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Brackishwater Shrimp Farming: Possible impacts on Estuarine Ecosystem

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1. Introduction

The supply of food and other products through aquaculture and fisheries constitutes one of the most direct and yet highly dependent goals in water resource management. Many prognoses of fish production suggest that capture fisheries are unlikely to grow by more than 1 or 2% per annum and will ultimately be limited by physical and biological constraints, deteriorating environments and steadily increasing resource and energy costs for exploitation. Aquaculture, on the other hand, has been widely accepted as a practice, which will supplement the traditional fishery production. It will also improve the living standards of the rural populace by generating various types of job opportunities, both directly and indirectly. Developing and underdeveloped countries have given high priority for coastal aquaculture as it has the potential to generate the much needed foreign exchange by exporting the high-value marine products (Williams, 1997).

While aquatic systems and the species they support may be tolerant to substantial external change and may continue to be productive even under the most stressed conditions, we can see increasing evidences of damage in the wake of excessive use of land and water resources, unchecked population growth and fast pace of industrial development. Aquaculture as a user of aquatic resources, may also contribute in creating some adverse

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impacts on aquatic environment if incorrectly conceived and/or operated (Pullin, 1993). However, armed with the knowledge of the potential which could be realised and given the opportunity to incorporate aquatic production goals into water resource management, we have clear prospects for improving the situation.

The tropical estuaries are very productive ecosystems and are being used for a variety of development activities, most of them bring in some environmental changes. In India, shrimp aquaculture has developed as the single largest coastal aquaculture practice. However, most of the development has also been taking place around the estuarine environment. It is in this context that we discuss here the possible impacts of brackishwater shrimp farming on estuarine life.

2. Estuarine Ecosystem

Although estuaries constitute a very small area of the marine hydrosphere they play a vital role in the life history and developed of many marine species. It forms a transition zone between the inland world of freshwater and the seawater lying offshore. Characteristically, the estuary is defined as a body of water in which river water mixes with and measurably dilutes seawater. There exists many definitions for an estuary but the often quoted definition is that of Pritchard (1967). He defines, "An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which the seawater is measurably diluted with freshwater derived from the land drainage".

Because of tidally influenced nutrient trapping and recycling, removal of metabolic wastes, circulation of detritus, transfer of energy from primary producers to various levels of consumers and moderation of temperature fluctuations, the estuarine ecosystem is considered as the most dynamic and biologically productive ecosystem in the world (Officer, 1983) which performs several important functions. Many benthic organisms such as oysters, clams, scallops etc. live out their entire life cycle in the brackishwater of the estuaries and a host of marine and coastal species use them for certain stages of their life cycles (e.g., larval stages of higher organisms). The brackishwater areas serve as breeding and nursery grounds for many marine species, particularly fin and shell fishes. They also serve as migration routes for anadromous species which breed in freshwater but spend most of their life in the sea or for catadromous species which breed in the sea but develop and grow in freshwater areas.

2.1. Physical processes

Conditions in the estuary are more variable than those in the freshwater or coastal environment. The variation is primarily felt in the salinity of the water which increases horizontally from virtually zero in the upper reaches (river) to the coastal water salinity of ≥ 30 ppt in the lower reaches (mouth of estuary). The salinity of the water may vary vertically by several parts per thousand (freshwater or very low saline water at the surface and high saline water at subsurface), particularly during the monsoon season when clear stratification develops. During fair seasons well-mixed homogenous condition prevails. Large variations may also occur corresponding to the tidal cycle (increase in salinity during flood tide and decrease during ebb tide). Occurrence of sudden and drastic changes in salinity is not an uncommon phenomenon. Seasonal changes in river flow introduce another time scale of salinity variation and annual differences occur between wet and dry years. Temperature fluctuations in the estuarine system also tend to be greater than those of offshore waters and the open ocean, since the inflowing river water tends to be colder than seawater in winter and warmer in summer. Generally, estuaries are turbid due to large amounts of silt in the water which prevents light penetration to deep layers unlike in the coastal and open ocean waters where the euphotic zone extends considerably deeper (see Officer, 1983).

