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4 authors:

Vijayan KK
Central Institute of Brackishwater Aquaculture

Balasubramanian C. P.
Central Institute of Brackishwater Aquaculture

Gopal Chavali
Central Institute of Brackishwater Aquaculture

Muniyandi Kailasam
Central Institute of Brackishwater Aquaculture

Diversification of Brackishwater Aquaculture: Options and Strategies

K. K. Vijayan, C. P. Balasubramanian, C. Gopal and N. Kailasam
ICAR-Central Institute of Brackishwater Aquaculture
75 Santhome High Road, RA Puram, Chennai-28

Introduction

Evolution of Indian brackishwater aquaculture from a traditional pond based capture system to a full-fledged aquaculture is truly remarkable. The industry grew from <100,000 t in 1991 to 4,34,558 t in 2014 (http://mpeda.gov.in/). In addition to the farming operation, a number of ancillary businesses such as hatchery, feed industry, equipment manufacturers, pharmaceuticals, chemicals and clinical laboratories have developed over the same time. The total revenue generated from the export of farmed brackishwater crops in 2015 is about Rs 20,000 crores. Thus, this agri-based industry plays a crucial role in food production, employment and marine products export of the country. However the industry is built on a single commodity- 'the shrimp'. Shrimp aquaculture in India, like other countries, has been vulnerable to many exogenous shocks. Shrimp, as an agricultural crop, is susceptible to various forms of uncertainty such as changes in the environment, climate changes, disease out breaks and market fluctuations. The frequent catastrophic epidemics, due to viral pathogens have been challenging the profitability and sustainability since the early phase of its inception. Disease causes high mortality rate, and forces the farmers to have a premature harvest that affect adversely the economics of shrimp industry. Economic consequences of such outcomes are substantial, and it leads producers or farmers to bankruptcy. Further, the more a system is managed to take a maximum yield, it would become less resilient and more vulnerable to exogenous shocks. Therefore, the measures to mitigate the problems due to the single-species-dependent-aquaculture are crucial for the sustainability of this production system. Impact of risk of shrimp aquaculture and alternatives to deal with the linked scenario captured attention of policy makers as early as 1990s. A widely accepted strategy to enhance aquaculture production as well as to reduce the vulnerability of single-species culture is the species diversification. Diversification has become an essential strategy to increase income from farming and reduce the risk due to crop failure (Singh *et al.*, 2006).

Diversification in agriculture, in the context of terrestrial agriculture, has been discussed in early 1990s. Diversification could possible at any one or all of the three levels: 1) a shift from a farm to non-farm activity 2) a shift from less profitable crop to more profitable crop and 3) use of resources in diverse but complementary activities. Whilst some of these situations are applicable to aquaculture, at the context of aquaculture particularly in brackishwater aquaculture, strategies should be different. Several levels of diversification have been recognized: species diversification, system diversification, market diversification and geographical diversification. In this article we primarily discuss the various levels of diversification. The roles of various stake holders of aquaculture such as government, academics and research institutes and private sectors are also evaluated.

Species diversification

Several penaeids and finfishes have been recognized as suitable for brackish/coastal aquaculture in India. However, we are yet to realize the potential benefits of species diversification in brackishwater aquaculture. Indian coastal ecosystem harbors diverse crustaceans, finfishes and molluscs. Aquaculture potential of many of these species has been recognized. This section provides a description of potential species for the diversification of brackish/coastal aquaculture in India.

Crustacean aquaculture in brackishwater

Fenneropenaeus (Penaeus) indicus

Indian white shrimp, *Fenneropenaeus indicus* has been a high-valued commercial species in Indian waters. It has been widely fished throughout the Indo-Pacific, and aquaculture potential of this species has been well recognized as early as 1970s. In India, hatchery technology and initial trials on the domestication was carried out before 1980s (Muthu *et al.,* 1992). However, when shrimp farming has become popularized in 1990s, the priority of this species has been overlooked and attention has been shifted to giant tiger shrimp, *P. monodon,* possibly due to the farmers' preference on the success of south Asian model of shrimp farming development (Muthu *et al.,* 1992).

Life cycle and hatchery production: Life cycle of *F. indicus* is that of typical penaeid shrimp. The adults live and breed in the sea, larval development takes place in the sea and post larvae migrate to the estuaries and coastal lagoons. Eggs hatch into nauplii and it metamorphoses to post larvae through protozoea (zoea) and mysis. Estuarine habitats provide shelter and food, and animals migrate back to the sea once it reaches the sub adult stage. The maximum size recorded for females of this species in the sea is 230 mm (total length) and 100 g (body weight) and for males 189 mm (total length) and 55 g (body weight). Hatchery technology of this species is similar to that of *P. monodon* at the hatchery larval survival up to post larvae from nauplius is about 60%. ICAR-CMFRI has already developed a technology for small and medium scale development of hatchery technology for the *F. indicus*. Recently, CIBA has revisited the research and development activities carried out in *F. indicus,* and commercial level performance at hatchery level and farm level were evaluated (CIBA, 2016).

