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Brackishwater aquaculture: Status, transitions and way forward

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It has been well convinced that aquaculture has enormous potential to feed the growing global population, if it is practiced in responsible way. With the world population predicted to increase to 10.9 billion people by 2050, where in India itself would expected to be 1.6 billion, the need to increase food production is the major challenge, particularly in areas that have high rates of food insecurity. Aquaculture has evolved almost four thousand years ago as an activity with goals similar to the terrestrial agriculture and animal husbandry. This simple but elegant food production system originated in Asia, and in many ways it resembled the dynamics of natural ecosystem. These traditional low-input systems had family and community roots, and they were beneficial or at least benign system.

Brackishwater ecosystem comprising the estuaries backwater, coastal lakes and adjacent water bodies are the subset of coastal system. It is a transient zone, constantly communicating with both sea and freshwater ecosystem. The unique characteristic of this ecosystem provides home for many economically important fish and shell fish resources.These resources have been exploiting for fisheries and aquaculture for centuries. Currently, brackishwater aquaculture, particularly shrimp culture, has been the most emotive and politically polarized aquaculture sector globally. Although a prototype aquaculture system has been practicing in coastal areas of many countries including India, the modern aquaculture has been started during early 1980s. In early 1980s many developing countries, focused on export oriented agriculture crops to provide financial capital to uplift the economy of the country. The government support along with the market demand for high valued seafood fueled the growth of brackishwater shrimp culture in India. During 2014-15, farmed shrimp alone contributed about 3 billion US$, which is more than half of the total marine product export of the country. This article summarizes how brackishwater aquaculture evolved through the past few decades and what are the major issues of brackishwater farming and way forward. It also provides how research and development played for the shaping the brackishwater aquaculture in India, and what are the research priorities to making this aquaculture a long-term sustainable system.

Shrimp aquaculture: Farming to industrialization

History of shrimp farming in India is almost similar to the other South East Asian countries. In early 1950s, juvenile shrimps were extensively fished from the paddy fields bordering the backwaters and estuaries of Kerala (*pokkali*), West Bengal (*bheries*), Karanataka (*Ghazan*) and Goa (*Kazhan*), and were exported to Myanmar to market as a shrimp product known as 'prawn-pulp'. Later due to the innovation in the preservation techniques in India, the demand for larger shrimps has increased considerably, and, therefore it was essential to grow the shrimp in the farm field to meet the demand of export industry. Thus the paddy field shrimp fishery has been evolved into a primitive form of aquaculture where, the naturally immigrating shrimp seeds from coastal waters are entrapped and prevented from returning to sea, and reared for few months, without any feed or aeration. Later, to augment the production, farmers started the practice of stocking the ponds with wild caught seeds (George and Rao, 1963), and thereafter, when commercial hatcheries started, with hatchery reared seeds. This form of improved extensive type of shrimp culture is still prevailing in Kerala with a production of about 400 kg/ha to 600kg/ha for a short period of culture without supplementary feeding (Sasidharan *et al.*, 2012), where it can be understood that this type of culture is a form of ecosystem based culture or an organic shrimp aquaculture, in perennial farms and pokkali rice farming fields.

Although extensive production system of shrimp started as early as 1960s, the industry only really began to intensify in the early 1990s, after the successful demonstration of commercial tiger shrimp hatchery in AP, through an MPEDA and DBT project, by TASPARC, with the help of foreign technological support, which triggered the establishment of commercial tiger shrimp hatcheries in private sector. The time line of the major event of shrimp aquaculture is depicted in the fig. 1. This development has not happened in the already existing traditional shrimp farming regions: Kerala, West Bengal, Karnataka and Goa, however, the modern shrimp aquaculture development largely centered in the areas where shrimp aquaculture did not have any prior history, such as Andhra Pradesh and Tamil Nadu. This can be attributed to the entrepreneurship of the local people, seasonal and geographical advantage. What followed is a spectacular growth of shrimp aquaculture system, during 1990-1995, with commercial hatcheries and farms with the use of desired quality seeds, formulated feeds and life supporting systems such as aerators. Farmed shrimp production showed a remarkable growth during this period of early 1990s, and thereafter production stagnated from 1996 to 2000, mainly due to WSSV pandemic and related crop failures. From 2000 to 2006 shrimp farming gradually increased and peaked with a maximum production of about 1.4 lakh tons in 2006, but production reduced drastically in 2008. Again, 2011

