Chapter 29
New Paradigms in Freshwater Aquaculture in Coastal Ecosystems in India: Happiness and Hope

J. K. Jena and P. C. Das

Abstract The 19-fold increase in fish production in the last seven decades in India, i.e., from 0.75 million metric tonnes (MMT) in 1950–51 to the present level of 14.2 MMT amply justifies the importance of the fisheries sector not only providing the protein and nutritional security of the masses but also its increasing contribution to the national economy. When the production from capture fisheries was stagnating, aquaculture has become a saviour for enhancing the targeted growth in fish production. From the meagre 0.37 MMT in 1980 to over 9.0 MMT at present, a 25-fold increase in aquaculture production in just four decades has placed the country as a forerunner on the global front. The freshwater sector that shares over 90% of total aquaculture production is largely contributed by carps and meeting the demand of the domestic front. The coastal ecosystem is contributing a significant share of the 8.2 MMT of freshwater aquaculture production with Andhra Pradesh, West Bengal, and Odisha being the major producers. Increasing production of diversified freshwater species including those of exotic striped catfish, pacu, and tilapia again is largely contributed by Andhra Pradesh. While carp polyculture and monoculture of exotic striped catfish have been steering the freshwater aquaculture production, a range of other non-conventional culture systems, viz., sewage-fed fish culture, integrated farming systems, cage and pen culture, and the new technologies like RAS and biofloc systems has made freshwater aquaculture an increasingly growing activity across the country. As a backyard avenue, ornamental fish breeding and rearing have been proved to be highly viable activity especially for the areas adjoining cities/towns due to their assured market. The self-sufficiency in quality carp seed production through large-scale adoption of the technologies of controlled breeding, hatchery production, and seed rearing has been ensuring guaranteed seed supply and practically guiding the aquaculture development in the country. Success in the development of breeding

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and seed production technologies of over 40 cultivable freshwater finfish and prawn species is leading farmers to adopt new species for culture diversification. In this endeavour, it is the coastal ecosystem led by the state of West Bengal contributing the bulk of the seed production in the country. Availability of a host of farmers'-friendly technologies with varied production potential, execution of different technology transfer programmes through the institutional frameworks, increasing private investments, good temperature regimes, productive soil, good water availability, and above all, increasing demand for fish have been instrumental for the accelerated growth of freshwater aquaculture in the coastal eco-regions. The fisheries sector in India has been able to demonstrate a phenomenal average annual growth rate of 10.88% to the national GVA in the last five years. Freshwater aquaculture has been the principal contributor to this growth, and it is expected that the sector would continue to take the lead in meeting the projected production target of 22.0 million tonnes of fish by 2025 and also contributing to increased employment generation.

Keywords Aquaculture diversification · Carp polyculture · Coastal ecosystem · Freshwater aquaculture · Integrated farming · Prawn culture

29.1 Introduction

Fish production in India has shown phenomenal growth in the post-independent period with the present production level at 14.2 MMT, a whopping 19-fold increase as compared to the 0.75 MMT in 1950–51(DoF 2020a). With marine fish catch hovering around 3.5 MMT since the last decade, aquaculture has been the main source of increase in fish production in the country. From a meagre 0.37 MMT in 1980 to over 9.0 MMT at present, aquaculture has shown a 25-fold increase in production in just four decades placing the country as a forerunner on the global front. The coastal ecosystem has provided significant support to increase fish production over these years. It consists of the nine maritime states and four union territories (UT) stretching to a total coastline of 8118 km producing 3.72 MMT of fish in 2019–20. Only, about 15% of the available 1.2 million hectares (m ha) of brackish water area all along the coasts have been put to use for the land-based aquaculture activity, mostly for the shrimp farming that produces about 0.8 MMT of cultured shrimp per year. Shrimp export from aquaculture contributed to about two-thirds of US$ 7.0 billion of seafood export from the country in 2019–20. These coastal states also possess 59.1% (1.438 m ha) of the country's 2.433 m ha pond and tank resources which form the basis of freshwater aquaculture (Fig. 29.1). Also, 72.4% of the 2.93 m ha reservoir and 62% of the 7.98 m ha wetland resources of the country are present in these coastal states (DAHD&F 2018). About 65% of the total inland production in 2019–20 came from these coastal states, and further, a significant share of this (5.89 MMT) was contributed by the states of Andhra Pradesh, West Bengal, and Odisha (DoF 2020a).