2.2. Biological processes

Salinity (physiological constraint) and current velocity (physical constraint) primarily define habitat within an estuary. Most of the estuarine animals are essentially marine forms and are therefore tolerant to seawater salinity. Many species which live in the shallow water zone on the continental shelf use the estuary as a nursery ground before migrating into the open sea. While the true estuarine species (endemic) are few in numbers, those, which have become adapted to this fluctuating environment, occur in large numbers. In any environment, an animal has two alternative reactions when countering stressful situations. It can either migrate to a more favourable environment, or remain and adapt itself to the changes. The adaptations of estuarine organisms reflect their modes of existence. As a group these can be broadly classified as being more euryhaline and eurythermal than open ocean forms. Many have evolved considerable tolerance to oxygen deprivation but ability to tolerate desiccation is limited primarily to intertidal species. As a group, these organisms have evolved a wide range of

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physiological adaptations that permit them to utilize the fluctuations of the estuarine environment to their advantage (see Vernberg, 1983).

2.3. Phytoplankton

Phytoplankton (Microscopic algae) occupy the lowest level in the food chain. They produce organic matter by photosynthesis (primary production) and transfer the energy through the primary consumers (herbivorous zooplankton to the secondary level in the food chain. Most of the phytoplankton species occurring in the estuaries are also common to coastal and offshore water. Some of the common forms are *Nitzschia*, *Coscinodiscus*, *Skeletonema*, *Tetraselmis*, *Rhizosolenia*, *Navicula* and *Bacillaria*. the phytoplankton in estuaries has the same requirements (availability of essential nutrients, vitamins, trace elements and adequate sunlight) for survival and growth as in any other aquatic environment. Phytoplankton dynamics are affected with changes in environmental conditions and therefore the species composition may vary in response to and depending on the prevailing water quality parameters particularly salinity, temperature, light and nutrients. Nutrient rich environment may trigger off phytoplankton blooms leading to eutrophication. 'Red tide' is a common phenomenon occurring along the Indian coasts during the summer season and blooming of *Trichodesmium erythraeum*, a blue-green alga is responsible for this (Devassy *et al.* 1978). Some algae are know to produce toxic substances (see Smayda and Shimizu, 1993) and blooming of such algae may damage the flora and fauna of the coastal ecosystem.

2.4. Zooplankton

The distribution pattern of zooplankton (microscopic animals) is somewhat intermediate because some are predominantly estuarine (endemic) but most are derived from the nearby coastal waters. Based on their origin and relationship to salinity, Bousfield *et al.* 1975) have categorised the estuarine zooplankton into three groups:

- Marine coastal species which enter the estuary from sea;
- Estuarine endemic species which live only in the brackishwater of the upper estuary;
- Freshwater species which extend into brackishwater in the upper estuary.

Zooplankton population is comprised of both holoplankton (totally planktonic) and meroplanktonic (partially planktonic) organisms. Larval stages of most of the higher forms such as fish, molluscs, cephalopods, decapod crustaceans, etc. constitute a good percentage of the meroplanktonic population. Copepoda, pelagic Decapoda and larvae, Chaetognatha, Cladocera, Appendicularia, Ctenophora, Hydromedusae, Polychaeta, fish eggs and larvae, etc. are some of the common groups of meso-zooplankton (> 0.2 mm in size) abundant in the estuaries.

Sudden drop in salinity during the monsoon season totally changes the composition of the zooplankton population. Their abundance, biomass and diversity decline considerably. Only those species that can tolerate low saline condition survive during this period. Some freshwater/low saline forms make their appearance in the upper and middle reaches and at times dominate the population. Most of the euryhaline (salinity tolerant) forms move into the coastal waters where the conditions are conducive. Many of them perish, as they are unable to withstand the turbulent and drastic changes. Some of them (copepods and cladocerans) may possibly be producing resting eggs (as in temperate waters) to tide over the unfavorable conditions. Repopulation occurs gradually as the environmental conditions are restored (see Madhupratap, 1987; Achuthankutty *et al.* 1997).

Microzooplankton (20–200 μm) population is also very rich in the estuaries. They are constituted by larval stages of a number of metazoa (eg., copepod nauplii), a large variety of ciliates (*Tintinopsis*, *Eutintinus*, *Favella*, *Codonella*, *Rhabdonellopsis*, *Tintinnus*, *Tintinidium*), heterotrophic flagellates (eg., *Peridinium*) and sarcodines (Radiolaria, Acantharium, Foraminifera). They play an important role in the food chain (microbial loop) as they convert the bacterial biomass into animal matter on which the primary consumers feed (Reiman *et al.* 1990; Froneman and Mcquid, 1997).

