marine	
Length of coast line	8118 km
Exclusive Economic Zone (EEZ)	2.02 million sq. km
Continental shelf	530,000 sq. km
Number of fish-landing centres	1537
Number of fishing villages	3432
Inland	
Total inland water bodies	7.3 million ha
Rivers and canals	195,000 km
Reservoirs	2.9 million ha
Tanks and ponds	2.4 million ha
Floodplain lakes/derelict waters	798,000 ha
Brackishwater	1.1 million ha

that total. A small number of farmers are currently practising inland aquaculture in states such as West Bengal, Andhra Pradesh, Odisha, Assam, Punjab, Haryana and Telangana, and a Blue Revolution is occurring. By increasing the coverage of the water area and the productivity of existing bodies of water by 50%, total production could be doubled. However, there are some critical gaps that need to be addressed to achieve a true Blue Revolution.

Given that India has a large number of water bodies, reservoirs, lakes, and ponds, inland aquaculture holds the key to the Blue Revolution in the country. Fish farming will have three benefits: (i) an increase in farmers' incomes; (ii) progress in the country's exports and GDP; and (iii) ensured nutritional and food security in the country. The country has demonstrated consistent 6–7% annual growth in aquaculture over the last three decades, which is unparallelled in most other agricultural sectors. In the last decade, where the average annual growth rate of fish and fish product exports in the world has been 7.5%, India has witnessed an average annual growth rate of 14.8%. Looking at the potential for the development of fisheries, Prime Minister Shri Narendra Modi has called for a Blue Revolution. The government has merged all existing schemes and started a new Rs 30 billion umbrella scheme: 'Blue Revolution: Integrated Development and Management of Fisheries', which includes inland fisheries, aquaculture and marine fisheries comprising deep sea, mariculture and all the activities of the National Fisheries Development Board (NFDB). The Department of Animal Husbandry, Dairying and Fisheries (DAHDF) has prepared a National Fisheries Action Plan 2020 for the next five years to increase fish production and productivity. In the plan, all of the fisheries resources – ponds and tanks, wetlands, brackishwater, cold water, lakes, reservoirs, rivers, canals – are included. All states have been requested to prepare a SAP for the next five years to achieve the objective of Blue Revolution. The aim of the scheme is to increase fish production and productivity by 8% annually and to reach 15 million t by 2020. During the last two years, under fishermen welfare, construction of 9603 fishermen's houses have been completed, 20,705 fishermen have been trained and around 5 million fishermen have been provided with annual insurance assistance.

Species Diversification

The bulk of inland aquaculture production in India comes from three fish species – rohu, catla and mrigal. A handful of farmers are experimenting with exotic species such as silver carp, grass carp and common carp (Ayyappan and Jena, 2003). Recently the sector has witnessed interest in commercial farming of the exotic pangas catfish (Sahu and Sahoo, 2011). Thus, diversification is needed for efficient growth. The number of cultured species is less than ten, against more than 100 in China. Species diversity is an area that has not yet been explored and which has tremendous potential to increase production. Efforts are also being made to diversify the species mix in freshwater aquaculture by introducing high-value catfish like magur, freshwater prawns and regional species.

A Growing Industry

Major areas for the industry have been optimization of production and productivity; augmenting exports; generating employment; improving the welfare and socioeconomic status of fishermen; capture and culture, including inland and sea; aquaculture; gears; navigation; oceanography; aquarium management; breeding; processing; export and import of seafood; special products and by-products; and research. There exist several investment opportunities in the sector, but there are several challenges and issues facing fisheries such as accurate data on assessment of fishery resources and their potential in terms of fish production; development of sustainable technologies for finfish and shellfish culture; yield optimization; harvest and post-harvest operations; landing and berthing facilities for fishing vessels; and welfare of fishermen. The strong and sustaining ecological resource base, rational and preemptive policy, public and private investment and good governance hold the key for the sustainable growth of the sector. Full potential can be achieved through infrastructure, investment, technology intensification, diversification and value addition. Various issues relating to fishing activities in India need to be addressed in a time-bound manner, with mutual understanding and cooperation between the public and private sectors.

Fish constitute slightly more than half of all vertebrate species, some 28,000 species. In India, the potential of fish culture is yet to be fully exploited. Fish are a rich source of protein and have high nutritive value. Extensive development of aquaculture needs to be given priority after the Green Revolution in order to feed an ever-growing population. Success of fish culture depends, apart from other factors, on selection of suitable species, sufficient water supply and quality of land.