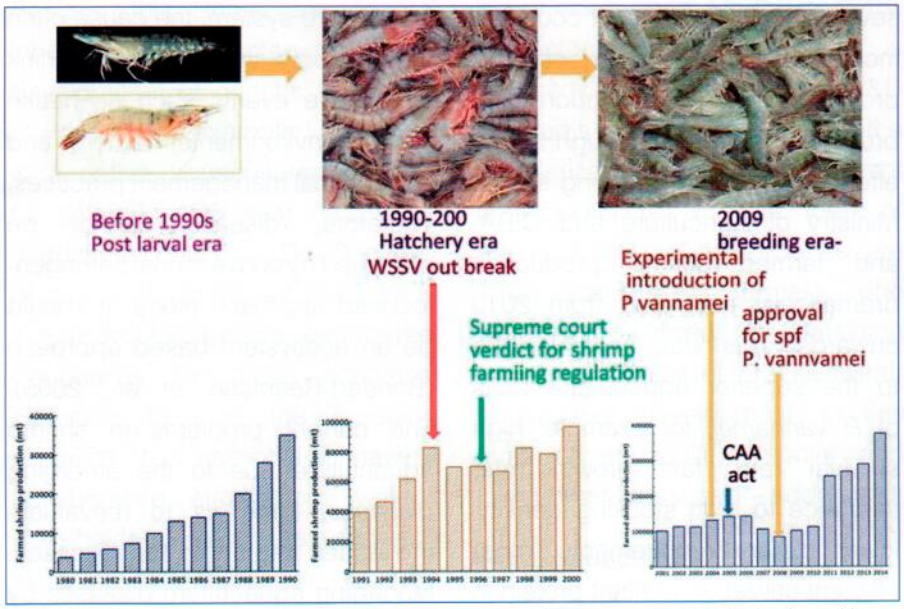

Fig. 1. Development of Indian shrimp farming sector, before 1990 the sector is dominated by traditional shrimp culture comprising both Penaeus indicus and P. monodon. It is generally named as post larval era as seed source was wild, subsequently it was changed to hatchery era where seed stocks are produced from wild caught brooders. From 2009 onwards, it is changed to breeding era where domesticated seed stocks are used.

onwards witnessed a remarkable upsurge of farmed shrimp, due to the introduction of, the exotic American shrimp, *Penaeus vannamei*, and farmed shrimp production reached at a level of 3.8 lakh tones in 2014 (FAO, 2012)

Introduction of *Penaeus vannamei*

Shrimp aquaculture has been faced several challenges, for example: criticism from the environmentalists that causes wide-spread media coverage, and it provided a negative image to shrimp aquaculture. The catastrophic shrimp mortality caused by white spot syndrome virus (WSSV) and subsequent crop losses occurred in 1995, in all Asian shrimp farming nations including India, and later in Americas. WSSV pandemic cast doubt about the economic feasibility and sustainability of shrimp aquaculture in India and across the globe (Chamberlin 2010).

No therapeutic options available for the control of viral pandemics such as WSSV and the only management way out is to adopt preventive strategies. The use of post larvae generated from the specific pathogen free (SPF) broodstocks along with strict biosecurity measure are the most effective management option to ensure successful crops, Unfortunately, India did not have an SPF programme for none of the native candidate species. The US was successful in the selective breeding, which they initiate much earlier in early nineties, resulted in the production of SPF *P. vannamei*, although the scale of shrimp farming was only limited in Americas. Again, the Taiwanese were the first to use SPF *P. vannamei* from US, with an initial success of *P. vannamei* production of 13 mt/ha within 75 days of culture (Wyban 2002). Following the success of Taiwan, *P. vannamei* was introduced into

several South East Asian countries including India. Indian officially provided licensee to import SPF broodstock in 2008, through a joint effort by the shrimp farming sector, Ministry of Agriculture and CIBA, and farmed shrimp production dramatically escalated from 2010 onwards. This was possible due to the superior aquaculture traits of *P. vannamei*, for example: high survival rate, fast growth rate, tolerance to high stocking density, lower dietary requirements, more efficient utilization of plant protein in the formulated diet and adaptability to low salinity make this species as the most preferred species for aquaculture. Also, the biological advantages such as column feeding habits, and reproductive success in captivity, contributed in the successful growth of Vannamei farming.

