# Brackishwater Aquaculture: Opportunities and Challenges for Meeting Livelihood Demand in Indian Sundarbans

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**Abstract**

Brackishwater farming in India has been a traditional practice for centuries and confined mainly to the *bheries* (manmade impoundments in coastal wetlands) in Sundarbans, West Bengal, India. Scientific brackishwater aquaculture started in India with tiger shrimp (*Penaeus monodon*) farming initiated during early 1990s. With the introduction of Pacific white shrimp (*Penaeus vannamei*) during 2009, Indian aquaculture industry has grown rapidly. In addition, certain marine/ brackishwater fish such as, seabass, mullets, milkfish and pearlspot have shown a lot of promise. Successful domestication of indigenous Indian white shrimp (*Penaeus indicus*) and experimental farming using hatchery-produced seed by ICAR-Central Institute of Brackishwater Aquaculture (CIBA) showed encouraging results. Besides domestic consumption, fishery products exported from the state were 1.05 million tons of value Indian rupee (INR) 33,4420 million during 2015-16. Indian Sundarbans located in the south-east end of West Bengal offers congenial environment for growth of variety of fishes and shrimps. Frozen shrimp and live crab are the main export items from brackishwater aquaculture in Sundarbans. As the economic benefit is greater, there is a tendency of Sundarbans dwellers to shift from fishing to aquaculture for better livelihood. About 25% of 2.1 lakh ha potential brackishwater areas in West Bengal are under use and the state has been the Indian leader in tiger shrimp production while farmers adopted white leg shrimp farming late compared to other Indian maritime states after successful demonstration by ICAR-CIBA at its research centre at Kakdwip. There is vast scope for sustainable development of brackishwater aquaculture in Sundarbans to meet the livelihood demand utilizing the unused and underused areas and adopting advanced farming practices. Challenges faced by Sundarbans aquafarmers need to be tackled by appropriate management tools like social mobilization of aqua producers, technology assessment and refinement, participatory planning, and capacity building of key stakeholders.

**Keywords** Sundarbans ●Brackishwater aquaculture ●Technology development ● Biosecurity measures ● Species diversification ●Sustainable development ●Livelihood ●Opportunities ●Challenges

## Introduction

The greatest challenge India faces is to ensure food security of the largely undernourished protein-starved population, especially in the context of declining land resources available for agriculture and animal husbandry. Hence fisheries, mainly aquaculture sector, would have to emerge as the savior to meet increased food demand. Carp in freshwater and shrimps in brackishwater form the major areas of activity in Indian aquaculture. Brackishwater farming in India is an age-old traditional system confined mainly to the *bheries* (manmade impoundments in coastal wetlands) of West Bengal, similar to *gheris* in Odisha, *pokkali*' (salt resistant deep water paddy) fields in Kerala, *kharlands* in Karnataka and Maharashtra, and *khazans* in Goa coasts (Alagarswami 1981). These systems have been sustaining production of 500–750 kg $ha^{-1}$ $year^{-1}$ with shrimp contributing 20–25% without additional input, except that of trapping the naturally bred juvenile fish and shrimp seed during tidal influx (FAO 2014).

Scientific farm management in brackishwater sector in India initiated during early 1990s concentrated around the giant tiger shrimp (*Penaeus monodon*), which witnessed a phenomenal increase during 1990–1994, and the bust came in 1995-96 with the outbreak of viral disease. Later, with the advent of bio-secured closed culture technology (Panigrahi et al 2009) using better management practices, semi-intensive shrimp farming started to regain its lost glory during early years of last decade. Apart from the giant tiger shrimp, certain marine/ brackishwater fishes such as seabass, mullets, milkfish, catfish and pearlspot have shown a lot of promise for commercial aquaculture. Since 2009, the culture of exotic white-leg shrimp, *Penaeus vannamei*, has attracted the farmers' attention because of its fast growth, low incidence of native diseases, availability of Specific Pathogen Free (SPF) domesticated strains, and culture feasibility in wide salinity range. Recently, ICAR-Central Institute of Brackishwater Aquaculture (CIBA) has been successful in domestication of indigenous Indian white shrimp, *Penaeus indicus*, and experimental farming using hatchery-produced seed showed promising result. Seabass farming was popularized by ICAR-CIBA through culture demonstration of seabass in different coastal states of India. India produced 4.88 million tons of aquatic animals through aquaculture during 2014, ranking second in the world only after China, while total fisheries production was 9.6 million tons (FAO 2016).

Indian Sundarbans located in the lower Gangetic region of the sub-continent at the apex of Bay of Bengal (within latitude 21°13' N to 22°40' N and longitude 88°03' E to 89°07' E), covering little less than half of the total Sundarbans, offers a congenial environment in terms of salinity and other hydrological parameters for the growth and culture of variety of fishes. This region is intersected by a complex network of tidal waterways, mudflats, and small islands of salt-tolerant mangrove forests, and presents an excellent example of ongoing ecological processes, which is vulnerable to environmental alterations. In this coastal region, there are a large number of poor marine fishermen who primarily depend on the Hooghly-Matla estuarine complex and the adjacent sea for their livelihood. As the economic benefit is greater than that in traditional fishing, there is a tendency to shift from fishing to aquaculture. In tune with the Indian trend, aquafarmers of Indian Sundarbans has adopted scientific brackishwater farming with remarkable success which has become an important tool for increasing livelihood security in such a vulnerable eco-region. There is vast scope for sustainable development of brackishwater aquaculture in

Sundarbans to meet the livelihood demand utilizing the unused and underused areas and adopting advanced farming practices. Challenges faced by Sundarbans aquafarmers need to be tackled by appropriate management tools like social mobilization of aqua producers, technology assessment and refinement, participatory planning, and capacity building of key stakeholders, which are being discussed in this article.

## Area, Production and Productivity

In India, about 13% of 1.24 million ha potential brackishwater resource is under use at present. Farmed tiger shrimp production recorded over five-fold increase from 28000 tons in 1988-89 to 144347 tons utilizing 149632 ha in 2006-2007 (MPEDA 2017), and was operating at around 100000 tons tiger shrimp till introduction of white leg shrimp during 2009. Afterwards, a shift towards white leg shrimp from tiger shrimp was observed over recent years (Fig. 1). In this process, tiger shrimp production was reduced to 81450 tons utilizing 68846 ha with productivity of 1.18 tons $ha^{-1}year^{-1}$, while production of white leg shrimp reached all-time high of 406018 tons utilizing area of 59116 ha with productivity of 6.87 tons $ha^{-1}year^{-1}$ during 2015-16 (MPEDA 2017).

Total fish production in West Bengal during 2015-16 was 1.67 million tons of which 0.12 million ton was contributed by shrimp (DoFWB 2016). West Bengal being the largest producer of tiger shrimp among Indian maritime states produced 61998 tons of tiger shrimp utilizing 50593 ha during 2015-16, and majority of this was produced in Indian Sundarbans covering two maritime districts (South and North 24 Parganas) occupying most of the 0.21 million ha potential brackishwater areas in the state. The age-old traditional farming methods of shrimp and finfish with some modification still exist because of their simplicity and cheapness. A part of these are being gradually replaced by modern improved culture practices.

Brackishwater farmers of West Bengal started adopting white leg shrimp farming late compared to other Indian maritime states. First, white leg shrimp farming demonstration in West Bengal was carried out by ICAR-CIBA, Kakdwip Research Centre, Kakdwip during 2012, and farmers started to adopt its farming since 2013 replacing tiger shrimp. White leg shrimp production in West Bengal during 2015-16 was 6776 tons utilizing 1387 ha area with productivity of 4.88 tons $ha^{-1}$ $year^{-1}$. A comparative trend of tiger shrimp and white leg shrimp production in West Bengal is presented in Fig. 2.