Technologies Developed

The systems and technology used in aquaculture have developed rapidly in the last 50 years. Much of the technology used is relatively simple, often based on small modifications that improve the growth and survival rates of the target species, e.g. improving food, seeds, oxygen levels and protection from predators. Simple systems of small freshwater ponds, used for raising herbivorous and filter-feeding fish, account for about half of global aquaculture production. Advances in hydrodynamics applied to pond and tank design have enabled the development of closed systems that have the advantage of isolating the aquaculture systems from natural aquatic systems, thus minimizing the risk of disease or genetic impact on external systems. Developments in engineering, some adapted from offshore oil rig construction, increase the possibilities of a progressive offshore expansion of aquaculture using robust cages. Culture-based capture fisheries involving the release of young fish into the wild to improve harvest (an operation also referred to as restocking, stock enhancement or ranching) have been suggested for increasing production in large open-water systems, i.e. reservoirs (Sugunan and Sinha, 2000). Sea ranching has just begun, and its long-term viability is being assessed. Advances have also been made in capture-based aquaculture involving the growing/fattening of young fish (e.g. groupers, tuna) captured from the wild. Major progress has also been made in the development of aquafeed technology, combining a large number of ingredients into very small pellets.

The selection of the aquaculture system or approach in a particular development is determined by several factors including: development goals/objectives and target beneficiaries; acceptability/marketability of culture species; availability and level of technology; availability of production inputs; support facilities and services; investment requirements; and environmental considerations.

Freshwater Fish Farming

Freshwater fish farming in India has been synonymous with carp farming until recently. The carp group comprises three Indian major carps (catla, rohu and mrigal), exotic carps (common, silver and grass) and minor carps, which constituted 76.5% of total inland production in 2012. While the contribution of exotic carp was significant in earlier years, recent years have witnessed reduced popularity of these among fish farmers, shrinking to only 9.55% in 2012. However, the gap has been filled by increased production of indigenous major carp. Added to that, the last decade has witnessed several new entrants into the Indian aquaculture system, both indigenous and exotic species, which have boosted fish production as well as farm income. Aquaculture activity supports individuals on a full-time basis, industrial activity for the corporate sectors, as well as many entrepreneurs. Nationwide successful demonstrations of the developed aquaculture technologies have brought about a Blue Revolution in the country. Today, technologies have been standardized to produce fish using almost all types of water bodies, be they reservoirs, rivers, derelict waters, ponds, tanks, canals and the cold waters of the hill region. A brief account of the most significant technologies that have revolutionized the aquaculture sector are described below.

Breeding and Seed Production

Carp breeding and seed production

Riverine seed collection was the major source of seed during the first half of the 20th century. Since the 1920s, a number of natural and synthetic inducing agents such as the pituitary gland, human chorionic gonadotropin, pregnant mare serum, mammalian gonadotropin-releasing hormone, luteinizing hormone releasing hormone (LHRH), and LHRH-analogue were tried to breed carp (Gupta and Rath, 2011). However, the epoch-making achievement came in the form of the successful induced breeding of Indian major carp with the use of pituitary gland extract, in 1957, which led to the foundation of aquaculture development in the country (Chaudhuri and Alikunhi, 1957). Subsequently, ampouling of the pituitary extract, refinement of breeding protocol, evolution of an array of hatchery technologies and hatchery models, and better broodstock management techniques have helped increase efficiency of carp seed production. With assured seed supply and development of seed-rearing techniques, aquaculture activity increased and led to increased fish production.

Development of synthetic inducing agents

Use of pituitary gland extract as an inducing agent brought problems of variable efficacy besides the cumbersome protocol of having to inject brooders twice. This often led to higher handling stress, improper synchronization, poor breeding response and higher post-breeding mortality. Carp breeding was made easier with the development of synthetic analogues of fish gonadotropins. Ovaprim, a synthetic analogue of salmon gonadotropin (SGnRH) was the first of its kind and revolutionized the seed production activity (Ayyappan *et al.*, 2016). This was followed by a series of synthetic chemicals like Ovatide, Ovopel and WOVA-FH, which have helped the hatcheries cater to the ever-increasing seed requirement, despite significant rises in seed demand over the years.