Performance in grow out production system: Growth and production performance are the important criteria for the candidate species for aquaculture. The tiger shrimp, *P. monodon,* received huge popularity due to its higher growth performance; this species attains 25-30 g within 120 to 130 days. The growth and production performance of *F. indicus* is comparable or even slightly better to the pre-domesticated *Litopenaeus* (*Penaeus*) *vannamei* (Table 1). For example, *F. indicus* attained 18.4 g within 114 days at a stocking density of 30 shrimps/m^2, whereas *L.*

vannamei took 147 days to reach similar body weight even at low stocking density of 12 shrimps/m^2. Similarly the gross production was higher in the case of *F. indicus* (Table 1). More over this species is highly amenable to culture under high stocking densities and high production of about 16-18 t/year has been reported in early 1990s. This species is an ideal species for growth improvement through selective breeding and could be an alternative for the exotic American shrimp, *L. vannamei*.

Potential advantages of developing selectively bred *F. indicus* are multifold:

- As *F. indicus* is native species, all the quarantine measures to import *L. vannamei* could be avoided or minimized.
- *F. indicus* is not a natural host of many emerging diseases, and it is comparatively easy to develop disease free stock.
- In India, four distinct genetic populations of *F. indicus* have been recognized, and it indicates the potential for genetically distinct population and scope for genetic improvement.
- As *F. indicus* is native to India it may exhibit greater tolerance and better growth than *L. vannamei*
- This species is a strong osmoregulator and can be cultivated under wide range of salinity conditions.

While formulating criteria for the development of native species for aquaculture Ross *et al.* (2008) summarized basic requirements for establishment of aquaculture of native species. The success of domestication is largely depends on previous degree of domestication of this species and core scientific knowledge generated on this species. It includes: 1) basic biology, 2) environmental physiology 3) closed reproductive cycle 4) nutrition 5) feeds and 7) on growing systems. The generation of this scientific knowledge is expensive and lengthy procedure. However, in the case of *F. indicus*, a large body of knowledge has already been developed in India.

In the last fifty years considerable advance has been made towards the successful domestication of *F. indicus*. Controlled reproduction of this species has been extensively studied (Muthu and Laxminarayana, 1982). Various aspects of reproductive endocrinology and vitellogenesis have been studied by Mohamed and Diwan (1991a, b; 1992, 1993, 1994) and Diwan and Mohamed (2007 a, b). Extensive studies on the basic biology of molting as well as molting as a function of growth have been studied by Vijayan *et al.,* (1993 and 1997) and Vijayan and Diwan (1995 and 1996). Nutritional requirements for *F. indicus* were studied by Ahmed Ali (1982), Gopal (1986) and Vijayagopal *et al.* (2008, 2009). Several grow-out experiments on *F. indicus* have been conducted (Sivakami, 1988 and Prasad, 1999). Thus, ample core science has been published, which is sufficient for the development of breeding program of Indian white shrimp, and this species could be the focus of diversification of coastal aquaculture in India.

Table 1. Summary of pond culture performance of *L. vannamei* (pre domestication period) *and F. indicus*

Characteristics	*L. vannamei* (Sandifer *et al.* 1993)	*F. indicus* (Prasad, 1999)
Pond size (ha)	0.1-0.5	0.6
Stocking density shrimp/m^2)	12	29.5
Initial mean weight (g)	0.01	<0.04
Final mean weight (g)	19.7	18.4
Days of culture	147	114
Daily weight gain (g/day)	0.13	0.16
Production (kg/ha)	2477	2557
FCR	2.1	1.6
Salinity (‰)	28	11.1

Penaeus (Fenneropenaeus) merguinesis

Banana shrimp, *P. merguinesis*, has attracted the attention of aquaculture community as a potential species for aquaculture in India and several Asian countries. Morphology of this species is similar to *F. indicus*, however, it grows larger than *F. indicus*. In wild, females grow up to 240 mm (total length) and 120 g (body weight), and males grow up to 195 mm (TL) and 60 g (BW). The commercial availability of this species is restricted to North West to the Karwar coast and to the Odisha coast north of Chilka lagoon. In Andaman & Nicobar Islands this species completely replaces the *F. indicus.*

Life cycle and hatchery production: Life cycle of *P. merguinesis* is similar to *F. indicus*. Hatchery technology of this species has been standardized by CIBA, and this species can reach full ovarian maturation under captivity. Further it can mature and spawn without eyestalk ablation. Thus, hatchery production could be independent from the wild stock, indicating the potential for the domestication and selective breeding program.