## Contribution of the Sector to the Indian Economy

India has shown continuous and sustained increments in fish production since independence. Constituting about 6.3% of the global fish production, the sector contributes 1.1% of the GDP and 5.15% of the agricultural GDP of India. The total fish production of 10.07 million metric tons during 2015-16 had nearly 65% contribution from the inland sector of which major share came from culture fisheries (NFDB 2017). There are 429 Fish Farmers Development Agencies (FFDAs) and 39 Brackishwater Fish Farmers Development Agencies (BFDAs) in India for promoting freshwater and coastal aquaculture. The annual carp seed production is to the tune of 25 billion and that of shrimp about 12 billion, with increasing diversification in the recent past. Fish and fish products have presently emerged as the largest group in agricultural exports of India with 1.05 million tons in term of quantity and INR 33,4420 million in value during 2015-16. This accounts for around 10% of the total exports of the country and nearly 20% of the agricultural exports. More than 50 different types of fish and shellfish products are exported to 75 countries around the world (NFDB 2017).

Fisheries sector of West Bengal contributed 2.35% of Net State Domestic Products (NSDP) during 2014-15 which is much higher than contribution of the sector in Indian GDP indicating its importance to the state’s economy (DoFWB 2016). Besides domestic consumption, fishery products exported from the state was 91263 tons of value Rs. 34390 million during 2015-16. Frozen shrimp and live crab are the main export items from brackishwater aquaculture in Sundarbans.

## Advances in Brackishwater Aquaculture Technologies

There are five different brackishwater aquaculture practices mentioned in the literature, ranging from traditional to super-intensive (Shiva and Karir 1997, Primavera 1998, Rosenberry 1999). Most common practices followed in Sundarbans are traditional, extensive, semi-intensive, and intensive. These are divided according to stocking densities and the extent of management, i.e. level of inputs (Table. 1), which turns out into different economic outcomes (Table. 2).

Traditional systems are often characterised by polyculture of shrimp and fish or by rotation with rice. In this method, low-lying areas near the banks of saline water rivers and creeks are encircled by peripheral dyke, and tidal water is allowed to enter into the impoundment along with natural seeds of various species of shrimps, crabs and fishes. Water is retained with periodical exchanges during lunar cycles and the animals are allowed to grow utilizing natural food. After 3 – 4 months, partial harvesting starts using tidal inflow during lunar cycles and continues up to 10 – 11 months. Productivity in this system ranged between 500 – 750 kg $ha^{-1}year^{-1}$ of which about 30 percent is constituted by prawns/ shrimps and 70 per cent by other brackishwater fishes.

The extensive farming is commonly known as improved traditional farming, which relies on the tides to provide most of the food for the shrimp and as a means of water exchange. Feed for shrimp is naturally occurring, and in some cases fertilizers or manure is added to promote algal growth. Low stocking densities result in modest yields. This system involves construction of peripheral canals/ ponds of size ranging from 1 – 5 ha. Shrimp seed at the rate of 15000 – 20 000 per ha are stocked. The average yield is 1500 – 1700 kg $ha^{-1}$, including finfishes. Supplementary feeding is not generally practised; however, some farmers use oilcakes and rice bran as supplementary feed.

Semi-intensive cultivation involves stocking densities beyond those that the natural environment can sustain without additional inputs. Consequently, these systems depend on reliable shrimp post larvae (PL) supply and greater management intervention compared to extensive ponds. With stocking rates of 6-20 shrimp PL per $m^2$, fertilizers are applied to augment natural food in the ponds. Supplementary feeding is done using formulated feeds preferably in pelletized form. Maximum annual yields range from 2 to 6 tons per hectare. The risk of crop failure increases with increasing farming intensity, which is mainly due to the impact on water quality exerted by the high stocking densities and supplementary feeding. The higher the culture intensity, the higher the capital required, and higher the risks involved. Thus, the increased capital inputs required for semi-intensive culture often preclude its adoption by small-scale producers. Most of the tiger shrimp monoculture is carried out in this system.

Intensive grow-out systems utilize ample supplies of clean sea/ estuarine water, adequate infrastructure, and well-developed hatchery and feed industries. Intensive shrimp farming introduces small enclosures (down to 0.1 ha), high stocking densities (20-50 hatchery-produced shrimps per $m^2$), around-the-clock management, very high inputs of formulated feeds, and aeration. Yields range from 7 to 15 tons $ha^{-1}year^{-1}$ with high risk of crop failure due to diseases. Most of the *P. vannamei* farming is conducted in this method using specific pathogen free (SPF) seeds under strict biosecurity protocol.

## *Scientific Shrimp Farming Practices Followed in Indian Sundarbans*

### Site Selection

The site is selected only after thorough analysis of information on topography, ecosystem, meteorological, socioeconomic conditions, and economic viability. Coastal sites with gentle slopes towards the sea are selected requiring less financial inputs. Clay loam or silty clay loam soil is preferred (CIBA 2004). Site should be easily accessible with availability of basic needs and not within coastal regulation zone (CRZ) following Coastal Aquaculture Authority of India (CAA) guidelines.

### Farm Design and Construction

Proper designing and construction of farms are essential for efficient management and for promoting environmental protection. A typical shrimp farm is shown in Picture. 1. The height of peripheral dyke is built in accordance with highest flood level. Height of the pond dyke should be at least 2 m with side slope of 1:1 for clayey soil and 3:1 for sandy soil (CIBA 2004). Rectangular or square ponds are appropriate. A reservoir pond is required to act as settlement pond. Effluent treatment pond (ETP) becomes an essential part of a semi-intensive farm.

**Pond Preparation**

Good pond preparation is the key to reduce disease risks and improving shrimp production. Presence of black soil in pond bottom is checked in wet condition. Black soil may be removed either using mud pumps in wet condition or manual labor after drying. Optimum average soil pH should be 6.5-7.5. Lower soil pH may be corrected applying lime. Soon after pH correction, ponds are filled with optimum quality water up to a depth of 120-150 cm after screening through 60-80 mesh net. Water is retained for 3 days with aeration for 1-3 hours daily. Aerators are positioned properly to achieve maximum water circulation. Every 500 kg production beyond 2000 kg $ha^{-1}$ requires minimum 1 KW aeration power (Boyd 1998). Pond is disinfected by applying bleaching powder @ 60 ppm (20 ppm chlorine) during late evening. After 5 days, dolomite @ 100-200 kg $ha^{-1}$ and organic juice @ 200 litre $ha^{-1}$ on the following day are applied to stimulate plankton bloom. This schedule is repeated three times at a gap of 3 days. Organic juice is prepared by mixing 60 kg paddy flour, 20 kg molasses and 3 kg yeast in 200 L freshwater $ha^{-1}$, and incubated for 48 hours in air tight condition (Panigrahi et al 2009). When the color of the water is green, fluctuation between morning (6:00 AM) and late afternoon (3:00 PM) pH is below 0.5 and other parameters in optimum range, the pond is ready for stocking.