Development of different hatchery models

Hapa breeding, the common method used for carp breeding until 1980, was having problems of dependence on environment. Gradually, the quest for improving the efficacy of induced breeding led to the development of a number of hatchery models with better-controlled facilities and more reliable results (Dwivedi and Zaidi, 1983; Gupta and Rath, 2011). These include the glass jar hatcheries and plastic bin hatcheries developed during the 1980s. The Chinese circular carp hatcheries developed during the early 1990s, with simulation of all the natural conditions required for spawning, proved to be the most efficient model. The fibreglass reinforced plastic carp hatchery, a smaller and portable version of the Chinese eco-hatchery, was launched by ICAR-Central Institute of Freshwater Aquaculture (CIFA) in 2006. Its ease of portability has made it suitable for small and marginal seed producers and has made it possible to take the induced breeding technology to remote areas.

Multiple spawning

In order to avoid the maintenance of large populations of broodfish by hatchery owners, ICAR-CIFA standardized the multiple spawning technique during the 1990s (Gupta *et al.*, 1995). With this technique, the same broodfish of major carp could be bred as many as four times between March and September, thereby stretching the breeding season (June–August). It has been able to demonstrate two- to threefold higher spawn recovery over conventional single breeding during a season.

Cryopreservation of carp milt

The cryopreservation technique to preserve fish milt was standardized during the 1990s by ICAR-CIFA. This technique made it possible to preserve Indian major carp semen for 18 hours at 4°C prior to artificial insemination. Four fish-semen cryobanks, two in Andhra Pradesh and two in Odisha, were established in 2009/10 and are being used for stock upgrade of Indian major carp in hatcheries with more than 40% hatchlings recovery. Today, the country is almost self-sufficient in the production of carp spawn through a network of more than 2000 freshwater hatcheries, including about 350 fibreglass reinforced plastic hatcheries established in the country through both private and public participation.

Seed production of diversified species

The aim to diversify freshwater aquaculture has led to significant developments in the breeding and seed production of several other species. These include several minor carp, freshwater prawns, catfish, murrels, climbing perch, etc. Breeding and seed production technologies have been standardized for many indigenous minor carp, i.e. *Labeo calbasu, L. fimbriatus, L. gonius, L. bata, Cirrhinus cirrhosa, C. reba* and barbs, i.e. *Puntius sarana, P. pulchellus* (Ayyappan *et al*., 2016). Ease in seed production and assured availability of seed has ensured their wider domestication all over the country. Intercropping of these minor carp in the mainstream major carp production system has demonstrated a 30% increase in biomass production besides ensuring availability of varied protein.

Next to carp, panga (*Pangasionodon hypophthalmus*) has become a popular species spreading over more than 15,000 ha in Andhra Pradesh and a considerable area in Bihar and Chhattisgarh. It is a fast-growing species relying on a feed-based system and suitable for cage culture. Much of the seed of this species used in the country at present is sourced from neighbouring Bangladesh, although several commercial hatcheries have been established in West Bengal, Odisha and Andhra Pradesh. New hatcheries are coming up in several other states. Seed production of magur has been an important activity in Assam, West Bengal and Odisha, catering to a large culture area in West Bengal and the north-eastern states. Several other hatcheries in the plain areas are catering to the grow-out activity. Establishment of a pabda hatchery is an upcoming venture due to the popularity of this species among farmers in West Bengal and other north-eastern states during the last decade. A few hatcheries have been established in West Bengal. The giant freshwater prawn (*Macrobrachium rosenbergii*) has been successfully bred in captivity (Rao and Tripathi, 1993) and is cultured under monoculture and polyculture with carp. More than 35 freshwater prawn hatcheries were operating in the country; however, the number has fallen in recent years due to the decrease in culture area of the freshwater prawn with increasing interest in the farming of the exotic Pacific white shrimp in these freshwater areas. The wild collection of prawn juveniles has also been catering to the need for prawn seed to a large extent, especially in the states of West Bengal and Odisha.

Standardization of breeding protocols for different ornamental fish, both indigenous and exotic, has contributed to boost the ornamental trade (Swain *et al*., 2011). Several programmes relating to ornamental fish have been devised to motivate local people in the north-eastern states of Meghalaya, Arunachal Pradesh, Assam and Tripura, and the plains. Several ornamental fish villages have come into existence in West Bengal, Odisha, Tamil Nadu, Kerala and Karnataka, and have proved to be a potential means to empower rural women.