Issues in Brackishwater aquaculture in India

Disease management

Success of any agriculture enterprise depends on its ability to evolve, and brackishwater shrimp farming has been evolved successfully from a rural coastal aquaculture with limited technological efficiency to an efficient industry. Although shrimp aquaculture has been widely recognized as a success story of modern aquaculture, there are several problems still to be resolved. Aquatic system is complex, and therefore, it is often indistinguishable between sub optimal performance and disease. When an epidemic outbreak occurs in a culture system, the cause often may not be a single, it may interlink of multiple events such as health status, environmental factors and sub-optimal management practices. Therefore, disease cannot be managed by conventional pathogen-focused approach alone. It should be an ecosystem based approach (Bondad-Reantaso *et al.*, 2005). The current problems in shrimp aquaculture due to the emerging diseases, force us to reevaluate the issues related to the diseases. Managing aquaculture diseases by focusing microbiological causes may not solve the issues of ever increasing diseases incidences (Doyle 2016). Further, Doyle (2016) hypothesizes that genetic erosion at the farm level due to inbreeding may stimulate the disease problems. This problem may likely to continue as long as we are relaying up on non-native single shrimp species from limited brood stock suppliers. Currently, the broodstocks of *P. vannamei* is being obtained from a single source, and development of potential native species such as Indian white shrimp is one of the strategies to resolve the genetic erosion due to the non native species.

At this context, Indian white shrimp, *P. indicus* is found to be better alternative for the development of specific pathogen free stock for shrimp culture in India. The most important criteria for domestication and selective breeding of any species are complete control of reproduction under captivity. Although regulation of reproduction of penaeid shrimps has still been elusive goal of shrimp culturists, some penaeid species are relatively easy to breed under captivity, for example: *P. vannamei* and *P. indicus* (Primavera, 1986). The relative ease of captive breeding of *P. vannamei* has helped, to a large extent, in developing the domestication and selective breeding of *P. vannamei*. Indian white shrimp, *P. indicus*, is one of the first few penaeids whose breeding technology has been standardized. Further, initial experiments on the development of pond-reared broodstock also show the potential for development of domesticated stock for this species (Muthu and Laxminarayana, 1979).

Growth and production performance are the important criteria for the candidate species for aquaculture. The tiger shrimp, *P. monodon*, received the high popularity due to its higher growth performance; this species attains 25-30 g within 120 to 130 days. The growth and production performance of *P. indicus* is comparable or even slightly better to the pre domesticated *P. vannamei* (Table 1). For example, *P. indicus* attained 18.4 g within 114 at a stocking density of 30 shrimps/m^2, whereas *P. 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 *P. indicus* (Table 1). More over this species is highly amenable to culture under high stocking densities and it has been reported a high production of about 16-18 mt/year in early 1990s.

Potential advantages of developing selective bred P. indicus are multifold

- As *P. indicus* are native species, all the quarantine measures to import *P. vannamei* could be avoided or minimize.
- *P. 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 P. *indicus* have been recognized, and it indicates the potential for genetically distinct population.
- As *P. indicus* is native to India it may exhibit greater tolerance and better growth than *P. vannamei*
- This species is a strong osmo-regulator and can cultivate under high saline and high temperature conditions
- Natural distribution of *P. indicus* is wide compare to the limited natural distribution of *P. vannamei* (Fig. 2)

Besides this, there are several inherent advantages for development of genetic stocks for *P indicus*, for example: *P. indicus* is a native aquacultured species for several south east Asian and middle east countries. Development of genetically improved stock for P. indicus would provide a novel market opportunity for these countries. However, to start the breeding program, it is essential to have a collaborative effort from various stakeholders such as research institute, developmental agency, central and state governments and private partners.

Immanent versus Interventional aquaculture

Opportunity rather than necessity is the major driver for development of aquaculture, particularly brackishwater aquaculture, and therefore it is market driven development. In aquaculture literature it has been referred as "immanent system". Therefore, the innovation or intervention from the public R&D may be minimal once it was established. On the contrary, the "interventionist aquaculture" is a system where public-funded R&D programs play a pivotal role in the popularization and establishment of aquaculture. In this form of aquaculture, the beneficiaries are small scale aqua farmers, who were marginalized in obtaining the direct benefit of brackishwater aquaculture development. In this form of aquaculture social and environmental issues are addressed.