**Biosecurity Measures**

Biosecurity measures are of immense importance in shrimp farming to protect the stock from diseases. Farm should be protected with bird and crab fencing (CIBA 2010a). A typical biosecured shrimp pond is shown in Picture. 2. Proper hand and foot wash in potassium permanganate solution is mandatory before entering the farm. Every pond should have separate implements. Water depth more than 120 cm in the pond reduces stress and risks of diseases. Farming in closed ponds i.e., '0 exchange' restricts entry of pathogen and carriers of diseases. All implements are washed in chlorinated water before first use. Proper understanding of the personals on biosecurity measures is most important.

**Stocking**

Selection of good quality PL for stocking is an important criterion. Good quality seeds are characterized by uniform size, intact appendages, healthy appearance and active movement. Further, seeds which tested negative for monodon baculo virus (MBV) and white spot syndrome virus (WSSV) are stocked. Stocking is done during early morning or late evening after proper acclimatization to pond water condition. Recommended stocking density is up to 30 number per $m^2$ for specific pathogen free (SPF) *P. monodon* (CAA 2012) and up to 60 numbers per $m^2$ for *P. vannamei* (CAA 2009).

**Feeding Management**

Feed accounts for about 60% of total operational expenditure. Both over-feeding and under-feeding may result in crop loss. Feed should contain appropriate nutrients for the particular species and should be of appropriate crumble or pellet size as per size of shrimp. Feed should be stored in dry and aerated place. Daily ration is divided into meals and applied as per Tables. 3 and 4. Daily ration is calculated as per Tables. 5 and 6. Blind feeding is practised up to 50 days and feed requirement afterwards is calculated based on estimated biomass through sampling and using the formula (Chanratchakool et al 1994):

$$Daily\ ration\ (kg) = \frac{Mean\ body\ weight\ (g) \times Stocking\ no \times Assumed\ survival\ (\%) \times Feeding\ rate\ (as\ \%\ of\ biomass)}{10000 \times 1000}$$

For example, daily feed requirement for 100000 tiger shrimp of 5 g average body weight with assumed survival of 90% using Table. 5 would be:

$$\frac{5\ \times 100000\ \times 90\ \times\ 5.5}{10000 \times 1000} = 24.75\ kg$$

Six check trays (80×80×10 cm) per ha are placed on the pond floor just beyond the dyke slopes and a small part of the calculated meal is placed in trays during feeding. Check trays are monitored after 2 hours of feed application. If some feed is left in trays, feed is reduced by 10-20%; when feed is fully consumed within 2 hours, increment of 10-20% in the next meal is done. Quantity of feed in check trays varies with pond size and can be calculated from recommended ‘feed in each check tray (g $kg^{-1}$)’ provided in Tables. 5 and 6 for respective species using the formula:

$$Quantity\ of\ feed\ in\ each\ check\ tray\ (g) = \frac{1600 \times Feed\ in\ each\ check\ tray\ (g/Kg) \times Quantity\ of\ meal\ (Kg)}{Area\ of\ pond}$$

For example, feed quantity in each check tray for each kg of meal for tiger shrimp of 5 g average body weight (Table. 5) in different pond sizes would be:

$$Check\ tray\ feed\ quantity\ or\ each\ kg\ of\ meal\ in\ 1000\ sq\ m\ pond = \frac{1600 \times 24 \times 1}{1000} = 38.4\ g$$

$$Check\ tray\ feed\ quantity\ for\ each\ kg\ of\ meal\ in\ 2000\ sq\ m\ pond = \frac{1600 \times 24 \times 1}{2000} = 19.2\ g$$

**Water Quality Management**

Maintaining optimum water quality (Table. 7) is very important to minimize stress and disease risks, and to finally achieve better shrimp production. Liming is most important in water and soil quality management. Water pH should range from 7.5 to 8.5 with diurnal fluctuation less than 0.5. Dissolved oxygen (DO) should not be allowed to drop below 4 ppm at any time (CIBA 2010b). Aeration is done before each feeding. Organic juice is applied fortnightly to maintain C: N ratio in the pond. Commercially available probiotics are also used.

Mineral supplementation is required for *P. vannamei* at low salinity and in areas with mineral deficiency in soil. Mineral concentrations at a particular salinity should be equivalent to that of seawater diluted to that salinity (CIBA 2016). Mineral concentrations of seawater and factors for 1 ppt salinity are presented in Table. 8.

For example, concentration of calcium at 4 ppt should be 46.4 (4×11.6) mg/ L

Mineral requirement is calculated by using the following formula:

$$Mineral\ salt\ requirement\ (g/m^3) = \frac{Concentration\ of\ mineral\ in\ water\ (mg/L)}{Percentage\ of\ the\ mineral\ in\ salt} \times 0.1$$

### *Diversified Aquaculture Practices Recommended for Sundarbans*

In recent years, successful farming demonstrations of finfishes have paved the way for commercial farming expansion in brackishwater sector in West Bengal. Asian seabass, grey mullet and pearlspot are presently under farming in the state. Milkfish farming has been initiated recently with remarkable success.

#### Asian Seabass

Cannibalism being one of the most serious problems, Asian Seabass (*Lates calcarifer*) farming is done in two phases viz., nursery and grow-out. Nursery pond size ranges from 500 to 2000 $m^2$ with water depth of 50-80 cm. A well-prepared pond is important as predators and competitors can endanger the stocked fry. Fry ranging from 1 to 2.5 cm are stocked @ 20-50 individuals $m^{-2}$. Fry are fed with chopped and grounded (4-6 $mm^3$) trash fish at 100% of biomass initially and gradually reduced to 10% at the end in two equal meals during 9:00 AM and 5:00 PM. The nursing period lasts for about 30-45 days until fingerling stage (5-10 cm) is reached. Hapa, a net cage (mesh size 1.5-2 mm) having dimension of 2×1×1 m, is used for nursery rearing of seabass fry in pond, where 200-300 fry are stocked in series of hapas and fed with finely chopped trash fish in same way as in ponds. Fry in hapa rearing system can be fed with marine fish larval diet at three times a day (Biswas et al 2010). Fishes are graded in different size groups at 5-7 day intervals and restocked in thoroughly cleaned and sundried hapas. Better survival is achieved in hapa nursery rearing than in pond. For production of fingerlings, hapa is an ideal system for nursery rearing of seabass (Prem et al 2016). As cannibalism and differential growth are major problems in seabass nursery, supplementation of 0.5% of L-tryptophan in larval diet reduces cannibalism and improves survival of seabass fry (Prem et al 2017a).

The grow-out phase lasts for about 8-12 months. There are two culture systems employed in pond grow-out of seabass:

(i) The supplementary feeding system is followed in places with adequate supply of fresh trash fish at low-cost. Fingerlings are stocked @ 10000-20000 $ha^{-1}$. Chopped trash fish is fed twice daily in the morning at 8:00 AM and afternoon at 5:00 PM at 10% of biomass initially and gradually reduced to 5% at the end. A very recent development on improving the dietary intake of seabass is the introduction of moist feed. A production of 2-3 tons per ha can be achieved in 8-12 months.

(ii) Forage fish feeding system shows great promise. Abundant natural food is produced and selected tilapia brood stocks are released in the pond at the rate of 5000-10000 $ha^{-1}$. Sex ratio of male to female is 1:3. Tilapia is reared in pond for 1 to 2 months or until tilapia fry appear in sufficient number. Seabass juveniles (8-10 cm in size) from nursery are stocked at the rate of 10000-20000 per ha. Fertilization is continued to maintain tilapia seed production. Seabass production of 2-3 tons $ha^{-1}$ and tilapia production of 1-2 tons $ha^{-1}$ is achieved in 8-12 months (Biswas et al 2011a).