Development of indigenous systems of culturing pearls from common freshwater mussels, *Lamellidens marginalis, L. corrianus* and *Parreysia corrugate* is another important technology in the country (Janaki Ram and Tripathi, 1992). The easy surgical procedure, developed for production of both image and round pearl, has attracted the attention of many fish farmers, as witnessed by an increase in demand for training in this area in recent years.

Seed rearing

Most of the basic technologies of seed rearing and grow-out production in carp were developed in the 1980s at the Pond Culture Division of the Central Inland Fisheries Research Institute (CIFRI) at Cuttack. Subsequently, the techniques have undergone several modifications and refinements with respect to stocking density, use of critical inputs like feed and fertilizers, and efficient pond management protocol (Ayyappan and Jena, 2003). The present-day packages of nursery and rearing practices, with simpler pond maintenance, efficient input use and high seed survival, have helped increase survival, up to 50–60% in the nursery and 60–80% in the rearing phase, thereby making seed rearing a highly viable activity in farming. Instead of going for grow-out farming, several farmers nowadays are opting for seed rearing as a full-time activity.

Use of bigger concrete tanks for seed rearing of carp at high density has also proved effective. With better control of the environment in such systems, nursery rearing of carp spawn could be done at a density of 1000–2000/m^2 (10–20 m/ha), which has shown fry survival as high as 50% compared to 30% in an earthen pond (Jena and Das, 2011). Furthermore, use of aeration and water exchange in such systems have been proven to enhance seed survival by up to 60%. Use of such concrete seed-rearing systems has made it possible to achieve more than six times higher fry yield/unit area in every crop. Farmers are able to harvest three to four crops during a season, which makes this system highly viable economically.

At present, more than 45 billion fry are produced, making the country self-sufficient in fry production. However, there is a dearth in the production of fingerling, the right size for grow-out stocking. In recent years, special emphasis has been given, through many schemes and promotional policies, to promoting fingerling production in order to achieve adequacy of supply of yearlings. Protocols have been developed for the production of stunted fingerlings of carp to ensure all-year-round seed availability.

Development of Grow-out Farming Technologies

Composite fish culture technique

Growth evaluation and standardization of different species combinations with respect to stocking densities, species ratio and use of critical inputs has led to the development of a composite fish culture of the three indigenous major carp: catla, rohu and mrigal. Introduction of exotic species into Indian waters was another landmark to boost aquaculture production. Common carp (*Cyprinus carpio*) were brought in for a second time in 1957, while Chinese grass carp (*Ctenopharyngodon idella*) and silver carp (*Hypopthalmichthys molitrix*) were brought in in 1959. The higher growth rates of these exotic carp in tropical climates increased pond productivity and Indian fish farmers readily accepted them as candidates for culture.

Large-scale demonstrations of composite fish culture were undertaken in the country through a series of projects and schemes: the National Demonstration Project (NDP), Operational Research Project (ORP) in 1974–75, Central Inland Fisheries Research Institute (CIFRI)-International Development Research Centre (IDRC) Project on Rural Aquaculture in 1975–79, and the All India Coordinated Research Project (AICRP) on Composite Fish Culture and Fish Seed Prospecting between the 1970s and 1984 (Jhingran, 1991). Demonstration of carp production levels of 3–5 t/ha p.a. through the AICRP virtually laid the foundation for scientific carp farming all over the country (Ayyappan and Jena, 2001). The project had a great impact in West Bengal where some of the villages turned into total seed production centres, while others produced large quantities of market-size fish. In 1975, the Ministry of Agriculture of the Union Government implemented the Fish Farmers Development Agency (FFDA) scheme on a pilot scale. With the success of the scheme, the Union Government launched the Inland Fisheries Project during the 1980s with assistance from the World Bank to develop fish farming in large areas in five potential states, West Bengal, Odisha, Bihar, Uttar Pradesh and Madhya Pradesh, which was implemented through FFDAs. Since then, the network of 429 FFDAs established in almost all the potential districts in different states of the country shouldered the responsibility to popularize aquaculture in the country.