2.5. Benthos

The benthic community is comprised of organisms that live on the surface of bottom sediment (epibenthic) or burrowed (benthic). Shrimps, crabs and other crustaceans are typical examples of epibenthic fauna. Bivalves, gastropods, polychaetes, etc. are the benthic forms. All benthic plant organisms such as diatoms, macroalgae, seagrass etc. are collectively termed as phytobenthos whereas all animals that inhabit the bottom are termed as zoobenthos. Depending on the size of animals, they are further classified into meio-benthos ($< 0.5\text{mm}$) and macrobenthos ($> 0.5\text{mm}$). Meio-fauna

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usually consists of nematodes, harpacticoid copepods, turbellarians, small annelids, etc. Macro-fauna such as bivalve molluscs, sabellid polychaetes, sponges and ascidians are all suspension feeders while polychaetes, amphipods, isopods and gastropods are all deposit feeders.

Many complex factors are responsible for short- and long-term variation in benthic population. The physico-chemical variables include salinity, temperature, dissolved oxygen and nature of substrata. Introduction of domestic wastes, industrial effluents and toxins can significantly affect the structure of the benthic community. A number of biological factors may affect their reproduction, recruitment and survival.

2.6. Bacteria

They play the dual role of transformation and production. As transformers they are responsible for degrading complex organic molecules to simpler substances (e.g., inorganic nutrients such as phosphorous and nitrogen) that can be taken up by autotrophs like phytoplankton (Wood, 1967). Though infinitely small in size (1-2 μm), they are capable of carrying out many functions either by their cell bound or cell free enzymes like cellulase, amylase, protease or even mobilizing metals in water. As producers they can have a high turn over rate (see Kirchman and Ducklow, 1987). Bacteria generally occur either as free living or particle-attached forms. They are an important source of food to flagellates, protozoans (microbial loop) and filter feeders at the higher trophic levels. Some of the dominant groups are *Pseudomonas*, *Aeromonas* and *Vibrios* and some species belonging to these genera have been implicated in fish and prawn diseases (Anand *et al.*, 1996).

2.7. Fishes

A large variety of fishes inhabit the estuarine environment. Most of them are migratory marine species which use this habitat in their early life cycle as a nursery. Mulletts, milk fish, anchovies, flat fishes, sole and a number of crustaceans such as marine shrimp, crabs, etc. are some examples. Some fishes are the resident fauna of the estuaries that pass through their entire life cycle in this ecosystem (e.g., gobies, ambassids, sygnathids, etc. which are generally small in size. Anadromous and catadromous fishes also use this environment during their migration from sea to freshwater and vice versa, respectively.

All the Indian estuaries support very rich fishery. Most of the catch comprises of young ones of marine species. The fin fishes that contribute

in substantial quantities are *Hilsa ilisha*, *Lates calcarifer*, *Polynemus paradiseus*, *P. indicus*, *Mugil cephalus*, *M. dussumieri*, *Mugil* spp, *Sardinella* spp, *Chanos chanos*, *Sillago sihama*, *Platycephalus* spp *Leiognathus* spp, *Caranx* spp and several species of cat fishes and scianids. A number of marine shrimps also reside in the estuary during their juvenile phase and form an important constituent of the estuarine fishery. They include *Penaeus monodon*, *P. indicus*, *P. merguensis*, *Metapenaeus dobsoni*, *M monoceros*, *M. affinis*, *M. brevicornis* and *M. moyebi*. Several species of brackishwater prawns and crabs also are caught in fairly large numbers (Achuthankutty, 1990).