**Grey Mullet**

Full-scale commercial production of grey mullet (*Mugil cephalus*) is a new area of aquaculture diversification in India. This is done in two phases, namely nursery rearing and grow-out culture. After collection from natural sources, fry are transported in oxygen packs at a density of 240 fry $L^{-1}$ for long distance (Prem et al 2012). After acclimatization, fry are stocked in well-prepared earthen nurseries at high densities (up to 25 $m^{-2}$), where they depend mainly on natural food in fertilized ponds (Biswas et al 2012). Moreover, periphyton-based seed rearing is a better option compared to complete feed-based system (Biswas et al 2017). Rice or wheat bran is sometimes used as an additional source of food. Fry are kept in the nursery ponds for 4–6 months (from January-February till June-July) until they are about 20 - 30 g in weight. The fingerlings are then caught, either by draining the nursery ponds into catch ponds or by netting. Grey mullets are usually grown in monoculture or polyculture ponds. Prior to stocking, ponds are prepared by drying, ploughing, and manuring with 2.5–5.0 tons cowdung per ha.. Ponds are then filled to a depth of 25–30 cm and kept at that level for 7–10 days to build up a suitable level of natural feed. The water level is then increased to 1.5–1.75 m and fingerlings are stocked @ 1-2 $m^{-2}$. Extruded feed is supplied to semi-intensive ponds at 5% of biomass initially and gradually reduced to 1% at the end. The growing season is normally about 7–8 months. A production of 2.3-3.7 tons $ha^{-1}$ can be achieved. In polyculture, they are usually stocked with tilapia, milkfish and pearlspot in brackishwater, and with common carp and silver carp in freshwater. In this case, feeding and fertilization programmes are usually targeting the other cultured species, and the mullet feed on the natural feed, detritus, and feed leftovers. Acclimatized to the appropriate salinity, and stocked as 10–15 g individuals at 0.6–0.7 $m^{-2}$, a harvest of 4.3–5.6 tons $ha^{-1}$ $crop^{-1}$ can be obtained.

**Pearlspot**

Pearlspot (*Etroplus suratensis*), also known as 'green chromide', is cultured in the state of Kerala in traditional manner in the Pokkali fields. Farming of this species is practised in West Bengal in a small scale. This fish is highly adapted to captive farming due to its ability to feed on a variety of natural foods. Pearlspot can spawn many times during a prolonged breeding season. Environment simulation, rather than hormonal manipulation, is employed for inducing captive breeding of pearlspot. Captive breeding is carried out either in ponds, tank and cage systems provided with artificial substrates and breeding pits. Appropriate water levels and moderate water flow trigger captive breeding in tank system. Around 400–2000 eggs are laid per brood and over 90% survival is generally obtained. Tank based breeding is also possible for captive seed production (Biswas et al 2014). Nursery rearing is done in small earthen ponds and tank system (Biswas et al 2013). Ponds are sun-dried and limed before letting in water. Water is taken through fine mesh filters to avoid entry of predators. Organic fertilizer is applied @ 500 – 1000 kg $ha^{-1}$ to boost up plankton bloom. After achievement of sufficient plankton bloom fry of 1 – 1.5 cm size are stocked @ 5 – 10 no. $m^{-2}$. Fishes are fed with mixture of rice bran and mustard oil cake (3:1) in fine powder form at 20% of biomass initially and gradually reduced to 5% at the end. After two months, fishes attain a length of 5 – 10 cm depending on availability of natural food in the nursery ponds. Most of them are harvested to be sold as ornamental fish. Grow-out monoculture is done in similar way with 2 – 5 no. $m^{-2}$ and feeding is done at 5% of biomass initially and gradually reduced to 2% at the end for 6 - 8 months. Fishes attain an average body weight of about 100 g in this practice.

**Milkfish**

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. It constitutes important seafood in Southeast Asia and some Pacific Islands. It is called 'bangus' in the Philippines, where it is the national fish. In India, extensive seed availability is observed in south-east and south-west coast during April-June and October-December. Seeds are collected from those areas and reared in saline impoundments. Recently, success in captive breeding has been achieved by ICAR-CIBA. Nursery rearing is carried out in small earthen ponds. Fry are stocked @ 10-25 $m^{-2}$ and fed with 1: 1 mixture of oil cake and rice bran as supplementary feeding at 20% of biomass initially and gradually reduced to 6% at the end. Fishes attain 10- 30 g in 2-3 months nursery rearing. Pond grow-out is mainly done depending on natural food with low production ranging between 1 to 2 tons $ha^{-1}year^{-1}$ (Biswas et al 2011b). Recent culture trials in Sundarbans by Kakdwip Research Centre (KRC) of ICAR-CIBA at stocking density of 1 fish $m^{-2}$ and feeding with formulated floating pellet feed (crude protein: 24%, crude fat: 4%) @ 2-6 % of fish biomass in non-aerated periphyton supported brackishwater pond, and has achieved production of more than 4 tons $ha^{-1}$ in 8 months. Fishes grew to 400-500 g during 8 months rearing period registering over 90% survival. This fish is a good candidate species for polyculture with shrimp as it has stronger mucosal immune properties compared to that of mullet and seabass (Prem et al 2017b) and may help in disease prevention.

## Opportunities, Challenges and Conflicts

### *Opportunities*

There are different opportunities to improve brackishwater aquaculture production. Among short-term strategies, improving traditional system of farming, development and dissemination of low-cost farm-made feed, control of diseases, and improved production through good aquaculture practices like, biofloc and periphyton based system, are the best options available. Long-term strategies like, development of organic farming, genetic improvement of shrimp stock through selective breeding, improved and intensive culture methods, adoption of cage farming of fishes, and overcoming the constrains through participatory fisheries management, public-private partnership, refinement of indigenous technical knowledge, can be taken up (Mehta 2009).

Domestic markets for fish and fish products not only provide an entirely new opportunity for growth but also can act as a buffer in case of gluts in the international markets. Institutional agencies have an onerous task on hand for enabling the domestic markets for fish to establish itself.

#### Improvement in Traditional Farming

Polyculture is potentially more sustainable than monoculture is, due to the reutilization of waste products of one species by another. Shrimp polyculture represents an important alternative to solving and⁄or minimizing some of the problems (i.e. environmental pollution, diseases and decreasing prices) that shrimp aquaculture has faced in the past two decades. Several species from diverse trophic levels have the potential to be co-cultured with shrimps. A good knowledge of the species that are candidates for polyculture and availability of an adequately designed culture system are the most important points to consider when co-culturing shrimp is practised with other species (Martı´nez-Porchas et al, 2010). Modification of age-old traditional brackishwater polyculture is a logical choice towards sustainable intensification of aquaculture.