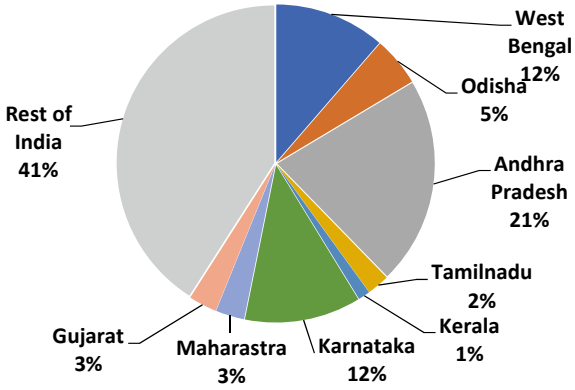

Fig. 29.1 Tanks and ponds in coastal states (Country total—2.433 m ha)

The coastal ecosystem of the country is spread on both east and west coasts and falls under a varied agroclimatic zone. It supports the livelihood of about 30% of the inland fisherman population of the country apart from the entire marine fisherman population. While the states on the east coast possess 40% of the freshwater pond resources of the country, 19.2% are available on the west coast. The diverse resource base provides wide scope for the culture of diversified fish species. Most of the freshwater aquaculture activity incidentally is concentrated on the east coast, especially in the states of Andhra Pradesh, West Bengal, and Odisha.

The breakthrough in the induced breeding of carps in 1957 and subsequent technological developments in various aspects of aquaculture including mass-scale hatchery seed production, nursery rearing, and fingerling production, and grow-out carp polyculture principally steered the freshwater aquaculture development in India (Ayyappan et al. 2011). Implementation of the 'All India Coordinated Research Project on composite carp culture and fish seed production' by the Indian Council of Agricultural Research (ICAR) in 1970s, which helped in the refinement of the packages of practices of carp culture further, was instrumental in the dissemination of scientific carp farming (Ayyappan and Jena 2005). In recent years, the sector has seen significant progress on all fronts, be it technology upgradation in seed production and grow-out culture of diversified species, system diversification, breed improvement, production of balanced feed, or improved health care; all contributing to the increase in production and productivity. The increased realization of fish farming as a potential full-time activity, substantial investment flow and strong government support in terms of numerous developmental schemes have also catalysed the aquaculture development in the country.

29.2 Aquaculture Diversification

Freshwater aquaculture in the country has remained mostly carp-centric, especially the culture of the three Indian major carp species (catla *Catla catla*, rohu *Labeo rohita,* and mrigal *Cirrhinus mrigala*) under the polyculture system. Apart from these, the three exotic carps, viz., silver carp *Hypophthalmichthys molitrix*, grass carp *Ctenopharyngodon idella,* and common carp *Cyprinus carpio* also formed an important component of composite carp farming in several places. Taking the advantage of the rich fish biodiversity of the country, the freshwater aquaculture during the last 3–4 decades has been able to expand its species spectrum to over 40 indigenous fish and prawn species, and several of which are regionally important ones with very high consumer preference and market price (Raizada et al 2019). The availability of the breeding and mass-scale seed production technologies and further access to the hatchery-produced seed also provide ample opportunity to the farmers to diversify culture practices. The important species include minor carps and barbs (kalbasu *Labeo calbasu*, fringed-lipped carp *Labeo fimbriatus*, Kuria labeo *Labeo gonius*, bata *Labeo bata,* reba *Cirrhinus reba,* Olive barb *Puntius sarana*), catfishes (magur *Clarius magur*, singhi *Heteropneustes fossilis,* butter catfish *Ompok pabda,* and *O. bimaculatus*), murrels (*Channa striata* and *C. marulius*), other finfishes of importance (climbing perch *Anabas testudineus*, chital *Chitala chitala*), and freshwater prawn (giant freshwater prawn *Macrobrachium rosenbergii* and Indian river prawn *M. malcolmsonii*). In recent years, the sector further has witnessed increasing adoption of diversified freshwater species including those of exotic striped catfish (*Pangasianodon hypophthalmus*), pacu (*Piractus brachypomus*), and tilapia (*Oreochromis niloticus*). Freshwater aquaculture production of the country is estimated to be about 8.2 MMT, out of the total inland fish production of 10.44 MMT (DoF 2020a) and the important groups being major carps, exotic carps, minor carps, catfishes, and others (Fig. 29.2).