Polyculture of Indian major carp alone, or along with exotic carp at lower to moderate stocking density, has been realizing production of 4–10 t/ha p.a. The technology of intensive carp polyculture, involving stocking of larger fingerlings (25–50 g) at higher densities of 15,000–25,000/ha, provision of high-quality critical inputs such as seed, feed and fertilizers, along with additional provision of aeration, water-exchange facilities and fish-health management, has been in vogue, demonstrating higher production levels of 10–15 t/ha p.a. (Jena and Das, 2011). Market-driven forces have become the deciding factor in the modification of the present-day commercial culture system. Higher demand for rohu has forced fish farmers to adopt a bi-species culture of rohu and catla in the Kolleru Lake region of Andhra Pradesh, with rohu constituting 90% of the stock. Farmers in this region have also started stocking stunted juveniles/yearlings of 100–300 g in a multi-stocking, multi-harvesting, grow-out system, and have been realizing higher yields. The poor market for exotic silver carp, grass carp and common carp has led to the gradual reduction in the culture of these species in recent years despite their higher growth rate than their Indian counterparts.

The Kolleru Lake region of Andhra Pradesh has become the hub of organized aquaculture activity. At present, more than 1 million t of fish are being produced from the Krishna and West Godavari districts alone, which is supplied through organized cold-chain marketing to almost all parts of the country. Production from the culture sector has also increased significantly in recent years in states like Chhattisgarh, Jharkhand, Bihar, Odisha and Assam, apart from the significant contribution of West Bengal.

Cage and pen culture

The last decade has witnessed a surge in cage and pen culture activity with many states' fishery departments, with support from the National Fisheries Development Board (NFDB), promoting large-scale cage farming in reservoirs. States like Chhattisgarh and Jharkhand have been undertaking cage culture of exotic *P. hypophthalmus* in different reservoirs in a big way. Similar attempts at cage farming have also been undertaken by the fishery department of Odisha in the Rushikulya and Mahanadi river system and in the Hirakud reservoir.

Seed rearing in cages and pens in open waters for the promotion of culture-based capture fishery are another avenue of entrepreneurship that is becoming popular across the country. Stock enhancement through pen culture has been demonstrated by ICAR-Central Inland Fisheries Research Institute (CIFRI) in selected wetlands of Assam, mainly aimed at culture-based fisheries among the beel fishers. Such attempts, through pens erected in wetlands, have improved fish productivity considerably (Bhowmick and Das, 2011).

Culture-based capture fisheries

The reservoir resources in India cover more than 3 million ha distributed in varied climatic environments congenial to fish growth. Over the years, these natural waters have suffered from dwindling stocks of indigenous fish owing to anthropogenic activity such as construction of dams and barrages, environmental pollution and over-exploitation. The productivity of many of the small and medium-sized reservoirs has remained as low as 20–25 kg/ha, while the average fish production potential of these resources is estimated at 250 kg/ha for reservoirs and about 350 kg/ha for wetlands. As a move to improve the culture-based capture fisheries in the small and medium-sized reservoirs, many state governments have come up with reservoir management policies. With assistance from NFDB, seed-stocking programmes have been undertaken with seed produced from brooders indigenous to the same system. Awareness created among the local fishermen has helped improve the capture fishery resources of many of these water bodies, raising productivity to 150 kg/ha.

Wastewater-fed aquaculture

Technology has been standardized for utilizing treated sewage for fish production by the erstwhile sewage-fed fish culture wing of CIFRI and the present Regional Research Centre of ICAR-CIFA at Rahara. With this technology of using treated sewage, a large portion of the wastelands around Kolkata has been brought under fish production activity. Sewage water is proven to be an alternative to fertilizer for enhancing yield in paddy-cum-fish-farming systems and is being used in many areas of West Bengal.

Integrated farming systems

Several models of integrating fish culture with livestock have been developed over the years and have proved advantageous (Gopakumar *et al.*, 2000). Fish-cum-duck integrated farming using Indian major carp (IMC) as the fish component along with Khaki Campbell duck is a model accepted by rural farmers. Similarly, pig-cum-fish culture in north-eastern states and paddy-cum-fish culture in West Bengal and the north-eastern region have been accepted as popular farming systems.

Brackishwater Aquaculture

Although traditional fish farming in the *bheries* of West Bengal and *pokkali* fields of Kerala has a long history, scientific farming in the country was initiated only in the early 1990s (Rao and Ravichandran, 2001). The initial two decades of brackishwater farming were largely based on a single species of shrimp, the black tiger prawn (*Penaeus monodon*), owing to its high export market (Ponniah, 2011). Demonstration of the technology of semi-intensive farming with production levels of 4–6 t/ha in 4–5 months, coupled with institutional credit facilities and subsidies from the Marine Product Export Development Authority (MPEDA), helped in the development of commercial shrimp farming. Further, the entry of several big industrial houses to the sector has made for a vibrant and high-tech enterprise. Substantial investment was made towards the development of state-of-the-art hatcheries, feed plants, mega-size farms with modern equipment and gadgets, modern laboratories, processing plants and communication networks.