3. Mangrove Estuary

Mangrove is a specialised and unique environment found only along the tropical and subtropical intertidal zones (McIntosh, 1982). The mangrove vegetation consists mainly of *Rhizophora*, *Avicennia* and *Sonneratia*. Sundarbans in West Bengal is the largest and dense mangrove forest in India. Most of the Indian estuaries are fringed with the unique vegetation which are denoted as mangrove estuaries. The Hooghly-Matla estuarine system in West Bengal, the Mahanadi in Orissa, the Godavari and Krishna in Andhra Pradesh, the Cauvery in Tamil Nadu, the Narmada and Tapti in Gujarat and the Vembanadu and connected backwater in Kerala are the finest examples of mangrove estuaries (Achuthankutty, 1990). These estuaries support rich flora and fauna and serve as breeding and nursery ground for many marine fishes and shrimps. They also support a very rich fishery. They constitute a very productive ecosystem and provide essential nutrient inputs to shallow coastal waters. The rich particulate organic matter (detritus) derived primarily from the decomposed mangrove foliage is nutritionally very rich and hence forms an important source of food for juvenile fishes and shrimps (Snedaker, 1978).

3.1. Shrimp life cycle

Most of the marine shrimps complete their life cycle in two different environments (Penn, 1981). The adults live in deeper waters in the sea where they attain sexual maturity and spawn. The eggs hatch out as nauplii and go through various development stages. They adapt to planktonic life cycle and as the larvae grow, they move passively towards the coast and the early post larvae enter the estuary. Here, they further move into shallower

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regions fringed with mangrove vegetation. They reside and grow for a certain period of time and later migrate to deeper areas of the estuary and subsequently into the deeper waters of the sea where they grow to adult size and attain maturity, thus completing the life cycle. However, the residence period and size attainment in the estuary vary from species to species (Achuthankutty and Nair, 1983).

The estuarine phase of the early life cycle of marine shrimps is well established (Staples, 1980; Mair *et al.* 1982; Achuthankutty, 1988). The capture shrimp fishery potential has also been found to have a correlation with the existence of healthy mangrove ecosystem (Martosubroto and Naamin, 1977). In countries like Indonesia, Thailand, the Philippines, Taiwan, Ecuador, etc. where mangrove areas were indiscriminately cleared for various developmental activities including coastal aquaculture, the total capture fishery resources including marine shrimps were found to be adversely affected. This was essentially due to the fact that clearing and filling of the nursery ground had adversely affected the larval migration pattern and juvenile growth processes, which were reflected in the catch. This clearly indicates that capture shrimp fishery resources is very much dependent on the availability and existence of healthy mangrove ecosystem. The shrimp population in the estuary is otherwise also tremendously stressed, as they are fished as juveniles in large quantities, denying them an opportunity to grow and propagate. Another threat is the removal of wild larvae from the estuary for stocking in aquaculture ponds.

4. Brackishwater Shrimp Farming

With depleting marine resources and increasing population, the focus has been shifted to coastal aquaculture for enhancing food and protein production. The choice for coastal shrimp ponds often falls on areas such as the tidal and intertidal mudflats, salt marshes and mangrove swamps adjacent to the estuaries (Barg, 1992). Siting the farms near the estuaries facilitates quick and easy water exchange and waste disposal.

Traditional aquaculture is being practiced for centuries along the estuaries in many coastal states of India. The water exchange and seed stocking are carried out depending on the diurnal tides. Although many developments and improvements have taken place in shrimp aquaculture all over the world, the basic concept has not changed much. Until recently, brackishwater shrimp farming has been practiced under tide fed management where the pond water is replenished by tidal water from the estuary/tidal

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creek and for this purpose the site was selected within the intertidal zone of the coastal belt. Presently, different types of farming methods (extensive, semi-intensive, intensive) are being employed in shrimp aquaculture where use of pumps, aerators, chemicals and supplementary feeding are inevitable, but the site remains unchanged.

The sole dependence on estuaries for the development of shrimp aquaculture, may add further stress to this delicate ecosystem as it is already being used for several other developmental activities. Therefore, shrimp aquaculture may have some adverse impacts on the estuarine environment if proper monitoring and management practices are not adhered to.

5. Possible Impacts

5.1. Coastal aquaculture

The ecological problems that can be created as a result of coastal aquaculture has been grouped into 4 major areas by Barg (1992). They are,

5.2. Nutrients and organic matter enrichment

The metabolic waste products and unused food materials generated in the aquaculture ponds are directly discharged into the estuarine environment causing excessive levels of nutrients in the water column and loading of organic matter in the bottom sediments. When the soluble inorganic nutrient concentration (phosphorous and nitrogen) increases in the water column above normal levels, the phytoplankton growth increases many fold leading to algal blooms and high primary production. This condition is known as 'eutrophication'. Some algal blooms produce toxic substances that may interfere with the flora and fauna. Invariably, the excessive amount of primary resources produced is not utilised and the dead and decayed cells settle to the bottom further adding to the detrital biomass. However, there is no evidence to directly implicate that algal blooms have been caused by the waste discharge from coastal aquaculture farms.