**Selection of Compatible Species for Polyculture**

Modification of traditional brackishwater polyculture through selection of compatible species for sustainable better production and profitability were tested by KRC of ICAR-CIBA involving tiger shrimp (*Penaeus monodon*), Grey mullet (*Mugil cephalus*), Parsia (*Liza parsia*), and Milkfish (*Chanos chanos*) to assess the optimum species combination. Presence of all species and absence of one fish species in each combination were considered as treatments. The study was carried out at Manmathapur-Mundapara village (21.879493-21.894148°N, 88.263668-88.276199°E) of Kakdwip block in Indian Sundarbans for 240 days during 2013. Ponds were prepared following standard procedure and reared organisms were fed with commercially available sinking pellet feed (Crude Protein: 24%, Crude fat: 3%) @ 2-10% of fish biomass. Tiger shrimp, grey mullet, parsia and milkfish were stocked @ 2, 0.5, 0.5 and 0.25 no $m^{-2}$, respectively, which were decided based on normal practice in traditional farming as revealed from a semi-structured interview-based survey. Best growth (44.17±1.53 g) of tiger shrimp was achieved in presence of all species with lowest survival (17.9±3.4%), and highest survival was observed in absence of milkfish (41.3±5.6%) with moderate growth (42.65±1.25g). Best growth of parsia was observed in absence of milkfish (54.16±6.34 g), while highest survival was found in absence of grey mullet (61.9±4.1%). Grey mullet grew best in absence of milkfish (487.17±20.42 g) and survived best in presence of all species (60.5±4.4%). Milkfish grew best in absence of grey mullet (382.91±18.39 g), and highest survival (71.1±6.8%) was found in presence of all species. Significantly ($p<0.05$) higher total harvested biomass (1931.64 kg $ha^{-1}$) was produced in presence of all species followed by treatments with absence of parsia (1794.11 kg $ha^{-1}$), absence of milkfish (1739.42 kg $ha^{-1}$), and absence of grey mullet (922.51 kg $ha^{-1}$). Highest total income (INR 520650) was achieved in species combination without milkfish followed by presence of all species (INR 410303), without parsia (INR 360362), and without grey mullet (INR 203099) with respective benefit-cost ratio of 2.798, 2.048, 1.824 and 1.242. Growth, production and economic parameters of the study indicated technical and economic viability of mullets-tiger shrimp polyculture. Mullets-milkfish-tiger shrimp polyculture was also viable but with lower profitability.

**Development and Dissemination of Low-cost Farm-made Feed for Polyculture**

KRC of ICAR-CIBA took initiatives to standardize polyculture practices with indigenous brackishwater fish and shrimp, where use of low-cost farm-made feed with locally available feed ingredients helped the polyculture towards sustainable and economically rewarding activity. This successful model of polyculture has been disseminated among the farmers of the Sundarbans, paving the way for its wide adoption in the region. Several experiments using the low-cost feed were conducted in indoor system, on-farm, and in farmers' ponds, in order to standardize polyculture using indigenous brackishwater fish and shrimp species. Six species polyculture with different stocking densities, *Liza*

*Parsia* (5000 ha$^{-1}$), *Liza tade* (5000 ha$^{-1}$), *Mugil cephalus* (2500 ha$^{-1}$), *Scatophagus argus* (2500 ha$^{-1}$), *Mystus gulio* (30000 ha$^{-1}$), and *Penaeus monodon* (2500 ha$^{-1}$), resulted in 4764 kg ha$^{-1}$ production using low-cost farm-made feed, Poly$^{plus}$ (INR 25.32 kg$^{-1}$, USD 0.41 kg$^{-1}$) having feed conversion ratio (FCR) of 1.36, in three consecutive trials over 325 days in farmers' ponds (De et al 2016).

The farm-made feed (Crude Protein-29.77%) containing different unconventional ingredients (sunflower cake, mung husk) with 10% fish meal performed at par with that of feed containing 22% fish meal in respect of growth and FCR. Economic analysis revealed a net profit of about INR 291000 ha$^{-1}$ (USD 4693.5 ha$^{-1}$) with a benefit-cost ratio of 1.85. Feeding method standardization experiments suggested that low-cost farm-made pellet feed may be offered @ 2–10% body weight per day. Daily ration has to be distributed at three equal quantities in the morning (9.00 AM), at afternoon (1.00 PM), and at evening (5.00 PM) in trays. Every ration may be offered in two split doses at 1 h interval to meet requirements of fish with size variation (De et al 2016).

Production improvement of two to four-fold compared to conventional system has been observed and farmers showed increasing interest in adoption of polyculture farming system with low-cost feed (Poly$^{plus}$) developed by CIBA. To cater the need of farm-made feed, the brackishwater farmers of Sundarbans formed a cooperative society and established a pulverizer with the financial help of the State Government. The polyculture practice has been disseminated to 57 farmers of Sundarbans and about 30 ha area have been brought under improved brackishwater polyculture practices with low-cost formulated feed. There is a vast scope for further development of brackishwater polyculture using low-cost farm-made feed in Sundarbans.

**Production Improvement through Biofloc-based System**

The principle of biofloc technology is based on manipulation of carbon:nitrogen ratio (C:N ratio), and for brackishwater shrimp aquaculture C:N ratio of 10:1 is stated to be optimum. The biofloc is heterogenous mixture of bacteria, algae, protozoa, zooplankton, food particles, and dead cells with bacteria being the dominated component. The cultured shrimp often use the floc particles as their feed. For management of C:N ratio, carbohydrate is applied externally from different sources including molasses, rice flour, wheat flour, tapioca powder, rice bran, wheat bran, etc. In presence of higher carbohydrate, the heterotrophic bacteria utilize ammonia to produce biofloc and thus reduce the level of free ammonia in the water. So, the chances of ammonia toxicity are reduced. This culture system improves the growth rate of cultured shrimp. Apart from these, biofloc-based system reduces the feed requirement leading to reduction of input cost and it also lowers the possibility of diseases. Research work carried out at CIBA showed that biofloc improved the growth rate of juvenile and adult *Penaeus monodon* by 29 and 12.6 %, respectively over the control (Sujeet et al 2017). However, this type of production system produces high level of turbidity, which increases the need of aeration. The dissolved oxygen (DO) level should strictly be monitored regularly and the aeration should be done round the clock (24 hours a day) particularly at the end of the culture period.

**Production Improvement through Periphyton Supported Farming**

Artificial substrates for periphyton development have been widely used in fresh water aquaculture, particularly in carps, tilapia and giant fresh water prawn, to augment fish production. Similarly, promising results in terms of growth, survival and production were observed with periphyton in brackishwater penaeid shrimp, *P. monodon* (Khatoon et al 2009) and *P. vannamei* (Audelo-Naranjo et al 2011). Like biofloc, periphyton is also a heterogenous mixture of biota including bacteria, fungi, phytoplankton, zooplankton, benthic organisms, detritus, etc. But unlike biofloc-based system, here the mixture of biota is generally attached to any submerged surface such as bamboo stick, plastic sheet, polyvinyl chloride (PVC) pipe, ceramic tile, fibrous scrubber, etc. Periphyton-based system also increases the aquaculture production and develops the resistance to different diseases by augmentation of immune response. Work carried out at Kakdwip Research Centre of ICAR-CIBA reported 17.9% gain in production and 22.3% reduction in FCR compared to conventional culture in case of *P. monodon* (Shyne Anand et al 2013). The submerged substrates added into the aquatic system improve the water quality (Thompson et al 2002), and consumption of microbes and algal community present over submerged substrates enhances the growth of penaeid shrimp by providing natural food (Ramesh et al 1999).

**Diversification of Species**

Brackishwater aquaculture development in India was mostly oriented till 2009 to tiger shrimp, *P. monodon* culture, only. In 2009, the Coastal Aquaculture Authority of India (CAA) permitted the entrepreneurs to introduce a new species, *P. vannamei* (Pacific white leg shrimp), in India with prescribed guidelines (CAA 2009). Before introduction, risk analysis was carried out by Central Institute of Brackishwater Aquaculture (CIBA) and National Bureau of Fish Genetic Resources (NBFGR) following pilot scale initiation in 2003. Since introduction, *P. vannamei* farming showed rapid growth and a shift towards *P. vannamei* from *P. monodon* was observed in India due to its high productivity (6-10 ton $ha^{-1}$) and international market demand. Another species, Indian white shrimp, *P. indicus*, seems to be promising one as CIBA demonstrated a production of 3-5 tons $ha^{-1}$ using CIBA hatchery-produced seed.