Shrimp farming

The rapid development of shrimp aquaculture in the coastal areas of the country also raised some environmental concerns, and the need for a regulatory mechanism to control the indiscriminate growth of aquaculture has become apparent, and the Coastal Aquaculture Authority (CAA) has started functioning. Unregulated growth also led to severe disease outbreaks, affecting farming since the mid-1990s. However, the disease problems could be managed to a great extent through the adoption of good management practices, which led to sustained increases in shrimp production in subsequent years.

The introduction of the Pacific white shrimp, *P. vannamei*, to the culture system in India has now seen total dominance of the species in shrimp farming, registering a coverage of almost 90%. The species has attracted farmers' attention due to its fast growth, the possibility of culture at higher stocking densities, the low incidence of native diseases, the availability of specific pathogen free (SPF) domesticated strains, the culture feasibility in a wide range of salinity of 0.5–45%, and the ready international market for the shrimps (Ayyappan and Jena, 2001). Production levels of 8–10 t/ha/crop of four months is a common practice. Of the 487,000 t of farmed shrimps produced in India during 2015/16, about 400,000 t are Pacific white shrimp. The area under culture has seen an increase of about 12%. Farmed shrimp accounts for 38% of the quantity and 64.5% of the value (Rs 244.26 billion) of total seafood exports worth Rs 378.7 billion (US$ 5.78 billion) in export revenue.

Species diversification

Brackishwater aquaculture over the years has been based on value rather than volume. However, in order to achieve sustainable growth of the sector, aspects of diversification are being emphasized now. At present, emphasis is given to culture of several other potential finfish and shellfish species – Indian white shrimp (*Fenneropenaeus* (*Penaeus*) *indicus*), seabass (*Lates calcarifer*), grey mullet (*Mugil cephalus*), milkfish (*Chanos chanos*), pearl-spot (*Etroplus suratensis*) and mud crabs (*Scylla serrata* and *S. tranquebarica*). The technologies for breeding and seed production of most of these species have already been standardized (Arasu *et al*., 2009), and their successful farming has been demonstrated in recent years. However, it is necessary that mission-mode programmes are taken up for large-scale adoption of these technologies.

Future perspectives

In order to double the export earnings to the tune of US$10 billion in the next five years, it is necessary that additional areas are also brought under farming control, considering that vertical expansion may not be an ideal proposition due to environmental issues. For bringing the unutilized/underutilized areas under farming, aspects of environmental soundness, social acceptability, equity and resource conservation need to be addressed. Sustainable approaches like biosecured zero-water-exchange shrimp farming technology (BZEST), probiotic and biofloc-based farming technology, organic shrimp farming and pond-based crab fattening need to be considered to increase production and productivity.

The future action plan, therefore, necessitates promotion of innovative, ecofriendly and sustainable technologies; establishment of healthy brood banks and state-of-the-art hatchery facilities for quality seed production; species and system diversification for judicious utilization of available land/water resources; selective breeding of native Indian white shrimp; comprehensive health management; GIS-based mapping of potential brackishwater areas; and introduction of a comprehensive fisheries policy for coastal and inland saline areas.

Mariculture

Development of mariculture in India is in its infancy. The ICAR-CMFRI during the past five decades, however, has developed several technologies pertaining to mussels, oysters, pearl oysters and seaweeds, and, more recently, to the cage culture of marine fin fishes.

Culture of molluscs

The earliest mariculture attempts were made in 1958–59 with the standardization of culture techniques for green mussel (*Perna viridis*) and brown mussel (*P. indica*) (Kuriakose and Appukutan, 1996). Adoption of rack, long-line and raft culture methods, especially in the states of Kerala, Karnataka and Goa, has pushed cultured mussel production from almost zero in 1996 to about 15,000 t, annually, at present. Edible oyster (*Crassostrea madrasensis*) farming, which was initiated in the 1970s with the natural collection of spat, could not get impetus until the late 1990s. Subsequently, the popularization of the rack-and-ren method of culture in different estuaries and backwaters saw production increase to the current level of 17,000 t. The golden pearl oyster, *Pinctada fucata*, producing golden pearls, and the black lip pearl oyster, *P. margaritifera*, producing black pearls, are the species producing gem-quality pearls. The technology of pearl culture involving implantation of nuclear beads was developed in 1973 (Alagarswami, 1974). Onshore production of good-quality pearls larger than 6 mm diameter from *P. fucata* was also achieved. The technology for seed production of commercially important mussels, oysters, pearl oysters and clams was developed during the 1980s, which, however, is yet to be taken up on a commercial scale.