Organic enrichment of bottom sediment may directly affect the life of benthic community. There will be a sudden increase in the oxygen demand and if the demand exceeds availability, the sediment will become anoxic. This may bring about considerable changes in biological and chemical process in the sediment and impoverishment of benthic fauna. In certain extreme cases, it may even lead to excessive production of CO₂, methane, H₂S, excess remineralization of organic nitrogen and depletion in diversity and abundance of benthic community. Increased levels of dissolved

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and particulate organic carbon may also influence qualitative and quantitative changes in the microbial population of the water column and sediment of the ponds and adjoining water bodies. There is a possibility of certain groups of microorganisms becoming dominant in such situations and even pathogenic strains may make their appearance.

5.3. Chemical residues

The water discharged from the aquaculture farms may also contain remains of various types of chemicals used in the farms. These are therapeutants, disinfectants and biocides, which are used for disinfecting the farms to control pests and predators and to treat diseases. Sometimes anaesthetics and hormones may also be seen in small quantities if they are used for facilitating transfer of the stock or for inducing growth, respectively. Since only small dosages are used occasionally, the discharge water may contain only very small quantities of the residual chemicals, which are not considered to cause serious environmental problems. However, there is still a concern about the adverse effects of these chemical residues in the environment particularly on nontarget organisms and also the possibility of producing drug-resistant bacterial pathogenic strains.

5.4. Biological implications

Aquaculture may bring about some changes in the local/resident fauna. Introduction of exotic species and breeds may reduce the biodiversity and genetic resources of the ecosystem due to predation, competition and interbreeding. There is also a possibility of introduction of pathogens and diseases into the ecosystem which are carried by the candidate species. Diseases may also be caused as a result of the stress to which the farmed species are subjected to in the aquaculture system because stress increases the susceptibility to infectious diseases. Deterioration in certain critical water quality parameters may enhance the virulence of pathogenic strains which otherwise are dormant when the water quality is good. A stressed animal is an easy target for the pathogens, which leads to disease outbreak.

5.5. Damage to wetlands

Aquaculture has the greatest potential for area expansion and specialised ecosystems such as mangrove swamps and salt marshes are the primary targets. Vast areas of mangrove swamps have been reclaimed and converted for many developmental activities including aquaculture in several tropical countries, particularly the Southeast Asian countries. These ecosystems

are not only very productive but also perform several biological and physical functions. A variety of fauna and flora are endemic/resident to these ecosystems and a host of others particularly the marine fin and shellfishes use them as breeding or nursery grounds. They are also the storehouse of organic matter, which supplies to the adjoining coastal waters. They prevent coastal erosion and control floods. Conversion or modification of these delicate ecosystems may lead to irreversible damages to the ecology, productivity and stability of the estuarine and coastal ecosystems.

5.6. Shrimp aquaculture

Some of the ecological concerns which the brackishwater shrimp aquaculture may cause have been listed by several authors (see Pullin *et al.* 1983; Barg, 1992; Pillay, 1992). These, however, are only the possibilities which the estuarine and coastal environments may be subjected to if shrimp farming is practiced with out proper planning and scientific management. However, scientific data or evidence to support that all or any of the listed factors are directly causing damage to the estuarine and/or coastal ecosystem is not readily available. The following are some of the important environmental issues associated with brackishwater shrimp farming.

- o Shrimp farms are mostly located along the banks of the estuaries and backwaters. Since the land requirement is extensive, there is a possibility that salt pans and mangrove forests are likely to be converted.
- o Conversion and construction shrimp farms in estuaries and mangrove swamps may have adverse effect on the resident fauna and flora and also on those organism which use the ecosystem as breeding and nursery ground. This may also affect the capture fishery potential of some of the commercially important coastal and marine species.
- o Mangrove swamps have typical acid sulphate soil which is not suitable for shrimp farming. Oxidation of pyrite (FeS_2) takes place at the time of pond bottom drying, resulting in the release of sulphuric acid into the pond water and adjacent water bodies.
- o Construction of shrimp farms may alter the shoreline configuration of the estuaries and mangrove areas. This may also alter the coastal erosion process, affect the production and supply of organic matter to the coastal ecosystem, nutrient recycling, etc. This may also create ecological imbalance and adversely affect the productivity processes.
- o Construction of farms and other structures may reduce the water current and alter the flow pattern leading to increased deposition and