Andhra Pradesh, the major freshwater aquaculture producing state today initiated pond culture in the Kolleru lake region only in 1976. Initially, the state government constructed only 133 fish ponds covering an area of 2040 ha (Ramakrishna et al. 2013). During the last four decades, aquaculture in the state has turned to be a typical commercial activity, involving major carps, striped catfish, and pacu as the major species. The states of West Bengal and Odisha have been utilizing the resources mostly as a homestead activity comprising a wide range of species in the culture system. Fish being a preferred food item for over 95% population of these two states, more than two dozens of species including the indigenous major carps, minor carps, and barbs, catfishes, murrels, climbing perch, chital, and freshwater prawn are cultured in the pond systems of these states to meet the diverse options of the consumers. Compared to the east coast, the coastal states on the west coast have less freshwater aquaculture activity. Although most of these states, barring Gujarat, have a considerable fish-eating population, marine fishes have greater consumer preference over freshwater fishes. However, in recent years, freshwater aquaculture activity has received increased attention. The Deccan Plateau being the potential hub for several

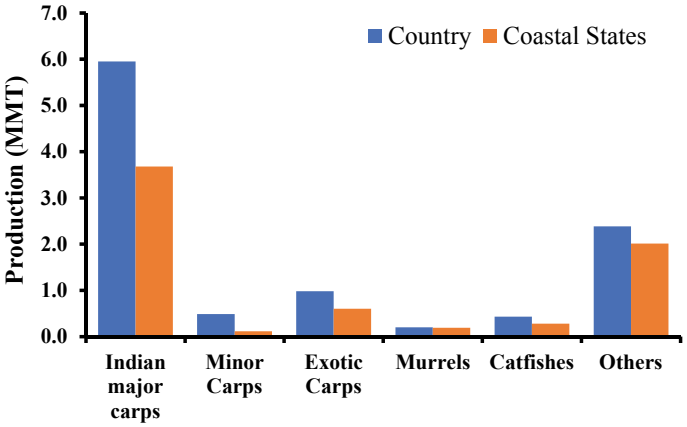

Fig. 29.2 Inland fish production of major species groups in coastal states in 2019–20

potential cultivable endemic fish fauna, particularly the medium-sized carps and barbs, there has been a greater focus on technology development of breeding and seed production of several species, viz., *Labeo dussumeri*, *Hipselobarbus pulchelus*, *Puntius karnaticus,* and *P. kolus.* While these diversified species have proved to be potential components in the major carp-based polyculture system, it is expected that their large-scale adoption would largely depend on their assured seed availability.

The exotic striped catfish has become the next important cultured species after carps in the pond culture system, specifically in Andhra Pradesh. Over these years, the species has also achieved its strong presence in several land-locked states, viz., Chhattisgarh, Jharkhand, Bihar, and Uttar Pradesh. The other important catfishes being adopted in the culture systems are magur, singhi, and butter catfish. While monoculture of these species has seen increased adoption in the northeastern states, in the coastal states, they are mostly cultured in West Bengal and to a limited extent in Odisha. These fishes are also cultured as the component species in carp polyculture and have been contributing to increased farm income due to their higher market price. Of late, the singhi has received increased preference as a promising species in the biofloc-based aquaculture system.

The high market value of murrels (striped snakehead *Channa striata* and great snakehead *Channa marulius*) especially in West Bengal and the South Indian states like Tamil Nadu, Andhra Pradesh, Telengana, and Karnataka although has created increased interest for culture of these species, inadequacy in seed availability has been the major bottleneck for their large-scale farming. However, the recent success in mass-scale seed production of these species has opened scope for their adoption in the culture system.

Besides the finfishes and freshwater prawns, the culture of freshwater mussel *Lamelliden marginalis* is increasingly becoming popular as a cash crop for freshwater pearl production in the coastal region. As a backyard avenue, ornamental fish breeding and rearing have also been proved to be highly viable activity especially for

the areas adjoining cities/towns due to their assured market. Although the country possesses rich biodiversity of indigenous freshwater ornamental fish, efforts during the years have mainly focussed to develop breeding and seed production protocol of a few low-valued indigenous and exotic species. Greater focus, however, is given at present to breed high-valued indigenous ornamental species. With the areas around Kolkata, Chennai, and Mumbai have become major hubs of breeding and culture of ornamentals over these years, several new units are coming up in the states of Kerala, Andhra Pradesh, and Odisha (Silas et al. 2011; Ayyappan et al. 2016). Being highly flexible in the scale of operation, ornamental fish farming is being adopted as a backyard activity by the small and marginal women farmers and also as large-scale commercial activity.