Rural aquaculture

Rural agriculture/aquaculture, sometimes used as synonymous for the rural development, is a low-cost production system suitable for the implementation of rural poor. Although aquaculture has rural or community roots, most development in the modern aquaculture has been stimulated by the urban needs. In 1980s, during the initial phase of shrimp aquaculture development, efforts have been made to include the rural poor in shrimp aquaculture, for example, shrimp farming at the periphery of Chilka lagoon.

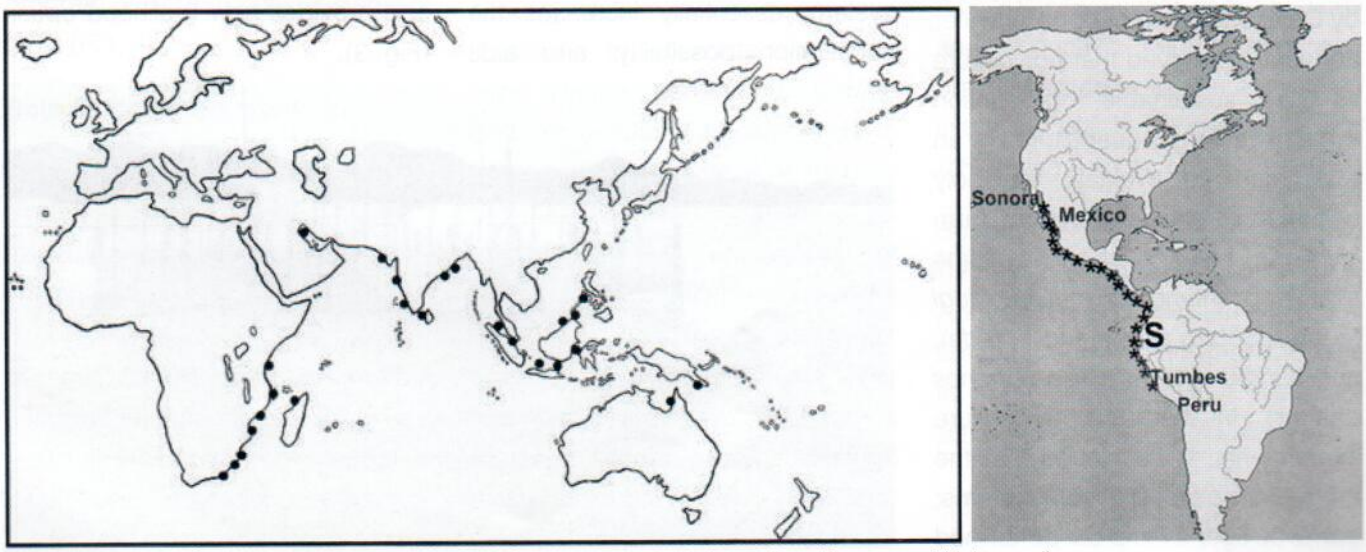

Fig. 2. General distribution of P. indicus (left panel) and P. vannamei (right panel)

However, when the first viral epizootic hit the shrimp farms in mid 1990s, these rural and resource-poor-farmers were unable to remain in the shrimp farming. Recently potential of aquaculture of other brackishwater species, for example mud crab and finfishes, has been demonstrated as livelihood option by Central Institute of Brackishwater Aquaculture. Advantages of these species, particularly mud crabs, are: they are inherently suitable for low-intensive aquaculture. Polyculture of these high valued crops with shrimp, finfishes and bivalves offer great potential for rural organic aquaculture. In polyculture, the non-competitive species utilize the habitat and natural food resources available within the pond more effectively. Additionally diversification of crops provides the farmers uninterrupted income, for example to obtain income from mud crab and finfish crops, minimum 6-8 months are required, if farmers rear shrimp along with these crops farmer will receive money from the 3-4 months onwards. On stations and field demonstrations carried out by Central Institute of brackishwater aquaculture proved that polyculture as a sustainable production system for rural aquaculture. In an experiment to evaluate the poly culture in an extensive system, farm level performance of two systems evaluated: shrimp with mullets (*Mugi lcephalus*, *Liza prasia* and *L. tade*), and shrimp with milk fish (*Chanos chanos*). In the 180 day culture experiments, it was found that the production is similar in both systems; however, tiger shrimp out performed in mullet-shrimp system than the milk fish shrimp system (Biswas, 2012). It indicates that the mullet is more compatible with shrimp than milk fish in West Bengal. CIBA has also demonstrated the potential of mud crab aquaculture with shrimp and mullets. These encouraging results demonstrate that resource poor farmers can adopt this system as the input cost and expenditure is low, and it would be still lower when farmers use on-farm resources. The compatibility of fin fish with shrimp increases the profitability and economic viability. These programs are being extended to all the coastal states and marginalized farmers shows overwhelming response to adopt these systems.