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- accumulation of organic wastes, siltation and water quality deterioration. This can create anoxic condition and production of hydrogen sulphide and methane which are harmful to the estuarine life.
- o The water carrying capacity of some estuaries may be less than the quantity required for regular exchange. The water exchange requirement of ponds may far exceed the flow rate of the tidal creek or supply canal. This may lead to a condition where instead of exchanging good quality water for waste water discharged, the farms may continue to recycle the waste water itself, deteriorating the water quality further and increasing the chances for disease outbreaks. This is particularly true for small estuaries/tidal creeks, estuaries with large number of farms and farms which are located away from the mouth of the estuaries.
 - o Constant and excessive use of fertilizers and live and artificial feeds will affect the water and sediment quality of the pond and adjacent water bodies. The nutrient concentration and organic matter production will increase resulting in ecological imbalance. It may lead to formation of anoxic sediments and triggering of algal blooms.
 - o Construction of channels for water supply and drainage and pumping of brackishwater inland may result in hydrological changes, siltation and salt water intrusion.
 - o A variety of antibiotics are used in treating diseases and preventing disease outbreaks (eg., chloramphenicol, oxytetracycline, streptomycin, etc). Over dose of antibiotics in shrimp farms may produce antibiotic resistant strains of pathogens. Disinfectants and chemicals (e.g., sodium hypochlorite, zeolite, calcium carbonate, etc.) used for water and soil treatment have not been known to cause any adverse effect on the ecology or life of the estuary. Use of some chemicals (e.g., formalin, malachite green, saponin, copper sulphate, etc.) has been found to affect the life of estuarine organisms and in certain cases eradication has also been reported. Excessive use of chemicals may also lower the quality of the farmed product and make it unacceptable for human consumption.
 - o There is a possibility of introducing some pathogens through accidental escape of infected farmed stock. Diseases can also cause due to excessive intensification of the ponds necessitating over feeding which may lead to waste and organic matter accumulation resulting in deterioration of water and sediment quality.

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6. Conclusion

In conclusion, the following points need to be considered for a sustainable and environmentally viable shrimp aquaculture:

- * There is no scientific data available to implicate that shrimp aquaculture has caused any serious environmental problems *per se* although it might have caused some local concerns. It is necessary to collect data systematically so as to ascertain the quality of water and sediment in the shrimp farms and its long-term effect on the environment.
- * Since the estuarine ecosystem is already being used for several other activities, some of which are known to cause environmental changes, it is necessary to take all precautions to minimise stress to this ecosystem as a result of shrimp farming.
- * Use of chemicals and antibiotics should be limited to the minimum possible levels. Most of the chemicals presently used have been developed for agricultural and veterinary purposes and may not be very effective and suitable for aquatic use. Their effectiveness on the farmed stock and long-term residual effect on the ecosystem should be thoroughly evaluated. R& D should be made strong to develop specific vaccines, antibiotics, etc. for shrimp aquaculture.
- * Introduction of bacterial strains through probiotics should be cautiously done since nothing is known about its influence on or interaction with the ecosystem and biota. Similarly, cautious approach should be taken while using immunostimulants. It is suggested that specific studies may be carried out to understand their long-term effects on the ecosystem.
- * Excessive feeding should be avoided as it may lead to organic enrichment in the receiving water bodies besides adding to recurring expenditure. Feed having high digestibility and appropriate nutritional formulations should be judiciously used.
- * Mangrove ecosystem is not a suitable site for shrimp farm development as it contains acid sulphate soil and also that destruction of this environment may have ecological implications.
- * The extent of development and method of farming should be based on the carrying and assimilation capacity of the receiving water bodies.
- * Creation of environmental awareness amongst shrimp farmers and incorporation of environmental management practices as part of the pro-

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duction strategy are essential for long-term sustainability of shrimp farming.

- * A master plan need to be prepared for each estuarine system after detailed feasibility study so as to avoid mushrooming and unorganised development of farms.

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