Andhra Pradesh is continued to be the major producer of inland fish production among the coastal states, followed by West Bengal and Odisha (Fig. 29.3). The bulk of the present culture production comes from about 70% of the available ponds and tanks resource in the country. The burgeoning demand for freshwater fish not only has necessitated 100% utilization of available resources but also advocated for increased intensification and expansion of aquaculture in new resources. Over the years, though carp polyculture and monoculture of exotic striped catfish have been steering the freshwater aquaculture production, a range of other non-conventional culture systems, viz., sewage-fed fish culture, integrated farming systems, cage and pen culture, and the new technologies like RAS and biofloc systems have made freshwater aquaculture an increasingly growing activity across the country. Further, within the carp production system, several modifications have been made in the

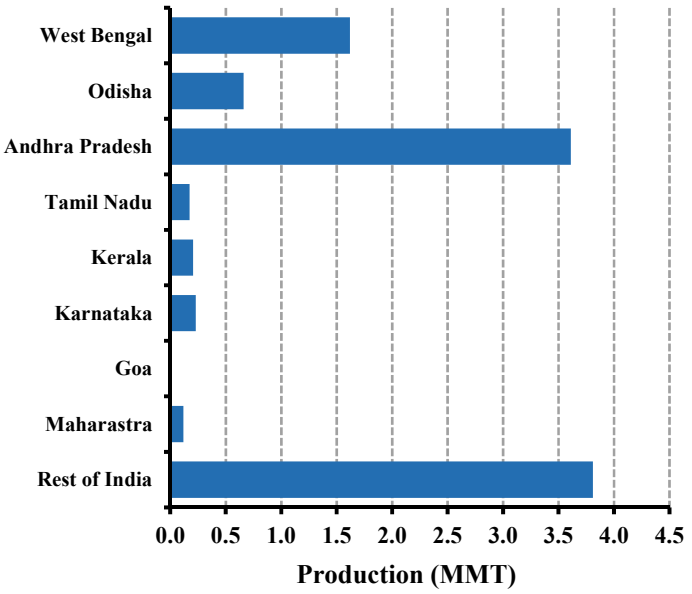

Fig. 29.3 Inland fish production in the coastal states in 2019–20

cropping patterns to ensure higher yield, low feed requirement, shortening of crop period, low investment, increased investment capacity, and lower risk factors. Some of the important farming practices in vogue in freshwater aquaculture systems in the coastal states are discussed.

29.2.1 Carp Polyculture

The technology of carp polyculture developed during 1970s brought the aquaculture to the level of industrial enterprise at present. The farming practices, however, have undergone several need-based modifications which were largely influenced by the market demand and investment capacity of the farmers in different parts of the country. But, the technology of carp polyculture yet has been the core of all developments with over 60% of the freshwater aquaculture production coming from three Indian major carp species. Carp farming further has also seen a marked shift from stocking fingerlings to adopting the concept of fattening with the use of a larger seed stocking size of 200–300 g to shorten the crop period, as adopted largely by the farmers of Andhra Pradesh. The average productivity in carp farming has been varying between 3–4 tonnes ha^{-1} yr^{-1}, while higher production levels of 8–10 tonnes ha^{-1} yr^{-1} are realized by several enterprising farmers in Andhra Pradesh and other states (Jena et al. 2020; Ayyappan 2021). Studies have also shown 15–20% increase in fish production with the introduction of minor carp and barb species in major carp-based polyculture systems. These species, because of their smaller marketable size, also have shown potential for better utilization of the seasonal ponds (Jena and Das 2011). Besides the conventional system of single stocking and single harvesting, the promotion of newer approaches, viz., single stocking at higher density and multiple harvesting, multiple stocking—multiple harvesting, and multiple cropping are also increasingly being adopted (Das et al. 2019). Such cropping systems also help in the reduction of FCR and assuring the periodical money flow besides reduction of investment and disease risk.

29.2.2 Monoculture of Striped Catfish and Other Exotic Species

The higher growth rate of the striped catfish *P. hypophthalmus* compared to other cultivable indigenous catfishes and feasibility of its farming at a very high density with higher yield realization were the principal factors for its increased adoption in the culture system of the country. The absence of intra-muscular bone further is a boon for its popularity in the North Indian states as well as for the hotel industry. Andhra Pradesh has been at the forefront to adopt striped catfish in the aquaculture system. The state has shown a steady increase in the culture area of the species since

the early 2000s to reach a maximum of about 32,000 ha in 2010 with an average yield of 17–20 tonnes ha^{-1} under monoculture (Belton et al. 2017). Further, with the use of balanced floating feed under intensive monoculture setup, the yield level often reached 40-50 tonnes ha^{-1}. However, due to the reduced market price of the species in the later period and its increased adoption in several other states, viz., Chhatisgarh, Bihar, Jharkhand, Uttar Pradesh, Punjab under both pond-based and cage culture systems, the coverage area in Andhra Pradesh has seen a marked decline in recent years. In terms of production volume, the contribution of striped catfish is next to the three Indian major carp species.