Production performance: On-station studies conducted by CIBA in low saline and zero-water exchange ponds indicated the potential for the development of aquaculture. The species attains commercial size within 130 days with an average production of ~1000 kg at a stocking density of 20 number/m^2. On the contrary to the popular belief of *P. merguinesis* as 'disappearing species', the study showed a reasonably high survival of 50%. This species requires less protein diet and amenable for high density culture.

Penaeus japonicus

Kuruma shrimp, *Penaeus japonicus*, is the first penaeid species whose life cycle has successfully closed. It is one of the most costly and luxurious food item in most of the top Japanese restaurants. This species is widely distributed in Indo-west Pacific from the coast of east Africa and red sea to Fiji and Japan. In India, it is found in stray catches except in Maharashtra where there is a minor seasonal fishery during June to September. Although the species has a typical life history of penaied, the migration of post larvae to less saline estuarine habitat is unlikely (Muthu *et al.*, 1992). The maximum size recorded in India is 235 mm (total length) and 100 g (body weight) for females and 200 mm (total length) and 70 g (body weight) for males.

Hatchery production: ICAR-CIBA has developed a successful hatchery technology for *P. japonicus*, and the species was successfully domesticated. Successful genetic improvement program of this species has been achieved in Australia and Japan. Although growth of this species is found to be lower than species such as *P. monodon* and *L. vannamei*, the niche market in Japan provides ample opportunity for *P. japonicus*. Farming of this species for live export market in Australia has become one of the most successful aquaculture industries.

Mud crab (*Scylla serrata*)

Mud crab has emerged as a new species of aquaculture owing to their high market value. They readily fit in to the coastal aquaculture facilities built for the shrimp farming. The variations in marketing options and biological characteristics of this species give it good scope. It has been an incidental crop in the traditional aquaculture farm for several decades; however, the aquaculture potential of this species attracted the aquaculture and research community in early 1990s. Although four mud crab species are so far recognized, only two species are reported from Indian waters: *Scylla serrata* and *S. olivacea* (Balasubramanian *et al.*, 2014). The maximum size of *S. serrata* so far recorded in the wild is 240 mm (carapace width) and 2. 8 kg (body weight) and *S. olivacea* is 181 mm (carapace width) and 0.83 kg (body weight). Mud crab possesses almost all requirements for a viable aquaculture candidate species, like high market price, rapid growth, simple feed, and less stringent environmental requirements.

Life cycle and hatchery production: *Scylla serrata* is closely linked to the estuarine and mangrove habitats, and market sized and reproductive females are frequently obtained from these habitats. However, the early larval phase has not been recorded from the estuarine mangrove habitats. Hatchery production of *Scylla* has been standardized recently although the survival at the hatchery phase is below 5% (Balasubramanian *et al.*, 2013b). Separate nursery phase is crucial for the mud crab aquaculture, and at nursery phase survival is above 50%.

Production performance: Aquaculture of this species needs long rearing period (10-12 months; below 1 g to above 500 g). This long culture period hinders the production efficiency, survival rate, and moreover, farmers are reluctant to adopt this farming as it take long period for obtaining revenue. In order to circumvent these issues and optimize the economy, a three tire modular farming system (multi-phased culture system), comprising a three months nursery rearing, and four months of mid grow-out and three months of final grow-out system, has been developed by CIBA (CIBA, 2015). Forty six percent of juveniles were survived after three months of rearing with an average body weight of 84.8 g and 280 kg/ha production. In the mid grow-out phase, nursery reared juveniles are reared at a stocking density 0.1 crabs per sq. m and reared for three months. The harvest weight was 270 g with a production of 1110 kg/ha (Balasubramanian *et al.*, 2013a). The final grow-out was for three months with a very low stocking density (0.01 crabs/sq. m) with 80% survival and a production of 1168 kg/ha. Mud crab is also found to be better option for polyculture with finfishes, and productivity of the mud crab in polyculture pond is about 2500 kg/ha.