The annual contribution of finfish to total aquaculture production has been increasing in recent years. The diversity provides very promising development opportunities for the brackishwater fish culture. Unlike other aquatic organisms, finfish can be cultured in a number of culture systems like, cages, pens, ponds. Variety of fishes is available suitable for different culture practices, such as for monoculture, polyculture, and can be integrated with livestock and agriculture. Therefore, fish plays major role in aquaculture production and there is lot of scope to expand the farming activities in a diversified manner.

**Improvement in Finfish Culture Practices**

Fishes like Asian seabass (*Lates calcarifer*), Grouper (*Epinephelus tauvina*), snappers (*Lutjanus sp.*), which are high-value carnivorous fishes, and striped grey mullet (*Mugil cephalus*), Tade mullet (*Liza tade*), Parsia (*Liza parsia*), milkfish (*Chanos chanos*), and pearlspot (*Etroplus suratensis,*), which are herbivorous/omnivorous, are available for farming in the coastal ecosystem. In addition to this, fishes like long whiskers catfish (*Mystus gulio*), popularly called as 'Nuna tengra', is being cultured in coastal ecosystem. Successful technology has been developed for the seed production of Asian seabass under controlled conditions and farming by ICAR-CIBA since 1997 (Thirunavukkarasu et al 2001, 2004). The controlled breeding of grouper (*E. tauvina*), striped grey mullet, and pearlspot has also been successful. In addition to this, an avenue has come by successful breeding and seed production of ornamental fish spotted scat (*Scatophagus argus*). Monoculture of Asian seabass is in practice in some pockets where cheap trash fish is available in plenty. Seabass seeds are stocked @ 10,000 – 15,000 per ha in well-prepared culture ponds. In this system the stock is totally raised on supplementary feed. Stocked fishes are fed with chopped trash fishes collected from landing centers. As seabass does not feed at the pond bottom the chopped trash fish is broadcast slowly twice a day. Feed is provided *ad libitum* at not more than 100% of total biomass and gradually reduced to 10% at the last phase of culture. In this method, after a culture period of 8 – 10 months seabass attains average size of 800 g with a survival rate of 60 – 70%, and a production of 2.5 – 4 tons $ha^{-1}$ is achieved. Polyculture of Asian seabass following 'predator-prey culture' system using tilapia as prey material has also been tried with considerable success. In this system, fish can grow similar to trash fish feeding system if sufficient prey fishes are available (Biswas et al 2011a). Scientific farming of brackishwater finfishes is a new intervention for brackishwater aquaculture development with immense potentiality.

**Improvements in Crab Farming Practices**

There is huge potentiality for mud crab farming in India. Still there is no organized aquaculture of mud crab for supporting the export trade. Major reason is the non-availability or inconsistent availability of crab seeds for farming. Technology for seed production, culture and fattening of mud crab, *Scyllla olivacea*, and green crab, *S. serrata*, has been developed by ICAR-CIBA (CIBA 2000). Some farmers are practising crab fattening in the coastal districts of West Bengal with considerable success. Survival up to 70-80% is generally achieved after 20-30 days of fattening operation (Suseelan 1996). After the inception of crab hatchery by The Rajiv Gandhi Centre for Aquaculture (RGCA) in Nagapattinam district in Tamil Nadu, hatchery-produced crab seeds are now available. Some progressive farmers in Kakdwip block, West Bengal have started crab grow-out farming with productivity of 1-1.8 ton $ha^{-1}$ with the help of hatchery- produced seeds. Some compatible fish like parsia, grey mullet, and milkfish can be co-cultured with crab to earn more profit.

**Ornamental Fish Culture**

Ornamental fishery has a very bright prospect not only in the domestic market but in the export market as well. West Bengal is pioneer in ornamental fish culture and ranks first in domestic production and export outside among all the Indian states. Brackish water ornamental fishes like spotted scat (*Scatophagus argus*), Puffer fish (*Tetradon cutcutia*), Loaches (*Botia* spp), and Eels (*Anguilla* spp), which are available in maritime districts of West Bengal, have started to gain importance in domestic and export market. Farming of all those species is going on depending upon natural seed availability. Pearlspot (*Etroplus suratensis*), introduced in West Bengal by KRC of ICAR-CIBA, has gained lots of popularity as ornamental fish. Seeds of pearlspot are produced in captivity using environmental manipulations. Farming of spotted-scat and pearlspot is on the way to fetch substantial profit.

**Organic Farming**

Today, the demand in the importing countries for high quality and safe shrimps/fish/crab, raised in an ecofriendly manner by adopting good management practices, has become an essential pre-requisite for Indian seafood export. The brackish water area available in India for shrimp farming offers good potential for organic farming (Mehta 2009). This includes the vast traditional prawn filtration fields located in West Bengal and Kerala. The traditional type of prawn filtration system is highly environment-friendly as they use no chemicals, drugs or antibiotics. Organic aquaculture ensures that the farming activity is in harmony with the nature, raised with due care for the good health and welfare of the cultured organisms. Organic products have become very popular of late due to the rising awareness in health and food safety. There is a growing demand for organic products in the global market, especially in Europe, USA, China, etc. The purpose to shrimp certification is to enhance the market share for the shrimp produced by responsible methods, inputs and practices, that would meet the expectations of socially and environmentally aware consumers. Certification process has to be simplified and branding of shrimp produced through improved traditional methods as ‘organic’ may fetch better price. A trial towards organic farming of shrimp was carried out by ICAR-CIBA at KRC showed promising result with better profitability (CIBA 2010c).

**Other Management Practices for Improvement**

Water exchange during lunar cycles is carried out in traditional farms to draw nutrients within the system. During the course of water exchange, silt carried by tidal water gets deposited resulting in swallowing of the impoundment. Shallow depth of the traditional farms enables physical and chemical water quality parameters to fluctuate abruptly triggering viral diseases especially during summer. Desilting of the traditional impoundments to increase water depth to more than 1 m might reduce prevalence of shrimp diseases. Application of yeast-based organic preparation in traditional farms may reduce shrimp disease as glucans contained in yeast acts as immune-stimulant. As traditional farming depends mostly on auto- stocking, natural shrimp seeds may carry pathogens of viral diseases. Closed culture and stocking of PCR- tested hatchery-produced shrimp seeds may improve crop security and farm income (CIBA 2010a).

Efforts towards adoption of improved farming technologies like recirculatory aquaculture system (RAS), improved polyculture, integrated multi-trophic aquaculture (IMTA) may make brackishwater aquaculture more environmentally acceptable, protocols of which are to be explored in order to provide more secured livelihood (Martínez-Porchas et al 2010).

## *Challenges and Conflicts*

Coastal aquaculture faces number of challenges including disease outbreaks, fluctuating market prices, rising input costs, etc. These challenges need to be tackled by appropriate management tools for sustainable development of aquaculture. These tools include social mobilization of aqua producers, technology assessment and refinement, participatory planning, and capacity building of key stakeholders. There is a need to create more awareness and knowledge among the stakeholders on various aspects of management tools for ensuring sustainable aquaculture development.

### Enhancement of Area under Cultivation

High potential and high return areas need to be identified. Out of 0.21 million ha, only 28% of brackishwater aquaculture resources of West Bengal are brought under culture (Govt. of India, 2017). As the fishery resources of the state were estimated quite some time back, due to considerable changes made on land and water use so far, the resources need to be reassessed qualitatively and quantitatively to launch specific programmes in high potential areas.