Apart from the striped catfish, the pacu and tilapia have made their way into the culture system in recent years. Although pacu is yet to be an officially approved species for farming in the country, its culture area has increased to over 2500 ha during the last 10 years, which, however, is largely confined to the state of Andhra Pradesh. Farming of tilapia was officially banned in the country over the decades due to its prolific breeding and threat to the environment. However, the relaxation given recently for farming of the improved variety of monosex tilapia and red tilapia, with certain restrictions, has led to a growing interest in their large-scale adoption in several coastal states. While pacu is being cultured as a component species in the carp polyculture system and also under monoculture, the farming of tilapia has been adopted under monoculture in ponds and also as a species of choice in the biofloc system. At present, a few farms in Kerala and West Bengal are producing tilapia on a very large scale and catering to the domestic and export market.

29.2.3 Culture of Freshwater Prawn and Marine Shrimp in Freshwater

The availability of hatchery-produced seed, a surge in demand due to the decline in marine shrimp production caused by white spot syndrome virus (WSSV) and the higher market price of freshwater prawn led to increased adoption of giant freshwater prawn farming in the country during the early 2000s, especially in Andhra Pradesh followed by West Bengal. Freshwater prawn culture took off in a big way in different districts of Andhra Pradesh, especially Nellore District during 2000–2003. With average annual productivity of about 1.0 tonne ha^{-1} under monoculture, the production of freshwater prawn had reached 41,870 ha during 2003–04, with Andhra Pradesh contributed about 90% of the total. The farming intensity, however, declined subsequently due to several reasons most important being the outbreak of White Tail Disease and reduced export price and less profit margin in farming. Further since 2012, successful cropping of the Pacific white shrimp *Litopenaeus vannamei* is taken up in freshwater ponds (Muralidharan 2016). Large areas of ponds have been converted considering the high returns of its farming. The culture of freshwater prawn, however, is showing the sign of revival with production reaching about

9500 tonnes during 2019–20, and it is expected that with the availability of genetically improved seed having 30% higher growth, farming of this species would expand in the coastal regions in coming days.

The feasibility of farming black tiger shrimp at low salinity due to its euryhaline nature also helped for its farming in low-salinity waters in some of the districts of Andhra Pradesh during the initial years. However, it was subsequently replaced after the introduction of the Pacific white shrimp in the late 2000s. In the last decade, a vast expansion of shrimp production has further taken place in the state through the construction of new ponds or the use of ponds previously used for fish farming.

29.2.4 Integrated Farming System

Based on the concept of waste recycling, the integrated farming system is an effective system for judicious and effective utilization of resources. Integrated farming system models such as pig-cum-fish culture, duck-cum-fish culture, and paddy-cum-fish culture are highly popular in the northeastern region. Fish-cum-duck farming and fish-cum-poultry farming are among the popular integration models which have been adopted by many farmers in the eastern coastal states. With demonstrated production levels of 3–5 tonnes of fish ha^{-1} water area, mainly through fertilization of water with the generated wastes from the quantified numbers of livestock or birds, integrated fish farming has proved to be highly economically viable and environmentally friendly technology (Gopakumar et al. 2000; Ayyappan and Jena 2003). Integration of high-valued horticulture crops such as strawberries and other seasonal fruits on pond dyke with indigenous fish species in the pond has become a popular model in West Bengal. Similarly, the rice-fish system with integration of seasonal vegetables and fruit crops, apiary and mushroom on dyke, and pulses/watermelon in the main field during rice fallow season is a popular model in lowland rice ecosystem of coastal Odisha.

29.2.5 Sewage-Fed Fish Farming

Sewage-fed fish farming forms an important aquaculture activity in certain parts of West Bengal, especially in the freshwater *bheries*. In such a system, the organic wastes/sewage after a certain degree of treatment is used as a nutrient source in extensive fish farming. The traditional technology of sewage-fed farming which was in vogue over decades, however, has undergone substantial modification over the years incorporating an aspect of primary treatment before the water is fed to the culture ponds. Polyculture of Indian major carp along with silver carp and common carp in large ponds with treated sewage water has been yielding production levels of 3.0–4.0 tonnes ha^{-1} yr^{-1}. Multiple stocking and multiple harvesting are common practices adopted (Ayyappan and Jena 2001; Jena et al. 2020). Further, the water released from such culture ponds also meets the water quality criteria specified for

irrigation water. High-density farming with the incorporation of minor carps, viz., *C. reba* and *L. bata* and tilapia along with major carps is quite a common practice.