Finfish aquaculture in brackishwater

Sea bass (*Lates calcarifer*)

Lates calcarifer is a protrandrous hermaphrodite fish inhabiting in the coastal waters, estuaries and brackishwater lagoons. A renewed interest in developing large scale aquaculture of sea bass has occurred in several south-east Asian countries including India. It is a diadromouos fish inhabiting rivers and they migrate to estuaries to spawn. Larvae and juveniles stay in brackish water and older juveniles live in upper reaches of the rivers. They grow up to 1500 to 3000 g in one year. Maturing males migrate to estuaries during monsoon and mate with resident females. Females broadcast eggs, and larval development takes place in the estuary. Although all phases of life cycle of this species can be found in the fresh and brackishwater environment, for embryonic development brackishwater is required. ICAR-CIBA has developed the hatchery technology of sea bass as early as 1990s and farming technology by 2000, and continuously supplying hatchery produced juveniles. Cage culture of sea bass has developed and demonstrated. This high value species has great potential as a candidate species for brackishwater culture in India.

Milk fish *(Chanos chanos)*

Milk fish is good affordable animal protein source, and it possesses several desirable characteristics as a farmed fish. Milkfish is euryhaline and tolerate wide range of salinity from fresh water to hyper saline water (125 ppt). Their high tolerance and preference to lower trophic level, considered to be opportunistic generalists, make them a desirable aquaculture species. No targeted fishery exists for milkfish. Although milkfish has been an incidental crop in the traditional farming system in India, aquaculture of milkfish, either a monoculture crop or polyculture, is emerging. Recently ICAR-CIBA has developed hatchery technology of milk fish. Indian market surveys indicate that milkfish is a good affordable protein source for many consumers.

Grey mullet *(Mugil cephalus)*

Grey mullet is a euryhaline species found to be distributed throughout world. It is a rapid growing herbivores species that can be reared in wide geographical and temperate regions. It can be an excellent candidate species for enhancement of aquaculture production in earthen brackishwater ponds. As a herbivores fish, a fish meal free feed can be produced, and it would be appealing to an increasingly-environmentally-aware -public. Recently, mullet roe has become a luxurious seafood commodity with an expanding market. Thus, mullet has good biological and economic potential for species and product diversification.

In addition to these, several species of finfishes such as *Etroplus suratensis, Lutjanus, Sillago sihama* are gaining importance as potential species for diversification.

System diversification

Currently brackishwater aquaculture in India is exclusively carrying out as a land based monoculture system for shrimp culture. This system is more vulnerable to abiotic and biotic shocks. Therefore, diversification of systems used for culture is considered to be the key element to strengthen the resilience to food production system and its sustainability. Integrated multi-trophic aquaculture systems, polyculture, and low volume cage culture in the open water bodies are potential option for the diversification of systems.

Integrated multi-trophic aquaculture (IMTA)

Integrated multi-trophic aquaculture, IMTA, is the farming of species from different trophic levels with complementary ecosystem function in proximity (Chopin, 2008). In this farming practice, un- eaten feed, nutrients, wastes and energy of one species or crop are recaptured and utilized as fertilizer, feed and energy for other co-cultured species or crops. When diet introduced to a fed species (for example: fish or shrimp), it will be partially egested as faeces or fully excreted as soluble nutrient, and that could be captured by co-cultured species (organic extractive: bivalves; inorganic extractive: seaweed) (Reid *et al.,* 2011). Thus, the efficiency of whole system would be improved. A distant prototype of IMTA existed in many Asian countries as a polyculture of different species, often species of same trophic level. The importance of IMTA as a management option for sustainable ecosystem functions along with economic benefits has been recognized recently. Recently ICAR-CIBA has conducted experiments and demonstrations to popularize IMTA. When comparing with the monoculture system, the productivity of IMTA system was higher than control: 3250 kg/h (IMTA) versus 2000 kg/ha (shrimp monoculture). Further, income and benefit-cost ratio was found to be higher in IMTA.

Low volume cage culture

The production of high value fishes such as sea bass has been a promising option for the diversification of aquaculture as well as the diversification of rural livelihood. This is particularly true for the development of cages in the brackishwater where investment for cages is lower when compared to marine system. Recently ICAR-CIBA has signed a MoU with farmers and self-help group of Kerala for the development of low-volume cage culture in the natural ecosystem. A total of eight hundred sea bass fingerlings (average 8g size) were stocked in a floating cage of 8.0 m^3 (2.0x2.0x2.0 m) initially, and after reaching to 100 g size, fishes were restocked in a cage with three compartments, in the size of 2.0x2.0x2.0 m. Feeding was done with trash fish procured @ Rs 30 per kg from the locality and fed @ 5% body weight twice daily. After 10 months culture period, the farmer has produced a total of 475 kg of sea bass (81% survival rate) with the size ranged from 500g-1.5 kg, with the productivity of 19.8 kg/ m^3. The farmer has sold 400 kg of sea bass @ Rs. 400/kg and realized the revenue of Rs.1.6 lakh. This form of culture provides an opportunity to land less farmers to involve in the culture of high valued brackishwater crops, and it will optimize the use of public water bodies.