### Improvement of Traditional Farming System

'Bhery' farming is an age-old traditional system with low productivity. Sludge removal from *bhery*s to increase water depth and adoption of improved polyculture are needed for sustainable production improvement (Ramsundar 2011).

### Availability of Quality Seed

Quality of seed is of prime importance in aquaculture. Due to absence of shrimp hatchery in West Bengal, farmers depend on southern states for hatchery-produced shrimp seeds brought through commission agents (Knowler et al 2009). Farmers are compelled to pay more cost and often receive poor quality seeds (Umesh et al 2010). Establishment of seed bank and viral disease screening facility is required. Hatchery-produced fish and mud crab seeds should be made available to the farmers through seed bank by establishment of nursery rearing facility (Ghoshal et al 2016).

**Availability of Quality Feed at Low-cost**

Feed accounts for about 60% of operational cost in aquaculture. Feed price is increasing by leaps and bounds due to low availability of fish meal as the key ingredient. Development of low-cost feed using locally available ingredients is very much required (Ghoshal et al 2016). As brackishwater fish monoculture is gaining popularity, species-specific feed is required to be made available to the farmers through establishment of small and medium scale feed mills. Traditional farmers have to be encouraged to use low-cost farm-made feed to improve production.

**Providence of Extension Services**

Proper farm design and construction is of immense importance in aquaculture to improve productivity and profitability (Jayanthi 2007). This aspect is the most ignored one at present state of aquaculture in West Bengal. Providence of extension services on engineering aspects during farm construction phase will surely lead to improved production and profitability. Proper pond preparation and culture management is the key to successful aquaculture. There is a need to educate farmers on the scientific ways to manage ponds for a specific culture practice. Farmers should be trained on better management practices (BMPs) and methods for quality improvement of farmed materials (Kumaran et al 2017).

**Soil and Water Testing Facility**

Establishment of small laboratories for water and soil analysis at strategic locations is very much required for better culture management. PCR test facility should be available within short distances (Khang et al 2008), which is far from adequate.

**Storage Facility and Value Addition**

Shrimp and fish from brackishwater resources are highly perishable commodities. From the production site to post-harvest processing plant of these export-oriented items, it takes long time to reach. Therefore, proper storage facility for harvested material and value addition are important measures to increase profitability and marketability (Pradhan and Flaherty 2007). This should be addressed with prime importance.

### Financial Support

Brackishwater aquaculture is a capital-intensive venture. In Sundarbans, majority of the farmers being small and marginal, require supports in terms of inputs or money to start modern aquaculture operations. The need for financial agencies to accept the scope offered by the sector in terms of returns to investment must be reinforced through training programmes, awareness campaigns, and other extension media.

### Environmental Concerns

In the brackishwater sector there are issues like waste generation, conversion of agricultural land, salinization, and degradation of soil and environment due to extensive use of drugs and chemicals, as well as destruction of mangroves (Primavera 2006). Farmers should be made aware about environmental issues related to aquaculture so that they act accordingly.

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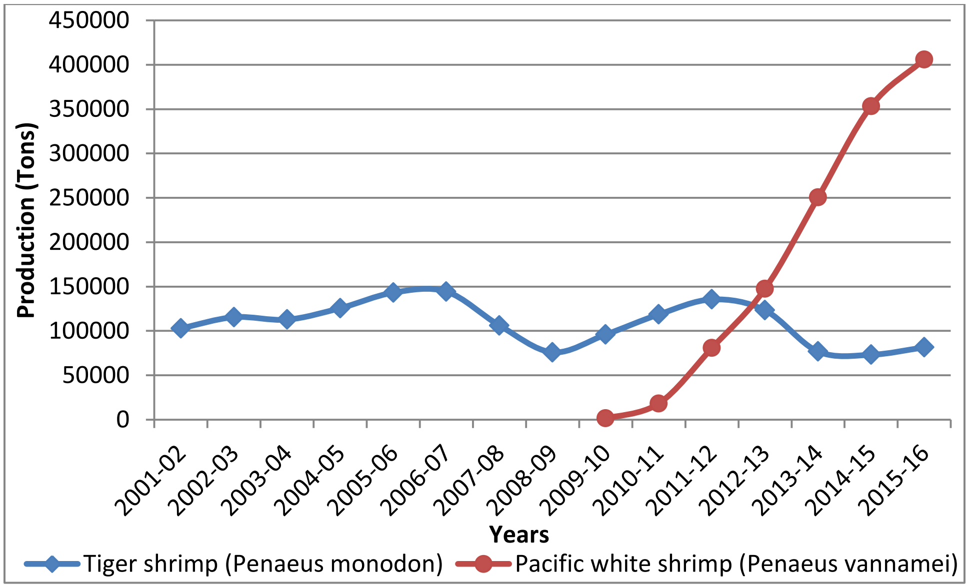


**Fig. 1** Shrimp production trends in India over last 15 years (Source: MPEDA 2017)

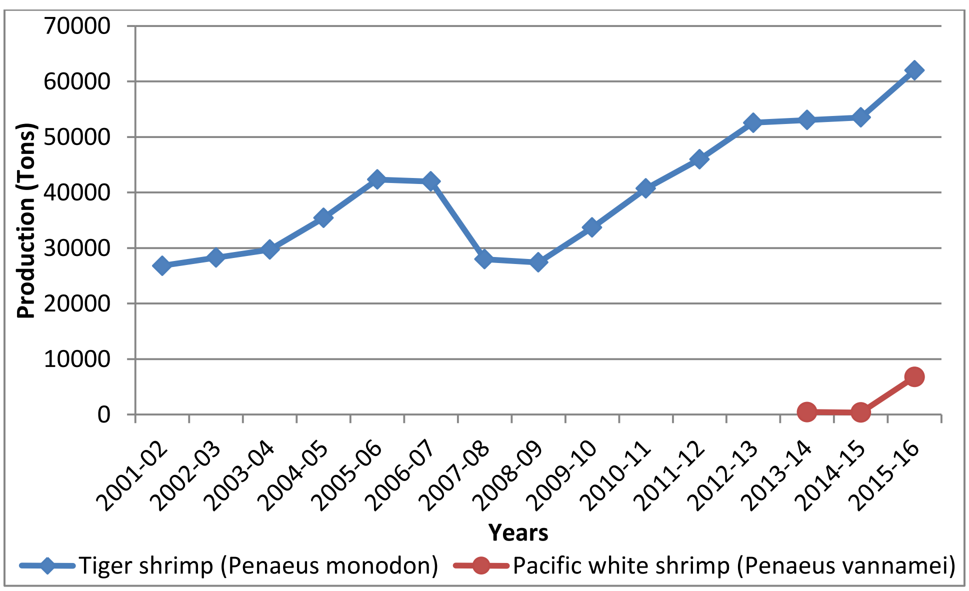


**Fig. 2** Shrimp production trends in West Bengal over last 15 years (Source: MPEDA 2017)

**Table. 1** Farming practices based on level of management, stocking density and production

| **Parameters** | **Traditional** | **Extensive** | **Semi-intensive** | **Intensive** |
|---|---|---|---|---|
| Pond size (ha) | 0.1-50 | 1-10 | 0.2-2 | 0.1-1 |
| Stocking | Natural | Natural + artificial | Artificial | Artificial |
| Stocking density (seed $m^{-2}$) | Unregulated | 2-6 | 6-20 | 20-50 |
| Seed source | Wild | Wild + Hatchery | Hatchery | Hatchery |
| Annual production (t $ha^{-1}$ $yr^{-1}$) | < 0.6 | 0.6-1.5 | 2-6 | 7-15 |
| Feed source | Natural | Natural | Natural + Formulated | Formulated |
| Fertilizers | No | Yes | Yes | Yes |
| Water exchange | Tidal | Tidal + pumping | Pumping | Pumping |
| Aeration | No | No | Yes | Yes |
| Diversity of crops | Polyculture | Monoculture, polyculture rarely | Monoculture | Monoculture |
| Disease problems | Rare | Rare | Moderate to frequent | Frequent |
| Employment (persons $ha^{-1}$) | 1-2 | 2-3 | 3-4 | 4-5 |