29.2.6 Aquaculture in Inland Open-Waters

The nine coastal states together possess 72.4% of the 2.93 m ha reservoir and 62% of the 7.98 m ha wetland resources of the country (DAHD&F 2018), and the greater part of the fish production from these resources comes from the capture fisheries and culture-based fisheries. The governmental intervention on stock enhancement during the last two decades, especially through *in situ* carp seed rearing in pens (enclosure) and ranching of pond-reared seed, along with other participatory management measures has helped to improve the fisheries of several reservoirs and wetlands in the country. Such interventions have led to increased productivity of many of the small and medium reservoirs from a level of 20–25 kg ha^{-1} to 150 kg ha^{-1}.

The developmental need to increase fish production from the reservoirs has led to increased cage- and pen-farming activities in recent years. The striped catfish has been the species of choice for cage culture due to its higher growth and production. In most common rectangular cages of 6 m × 4 m × 4 m, production levels of 2.5–3.0 tonnes are achieved in 6–8 months culture period. During the last decade, the technology although has seen greater adoption especially in the land-locked states of Jharkhand, Chhattisgarh, Madhya Pradesh, and Telangana, the coastal states also resorting to greater adoption of the technology these years.

29.2.7 New Generation Aquaculture Systems and Practices

During recent years, different new aquaculture systems, viz., biofloc system (BFS), re-circulatory aquaculture system (RAS), and aquaponics have been adopted in different parts of the country including the coastal states. Based on the principle of high-density fish production, these systems can be futuristic options, especially for peri-urban fish farming, when scarcities of land and water resources are going to be critical determinants for the expansion of aquaculture in coming years. Among these, the biofloc system has generated huge interest among fish farmers and particularly among the youths in recent years. Despite being energy and capital-intensive production system, it has proved to be an economically viable alternative system of fish production in many countries. However, at present, a limited number of farms are operating across these states where cultured species mainly include singhi, tilapia, striped catfish, and climbing perch. Research efforts are on to bring more high-valued species under the ambit of culture in the biofloc system. Impetus is being given through different governmental schemes for large-scale establishment of the *peri-urban* system such as biofloc and RAS, which are likely to increase fish production in the coming days.

Production of organic fish has now become an important intervention in aquaculture as the choice of consumers to opt for safe and quality food is increasing, even if it taxes higher price on them. Though lower stocking density and stringent farming protocol have been characteristics of organic farming, the higher price compensates for the production loss. Successful attempts have been made to produce organic fish and prawn species, and farmers are adopting this technology day by day.

With the availability of hatchery-produced seeds of important brackishwater species, it is also feasible to take some of these species like seabass (*Lates calcarifer*), grey mullets (*Mugil cephalus*), milkfish (*Chanos chanos*), and pearl spot (*Etroplus suratensis*) into the freshwater aquaculture system.

29.3 Fish Seed Production

Over the years, induced breeding and seed production protocols have been standardized for more than 40 freshwater species. Carps being the major cultivable species, in order to meet the seed demand, over 3000 eco-hatcheries including small-scale FRP hatcheries are engaged in carp breeding and seed production in the country. West Bengal has been at the forefront of freshwater fish seed production with more than half of these carp hatcheries are operating in the state. The state is also operating several specialized hatcheries for striped catfish, magur, pabda, murrels, and other cultivable finfish species. Among the other coastal states, Odisha and Andhra Pradesh have also been able to boost seed production of different species including freshwater prawn over these years through the establishment of new hatcheries in the private sector. Availability of synthetic inducing agents and hatchery technologies for different species together with the experience gained over the last six decades has been instrumental for bringing self-sufficiency in seed production of 52 billion fry in the country in 2019–20 (DoF 2020a). West Bengal is playing a pivotal role in the seed supply chain in the country. Besides, the entire production of the freshwater prawn and shrimp seed comes from over 550 hatcheries in the coastal states, the bulk of which, however, is again contributed by Andhra Pradesh.