Culture of seaweeds

The culture of seaweeds in the country is mostly confined to cultivation of agarophyte, *Gracillaria edulis* (Gopakumar *et al*., 2007), due to its high regenerative capacity and commercial value. Recently, the culture of the carrageenan-yielding seaweed *Kappaphycus alvarezii* has become popular due to its fast growth and low susceptibility to grazing by fishes, and is being cultivated in selected coastal districts of Tamil Nadu, producing about 20,000 t (wet weight) annually.

Culture of marine ornamental fishes

Globally, a lucrative marine ornamental fish trade has emerged in recent years, which has become a low-volume, high-value industry. A long-term sustainable trade of marine ornamental fish could be developed only through hatchery-produced fish. Technologies of breeding, seed production and culture of over 20 marine ornamental species, which include the high-valued clowns and damsels, have been developed and extended for their commercial production (Gopakumar *et al*., 2011).

Open-sea cage culture

Sea cage farming in the country was initiated in 2007 with seabass (*Lates calcarifer*). The potential of the farming practice was demonstrated on both the west and east coasts of India. After achieving success with seabass, cage farming was extended to cobia (*Rachycentron canadum*), groupers (*Epinephelus coioides*), pompano (*Trachinotus blochii, T. mookalee*), red snapper (*Lutjanus argentimaculatus*) and lobster (*Panulirus homarus*). Successful open-sea cage culture of seabass, pompano and cobia is being demonstrated in 6 m-diameter × 5 m-deep circular HDPE/GI cages with production levels of 25–35 kg/m^3/eight months (Ayyappan *et al*., 2016). Currently, cage farming is practised in over 1000 cages by the farmers of Gujarat, Goa, Karnataka, Kerala, Tamil Nadu and Andhra Pradesh. CMFRI has also successfully developed and standardized the breeding and seed production protocols of important finfish species like cobia, silver pompano, Indian pompano, orange-spotted grouper and pink-ear bream. It is envisaged that selective intensification, scaling up of the culture systems and formulation of an appropriate policy framework would lead to a substantial increase in the production of marine fish through sea-based cage culture in the coming years, which can contribute substantially to the Blue Revolution in the country.

Genetic Improvement

Over the years, efforts have been made to exploit the genetic potential of freshwater fish and prawns, particularly through genome manipulations in the early 1980s and through selective breeding from the 1990s onwards (Reddy *et al.*, 1999). The Jayanti rohu, produced through the selective breeding programme, has shown a 17% higher growth response/generation after eight generations. Being the major component of the species composition, this improved rohu has exhibited phenomenal increase in the vertical productivity of culture ponds. Apart from growth, disease resistance against *Aeromonas hydrophila* was also included in the rohu breeding programme from 2004 (Sahoo *et al.*, 2011). At present, ten multiplier units are in operation in different states for the dissemination of the Jayanti rohu, which has significantly increased the fish production in the country. With convincing success in selective breeding, similar programmes have been taken up for growth improvement of catla and freshwater prawn. A new programme has been proposed for the initiation of the selective breeding of Indian white shrimps, *Fenneropenaeus indicus*.

Availability of Feed Ingredients and Formulated Feed

Use of feed concentrate for freshwater farming was almost negligible, except for the sinking pellets produced for freshwater prawns. However, in recent years, awareness is increasing among fish farmers. Availability of commercially formulated, balanced feed has supported the feed-based aquaculture system and contributed significantly to boost fish production. At present, nearly 80 feed mills are producing supplementary feed for the sector in both sinking and extruded floating pellet form, which is based on the nutritional requirement of the desired species. The use of floating pellets has not only ensured better control of the feed ration and feeding strategy, but also is helping to curb the pollution caused by excessive feeding. Such feeding practice has become popular in the commercial aquaculture of major carp, catfish like *P. hypophthalmus*, and freshwater prawn. A number of feeds have been developed for different life stages of shrimp species like *P. monodon* and *P. vannamei*, and important cultivable finfish like *Lates calcarifer*. Cost-effective feeds have also been developed for both freshwater and marine ornamental fish species.