(Source: In-house data)

**Table. 2** Comparative economics of different brackishwater farming practices for 1 ha water area. Amounts are in INR (100 INR = 1.56 US $)

| **Particulars** | **Traditional** | **Extensive** | **Semi-intensive** | **Intensive** |
|---|---|---|---|---|
| Lease rent | 30000 | 30000 | 45000 | 45000 |
| Earth work | 20000 | 30000 | 40000 | 50000 |
| Water filling | - | 10000 | 20000 | 20000 |
| Bleaching powder | - | - | 12000 | 12000 |
| Lime | 8000 | 20000 | 40000 | 40000 |
| Organic fertilizers | 8000 | 18000 | 26000 | 26000 |
| Probiotics | - | - | 65000 | 120000 |
| Seed | 40000 | 75000 | 120000 | 300000 |
| Feed | - | 100000 | 540000 | 1040000 |
| Fuel | - | 30000 | 160000 | 280000 |
| Manpower | 120000 | 200000 | 280000 | 360000 |
| Harvest and marketing | 10000 | 15000 | 20000 | 25000 |
| Total expenditure | 236000 | 528000 | 1368000 | 2318000 |
| Gross return | 390000 | 810000 | 1800000 | 2880000 |
| Net return | 154000 | 282000 | 432000 | 562000 |
| Benefit cost ratio | 1.65 | 1.53 | 1.32 | 1.24 |

(Source: In-house data)

**Table. 3** Distribution of daily ration in meals in Tiger shrimp and Indian white shrimp farming

| | **Percentage of daily ration in meals** | | | | |
|---|---|---|---|---|---|
| | **6 AM** | **11 AM** | **2 PM** | **6 PM** | **10 PM** |
| 1st month | 40 | - | - | 60 | - |
| 2nd month | 40 | - | - | 30 | 30 |
| 3rd month | 20 | 20 | - | 30 | 30 |
| 4th and 5th months | 15 | 15 | 10 | 25 | 35 |

(Source: In-house data)

**Table. 4** Distribution of daily ration in meals for *P. vannamei* farming

| | Percentage of daily ration in meals | | | | |
|---|---|---|---|---|---|
| | **6 AM** | **9 AM** | **12 PM** | **3PM** | **6 PM** |
| 1st month | 40 | - | - | 60 | - |
| 2nd month | 40 | - | - | 30 | 30 |
| 3rd month | 20 | 20 | - | 30 | 30 |
| 4th and 5th months | 15 | 15 | 10 | 25 | 35 |

(Source: In-house data)

**Table. 5** Feeding schedule for Tiger shrimp and Indian white shrimp

| **For first 50 days** | | | | **50 days onwards** | | |
|---|---|---|---|---|---|---|
| **Age in days** | **Feed increment (g) /day** | **Feed (kg) /day /100000 PL15** | **Crumble/pellet size** | **Mean body weight (g)** | **Feeding rate (as % of body weight)** | **Feed in each check tray (g/ kg)** |
| 1 | - | 2.0 | Fine crumble | 5-10 | 5.5-4.7 | 24-28 |
| 2-10 | 400 | 2.4-6.0 | Fine & coarse crumble | 10-15 | 4.7-4.0 | 28-30 |
| 11-20 | 500 | 6.5-11.0 | Fine & coarse crumble | 15-20 | 4.0-3.6 | 30-33 |
| 21-30 | 600 | 11.6-17.0 | Coarse crumble | 20-25 | 3.6-3.0 | 33-36 |
| 31-50 | 500 | 17.5-27.0 | Coarse crumble & pellet | 25-35 | 3.0-2.3 | 36-41 |

(Source: In-house data)

**Table. 6** Feeding schedule of *Penaeus vannamei* farming

| **For first 50 days** | | | | **50 days onwards** | | |
|---|---|---|---|---|---|---|
| **Age in days** | **Feed increment (g) /day** | **Feed (kg) /day /100000 PL15** | **Crumble/pellet size** | **Mean body weight (g)** | **Feeding rate (as % of body weight)** | **Feed in each check tray (g/ Kg)** |
| 1 | - | 2.0 | Fine crumble | 5-10 | 5.5-4.5 | 2-3 |
| 2-10 | 400 | 2.4-5.6 | Fine crumble | 10-15 | 4.5-4.0 | 3-4 |
| 11-20 | 500 | 5.6-10.1 | Fine & coarse crumble | 15-20 | 4.0-3.5 | 4-5 |
| 20-30 | 600 | 10.1-15.5 | Coarse crumble | 20-25 | 3.0-2.5 | 5-6 |
| 31-50 | 700 | 15.5-28.8 | Coarse crumble & pellet | 25-30 | 2.5-2.0 | 6-7 |

(Source: In-house data)

**Table. 7** Normal, optimum and critical ranges of water quality parameters in shrimp farming

| Physico-chemical parameters | Shrimp farm pond water | | |
|---|---|---|---|
| | **Normal** | **Optimum** | **Critical** |
| Temperature ($^0$C) | 18-32 | 28-32 | < 14 |
| pH | 7.0-9.0 | 7.5-8.5 | < 6 (Daily fluctuation more than 0.5) |
| Salinity (ppt) | 10-35 | 15-25 | < 5 and > 40 (Daily fluctuation < 5) |
| Transparency (cm) | 25-40 | 30-40 | < 20 and > 60 |
| Dissolved oxygen (ppm) | 3.0-9.0 | 4.0-7.0 | < 4 |
| Total ammonia nitrogen (ppm) | < 4 | < 3.7 | - |
| Free ammonia (ppm) | < 0.1 | < 0.1 | >0.1 |
| Nitrite-N (ppm) | 0.25 | < 0.25 | >1.5 |
| Nitrate-N (ppm) | - | 0.2-0.5 | - |
| Dissolved-P (ppm) | 0.008-0.20 | 0.10-0.20 | - |
| Hydrogen sulphide (ppm) | < 0.003 | Nil | >0.003 |

(Source: In-house data)

**Table. 8** Mineral concentration (mg/L) in seawater and factors for each ppt of salinity in pond water

| | **Sodium** | **Potassium** | **Magnesium** | **Calcium** | **Chloride** | **Sulphate** |
|---|---|---|---|---|---|---|
| Sea water (35 ppt) | 10500 | 380 | 1350 | 400 | 19000 | 2700 |
| Factor* | 304.5 | 10.7 | 39.1 | 11.6 | 551 | 7.40 |

*Factor is multiplied with water salinity value to get mineral concentration required

(Source: In-house data)

**Picture .1** A typical shrimp farm design in Sundarbans (Courtesy: Authors)

**Picture. 2** A typical view of the biosecured shrimp pond in Sundarbans (Courtesy: Authors)