The development of aquaculture or propagation of any cultivable species largely depends on the timely availability of quality seeds of the desired species and size. Small and seasonal earthen ponds, which otherwise are not apt for grow-out production are effectively used for nursery rearing. It has been possible for the farmers to harvest one to two crops fry in such ponds within a breeding season of 3–4 months. High-density nursery rearing is now advocated in large concrete tank systems for more seed production per unit area as compared to the earthen ponds. Six to eight times higher fry production per unit area are being realized in such tanks through the harvest of 3–4 crops during a season. Despite assured availability of required carp fry in most of the states, there has been always a deficiency in the supply of fingerling which is a prerequisite for the success of any commercial culture. Fingerling rearing has so far been a less popular activity in the sector, largely due to possession of only one or two ponds by most of the farmers which they use for nursery or grow-out

production. This is the case in almost all coastal states except that of Andhra Pradesh where there have been several seed rearing hubs, which ensure the seed demand of the commercial farming hub of about 100,000 ha in Krishna-West Godavari Delta. The mega-programme 'Mission fingerling' launched by the government recently is expected to promote such activity and strengthen the seed chain of the cultivable species not only in the coastal states but also all over the country.

In grow-out carp culture ponds in many parts of India, especially in Andhra Pradesh, stunted juveniles of 200–300 g are commonly used for stocking (Belton et al. 2017). The increased demand for stunted fingerlings/juveniles has created an opportunity for a separate tier of seed rearing for the farmers who are engaged in full-time seed rearing activity around the year. Protocols are available for the production of stunted fingerlings and yearlings which have enabled the farmers to practise fish fattening with reduced culture duration.

29.4 Stock Improvement

Improving the seed quality has been of prime importance in the aquaculture sector to harness the production potential of different species. Over the years, several techniques have been applied that include hybridization, ploidy manipulation, selective breeding. Though more than 40 intra-generic, inter-specific, and intra-specific carp hybrids had been produced but had limited success in achieving hybrid vigour. The revolutionary success came through selective breeding in rohu, popularly known as '*Jayanti*', which after its 9th generation of selection has demonstrated over 50% higher growth than that of commonly farmed rohu at farmers' fields. With the demonstrated encouraging result in rohu, the ICAR-Central Institute of Freshwater Aquaculture (CIFA), Bhubaneswar, an institute located in the state of Odisha has also expanded its selective breeding programme to other important species, viz., catla and giant freshwater prawn. While in the case of freshwater prawn 30% higher growth has been demonstrated after 10th generation of selection, catla has shown 30% higher growth even after 2nd generation (Jena et al. 2020). The institute over these years has been able to promote the spread of these improved fish through 'Multiplier Units' in several states. The National Freshwater Fish Brood Bank (NFFBB), established under the aegis of the National Fisheries Development Board (NFDB), Government of India in 2013 on the campus of Odisha State Govt. Fish Farm at Kausayaganaga, Bhubaneswar, has also been disseminating the genetically improved seed to different hatcheries in Odisha and neighbouring states. Besides, several hatcheries across the country have also been employing the milt cryopreservation technique for stock improvement. The technique is not only helping to overcome the issue of inbreeding in the hatcheries but also ensures stock improvement through male gamete exchange and reduction in the cost and maintenance of brood fish (Ayyappan et al. 2016). There has been improvement in the protocols for the broodstock maintenance and induced breeding of the major carps. The use of specialized broodstock diets like CIFABROOD^{TM} is not only bringing early maturity in carps but also significantly

increasing the spawn yield. Protocols have been developed for multiple breeding in carps where the same broodfish could be bred 2–3 times through stretching the breeding season. Early breeding has been made in carps during the pre-monsoon period with environmental manipulations.

29.5 Nutrition and Feed

Feeding of cultured fish in aquaculture systems in the country was restricted to certain commercial aquaculture farms in different regions till recent years, which, however, has been increasingly accepted by the farmers across India. The coastal states being the hubs of aquaculture activity, both for freshwater species and shrimps, the farmers in these regions have been the early adopters to the feeding practice. In carp polyculture, the feeding practices are largely confined to bran-oilcake mixture through 'pole or rope feeding' (Ramakrishna et al. 2013), although some commercial farmers are shifting to floating pellet feeds at present. With the increased area and greater adoption of intensive farming practices in this region, there has been a significant upsurge in feed demand over these years. Although the country has been able to meet the growing feed demand for shrimp farming in the last two decades with the establishment of several feed plants by the private sector, significant development in the commercial floating feed supply for the freshwater species happened only in the last decade. Over 30 feed plants are operating for the production of shrimp feed, mostly in the coastal region, with an installed capacity of about 1.6 MMT (Ambasankar et al. 2017). Recently, a few factories are also established in Odisha, West Bengal, and other land-locked states with varied production capacities.