Organic aquaculture

Organic aquaculture is a process of production of aquatic plants and animals with the use of only organic inputs in terms of seeds and supply of nutrients and management of disease following aquatic principles. Organic food production promotes biodiversity, biological cycles and further organic farmers aim to manage production as an integrated whole system. Many of the traditional aquaculture practices in India follow an organic procedure. Organic foods have a separate niche market and many farmers are attracted to these farming practices.

Periphyton and biofloc based farming

ICAR-CIBA has attempted research effort to enhance the production and sustainability of shrimp farming. Periphyton based farming is an attempt in this direction. Periphyton refers to the entire complex of attached aquatic biota on submerged substrates comprise phytoplankton, zooplankton, benthic organisms and detritus. The study conducted by ICAR-CIBA (Shyne *et al.,* 2013) clearly indicates that periphyton has a beneficial effect of growth and production of shrimp. A better growth rate with a productivity of 1640 to 2796 kg /ha/crop was recorded in ponds provided with periphyton and stocked at a density of 8-12 individuals/m^2. Further, the rate of return over operational cost was higher in periphyton-based system (92%) compared to the conventional farming (54%). This level of improvement of pond production with cheap on farm resources enhance the productivity of shrimp ponds without deteriorating ecosystem.

Geographical diversification

Geographical diversification is one of the options to mitigate the risks of brackishwater shrimp farming. Further, geographical expansion would provide opportunity to farmers, from non-coastal areas, to utilize their water resources which were hitherto unutilized or underutilized. Vast expanses in the state of Haryana, Punjab and UP possess large resources of saline groundwater. This resource, once considered as unproductive due to its non-suitability for agriculture, livestock and industrial applications, is now fast turning in to an emerging opportunity for development, in the form of inland-saline-aquaculture (INSA). Saline ground water of inland origin can be used for brackishwater aquaculture, and it provides new options for farmers, who have traditionally been engaged in agriculture. Since the first successful demonstration of tiger shrimp, *Penaeus monodon* farming in 2008 and subsequently farming of white legged shrimp, *L. vannamei* during 2012 in Haryana and Punjab has made rapid strides in inland shrimp farming, especially due to the entrepreneurship by a section of farmers from the region. The popularity of shrimp farming practice is fast spreading to nearby states, mainly due to the higher profitability per unit area and shorter crop period.

Inland shrimp farming has several advantages over coastal shrimp farming. As the farming is carried out several hundred kilometers from the nearest sea in a naturally bio-secure environment, the possibility of serious viral disease outbreaks are much lower. Although the system is inherently bio-secure, large scale expansion of shrimp farming requires scientific bio-security measures .Further, when farming moves to inland areas where large volume of saline water is utilized, issue of salinization, and its impact on the freshwater aquifers, access and availability of drinking water resource, and its impact on agriculture need to be taken into account. Sustainable and environmental friendly farming cycles need to be developed, keeping balance with the agriculture activity in the area, under continuous monitoring of the state and central govt. agencies, to keep the balance between aquaculture and agriculture.

Inland saline shrimp farming is attractive due to the ready market demand in domestic and export market with handsome economic returns. However, like any other technology the future expansion of inland shrimp farming, will be exposed to the fluctuation in market process and profitability. In inland saline shrimp farming, the input cost can be on the higher side, due to the logistics on the availability of shrimp seed, feed and other inputs, hence the factors such as economic feasibility, environmental stability and social acceptability, need to be considered in the initial phase itself, to ensure the long term-sustainability of the farming. The expansion of this farming may have its share of environmental impacts which can affect communities and their sources of income.

Issues and way forward

Diversification strategies pose two questions to the international aquaculture community: Is it the right strategy to focus on existing established species or we should select a new species and how should these be selected? Naylor *et al.* (2000) suggested following guidelines while planning aquaculture in an area: 1) expansion of farming of species at low-trophic level, 2) reduction of fish meal and fish oil from the fish feed and development of integrated aquaculture system. Any species selected for new aquaculture should satisfy any or all of these criteria. In the diversification scenario, Government R&D has crucial role to play, as most of the species recognized for diversified aquaculture may not readily accepted by the conventional farmers. Further, technology development for the aquaculture of new species has to be carried out by the public funded R&D.

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