Diversification aquaculture

Diversification is the cornerstone for the sustainability of any enterprise in general and food production system in particular. Aquaculture particularly brackishwater aquaculture industry has been expanding, but fragmented. Currently it is found to be ripe for consolidation and diversification. A more diverse food production system, essentially increases the substitution possibility, and aids the system to be more flexible, and improves the optimization of resources. Further, diversity in species for culture contributes for the functional ecological resilience, and contributes to the stability of prices. On the contrary to the terrestrial meet production sector, with a limited diversity in the produce, for example, cattle, chicken and poultry, the aquaculture sector is diverse with 600 farmed species. Farmed species are from the entire spectrum of the trophic levels, and from the diverse production systems. Diversification of brackishwater aquaculture is possible both by system diversification and species diversification. Currently brackishwater aquaculture system at large is synonymous to land based monoculture system. This system limits the optimal use of brackishwater resource available for aquaculture; diversify the system in to open brackishwater lagoon and other resources such as salt pans would enhance the possibility of resources. Further it often helps to empower the land less coastal poor, and provides new livelihood option (Fig. 3).

Fig. 3. The cages developed in the open water for brackishwater aquaculture

Integrated multi-trophic aquaculture

It is one of the strategies for system diversification. Modern brackishwater aquaculture in India has been based on mono-specific (single species) shrimp culture since its inception during 1980s. Feed inputs accounts almost 60% of operational cost of shrimp culture, however, about 50% of these input enters into the ecosystem as waste. It causes eutrophication and associated damages to the coastal ecosystem. The overdependence of these external input not only causes adverse ecological impacts but also the economic returns of shrimp farming. It has been considered as one of the factors hampers sustainability of brackishwater aquaculture and future development. Integrated multi-trophic aquaculture (IMTA) is the modern offspring of the age-old polyculture, in which energy and nutrients unused by one species could be readily used by other organisms. CIBA has conducted several demonstration program of IMTA in coastal states of India (Fig. 4).

Fig 4. Integrated multitrophic aquaculture developed in Sindhudhurg district of Maharashtra

Role of regulatory frame work

Modern aquaculture was born in an age when public are more concern about the food quality, food safety and environment related issues. Thus developing regulatory frame work is essential for the development of a sustainable aquaculture. However, it is expressed concerns over negative relationship between stringency of environmental regulatory frame work and aquaculture growth. For example USA shows ~ 0.3% growth reduction of aquaculture from 2010 to 2014. Therefore, it is imperative to develop a regulatory frame work after proper research effort.

Concluding remarks

Shrimp aquaculture will remain to be the focus of future production and profitability of brackishwater aquaculture. The over-riding concern for the development of aquaculture in general, and brackishwater in particular, is to develop a sustainable production system harmonizing finfish farming, which is important for nutritional security, while maintaining economic feasibility. In countries like India with diverse geography, climate and socio-cultural backgrounds, a common template for sustainability of aquaculture cannot be suggested. The uniqueness of each region should be considered while formulating a strategy for aquaculture development. For example: in the east coast, Andhra Pradesh should have a different model other than Tamil Nadu and Orissa. Similarly on the west coast from Kerala to Maharashtra, where pattern of monsoon rains are different from the east coast, one common model can be suggested while keeping separate model for Gujarat. Research and Development form Government institutions need to be prioritized between the industrial scale shrimp farming and other brackishwater species which is mainly targeted for the domestic market.

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Table Summary of pond culture performance of Penaeus vannamei (pre domestication period) and P. indicus		
Characteristics	*P. vannamei* (Sandifer et al 1993)	*P. 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

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