Floating, sinking, and slow sinking forms of commercial feeds in varied pellet sizes are now available in the market. Specialized feeds for striped catfish, Indian major carps, and freshwater prawn are also available for the different life stages. Farm-made feeds produced from the identified non-conventional ingredients are increasingly used in several farms. There have been attempts to increase the efficiency of these feeds through effective feeding management to curb the FCR. While the demand for feed for fish and shrimp farming is increasing gradually, the non-availability of raw materials has been a concern at a time the aquaculture industry has to compete with the dairy and poultry industries. Efforts have been made to identify alternate feed ingredients from the locally available feed materials. The fishmeal, which is the most expensive and inevitable ingredient in the commercial feed of shrimp, freshwater prawn and carnivorous fishes, has to be replaced by ingredients of plant origin.

29.6 Disease Management

Increased intensity of farming over the years has also increased the vulnerability of the crops to disease emergence. Periodical occurrences of different diseases in shrimp and freshwater prawn farming, in particular, have led to setbacks in the growth of their farming, thereby requiring a greater focus on proper diagnosis, surveillance, and effective disease management. On the contrary, the health management in the freshwater fish farming sector has been at low key due to the lower occurrence of fatal diseases. Epizootic ulcerative syndrome (EUS) and parasitic infestation by *Argulus* have been the two common disease issues in freshwater aquaculture, which are being effectively managed by the application of CIFAX-a chemical formulation of ICAR-CIFA, and certain anti-parasitic drugs, respectively. Issues of poor growth and unexpected mortality in several cases are largely found to be due to the poor management and deterioration of water quality, especially during the latter part of the culture period. However, there has been a growing awareness among the farmers during these years to minimize their crop loss which may arise due to diseases, improper nutrition, and water quality deterioration. Implementation of the National Surveillance Programme on Aquatic Animal Diseases (NSPAAD) in 20 selected states and 2 union territories, including all the coastal states of the country during the last seven years has been a significant step forward to have a close vigil on the endemic and new disease outbreak in the aquaculture sector (Sood et al. 2020). The programme funded by the Department of Fisheries, Government of India, with the active participation of 29 partner organizations under the leadership of ICAR-National Bureau of Fish Genetic Resources (NBFGR), Lucknow, is tracing and tracking the emerging disease problems in different aquaculture systems through specialized laboratories and providing necessary guidelines for prevention and cure of the diseases. Under the programme, an 'emergency response system' is in place to tackle any new outbreak. Several diagnostic laboratories have been established by the entrepreneurs too, especially in the state of Andhra Pradesh. Refinement of environment management protocol, development of diagnostic tools, formulations of therapeutics, use of immuno-stimulants, etc. are some of the key tools being used at present to trace and control the diseases in the sector.

29.7 Fish Marketing

Almost total fish produced from aquaculture in India goes for domestic consumption, while cultured shrimps are mostly exported to other countries. The state of Andhra Pradesh produces bulk of the inland fish (3.6 MMT in 2019–20) and possesses an organized cold chain in fish marketing. It has been able to supply the fishes to several states of the country. Although the states like West Bengal and Odisha also produce a good quantity of fish from freshwater aquaculture, possessing about 95% of the fish-eating population, these states are also forced to source fish from Andhra

Pradesh. Recent years further witnessed live fish transportation to the short-distance local markets and holding facilities in most of the states, which have become a new marketing strategy to fetch a higher value. With the increasing consumers' preference for fresh fillets, ready-to-cook and ready-to-eat fish in recent years, there has been an increasing reach of freshwater fish in the domestic supermarkets too.

29.8 Perspectives

The fisheries sector in India has been able to demonstrate a phenomenal average annual growth rate of 10.88% to the national GVA in the last five years. Towards this, the share of freshwater aquaculture has been quite substantial through a consistent increase in fish production of the country. As stated, the coastal region has taken the lead to supply a lion's share of the produce, both for the domestic and export markets. It is expected that when the country is targeting to produce 22 MMT fish by 2025 (DoF 2020b) with a contribution of 15.5 MMT from aquaculture and again 14 MMT from freshwater aquaculture, the coastal states must continue to contribute significantly in the coming days. The task although seems to be quite challenging with all odds, viz., reducing freshwater resources, water shortage, high input cost, labour scarcity; apart from the environmental concern and climate change, it needs to be accomplished. The present R&D focus on frontier areas such as breed improvement, culture diversification, vertical increase in productivity, feed development for diversified species, disease surveillance and management, water budgeting, development of climate resilience systems and practices, post-harvest value addition, and market creation is expected to continue its significant role towards keeping the growth pace of aquaculture as earlier years. It is required that Indian aquaculture is further supported by innovative developmental programmes like the ongoing PMMSY, increased investment, and greater efforts on technology dissemination.

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