Several feed mills have been established in the country, producing customized feed according to the needs of the sector. Nearly 44 million t of concentrate feed are manufactured in the country at present for the different animal husbandry sectors, of which about 20% is currently being used for aquaculture. Considering the stiff competition for feed ingredients that aquaculture is going to face in the future, efforts are needed to develop alternative strategies to produce farm-made feed from non-conventional local resources. Further, greater emphasis is needed on harnessing the natural productivity for feeding the cultured fish.

Disease Surveillance and Management

The increased occurrence of pathogens comes as a sequel to the intensification of aquaculture practice. The freshwater aquaculture sector has witnessed several incidences of diseases that have created havoc. The incidence of ulcerative disease syndrome is one such example. However, timely R&D intervention through development of CIFAX, a therapeutic for the same, has helped save the fish crop from this disease (Ayyappan *et al.*, 2016). A study on argulosis has yielded results that are useful to control the parasite and save the huge crop loss that otherwise would occur due to argulosis. Several diagnostics and therapeutics have been developed against important pathogens. The National Surveillance Programme on Aquatic Animal Diseases (NSPAAD) has operated in the last five years in 17 states and two union territories covering 115 districts. The programme, financially supported by the National Fisheries Development Board (NFDB) and implemented with the involvement of 25 partner organizations, has been largely helping both the freshwater and brackishwater aquaculture sectors to keep a close watch on disease problems and is proving to be a timely warning of disease situations for the farmers and also the governments. Emergency response systems are in place to tackle transboundary disease issues. The establishment of a National Repository of Fish Cell Lines, with possession of over 50 cell lines at ICAR-NBFGR, is a step forward for the advanced study of viral diseases (Goswami *et al.*, 2014).

The Way Forward

The consistent annual growth rate of 6–7% experienced in the past three decades has been instrumental not only in narrowing the demand–supply gap of fish for the domestic market but also in boosting exports to an impressive level. Aquaculture production further promises to grow in the future. The state of Andhra Pradesh has been the most important aquaculture state, both for freshwater aquaculture and coastal shrimp farming. Considering the growth trend of the recent past, it is envisaged that brackishwater aquaculture production (shrimp), would also continue to grow in Odisha, West Bengal and Gujarat. Clear business opportunities also exist in Andhra Pradesh with regard to the production of fish feed, post-harvest processing, quality testing laboratories, etc. In both brackishwater and freshwater aquaculture it is necessary to strengthen the complete value-chain approach, since there exists a need for better inputs and infrastructure for post-harvest processing. Awareness creation and promotion of better farm management practices are essential, and state governments need to realize the necessity. Especially with regard to domestic market access, which mainly contributes to the demand for freshwater aquaculture products, lack of infrastructure and processing facilities hamper market access. It is equally safe to enter the Indian aquaculture market with a focus on shrimp production for export markets as it is the domestic market through freshwater aquaculture production. The latter will be, however, more beneficial for food security and for meeting the increasing demand of fish in the days to come. The area in the country needs to expand horizontally and at the same time the vertical increase in productivity needs to be addressed. However, due to reducing per capita land-holding and increased demand for water, additional allocation of large areas for aquaculture to address the deficit in fish production would need a strategic action plan for effective and efficient use of resources. Hence, there is an urgent need for increasing both research and development efforts to enhance the productivity of existing water bodies through vertical expansion and with increased water-use efficiency. Besides aquaculture production, equal emphasis will be required on sustaining capture fisheries, both marine and inland, and focusing on culture-based fisheries in reservoirs and other large open-water bodies in inland areas. Aquaculture is being considered a ‘sunrise’ sector for increasing production; the R&D perspectives must focus, primarily, on species and system diversification by bringing more potential finfish/shellfish species of promise into freshwater, brackishwater and open-sea farming; development of cost-effective feed for all live stages of presently farmed and potential species to be brought under farming; genetic improvement of cultivable species for growth and disease resistance; development of culture systems for increasing water productivity and water-use efficiency; and effective fish health management measures including preparedness for risk of transboundary and emerging diseases. Increasing focus on post-harvest processing and value addition would not only help in extending the market reach of fish and fisheries products, but also in raising the income level of farmers. In order to keep up the pace of farming enterprises, it is essential for the sector to build efficient human resources with adequate knowledge and skills and to get much-needed policy support from the government, as well as enhanced alleviation for institutional credit. With these in place, growth in the fishery sector will certainly accelerate.

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