Chapter 34
Water Management for Sustainable Brackishwater Aquaculture in Coastal Ecosystem-Innovative Approaches

P. Nila Rekha and K. K. Vijayan

Abstract Brackishwater aquaculture is a coastal farming activity, which aims at deriving maximum benefits from unproductive and marginally productive coastal lands and brackish water bodies, and it has contributed significantly to the progress of the country's economy as well as the economic well-being of the rural poor. It is a fast-growing food industry, and the success mainly depends on the availability of good and adequate quality source water and water management during culture. Hence, the water management in coastal brackishwater aquaculture is paramount, which starts with the identification of good quality and adequate water resources, water monitoring during culture for maintenance of the optimum water quality, and discharge water management by reducing, reusing recycling, and remediation technologies. Coastal watershed-based integrated water resource management using the advancement in geospatial modeling, remote sensing, and geographical information system (GIS) helps to identify the potential site, water source, and its salinity regime during different seasons and to minimize the impact of upstream activities on the coastal aquaculture as well as the impact of aquaculture on coastal ecosystem. Of late intensive coastal aquaculture is rapidly expanding with the introduction of *Penaeus vannamei* which uses large water volume and high protein content in feed which results in significant nutrient-rich effluents. Recirculating aquaculture systems (RASs) seem to be a solution. Development and advancement of RAS, raceways, integrated multi tropic aquaculture (IMTA), zero water exchange systems, biofloc, seaweed bioremediation, algal bioreactor-based RAS, and aquaponics offer scope for higher productivity with better water management practices that maintain the serenity of coastal ecosystems. In the present article, all the above-mentioned water management technologies in brackish water aquaculture have been discussed for pristine coastal ecosystems.

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34.1 Introduction

Brackishwater aquaculture in India has evolved as a viable commercial and economic farming practice from the level of traditional backyard activity over the past few decades with the advancement in scientific culture practices and has been showing an impressive annual growth rate of 6–7%. India is blessed with 3.9 million ha of estuaries and 3.5 million ha brackish water resource of which 1.2 million ha is potential brackish water area available in India. However, the total area under brackish water farming is only just over 15%. To bring this vast resource under sustainable aquaculture, coastal watershed-based planning and water management are of prime importance. Brackish water aquaculture is synonymous with shrimp culture. The introduction of exoticwhite-leg shrimp, *P. vannamei*, has fascinated the farmers' attention for the reason of its profligate growth, high survival rate, acceptance to high stocking density, lower dietary requirements, more effective utilization of plant protein in the formulated diet, low incidence of native diseases, availability of specific pathogen free (SPF) domesticated strains, and culture feasibility in wide salinity range. The production of this species has reached a level of 6,22,327 tons during 2017–2018 (MPEDA 2018). At present, not only in India, worldwide, the most important brackishwater-cultivated species is *P. vannamei* which contributes approximately 52.9% among crustaceans in world aquaculture production (FAO 2020).

Generally, shrimp farming systems are categorized into traditional, modified-traditional, extensive, semi-intensive, and intensive systems. These classifications are made based on the degree of management inputs provided. At present, 90% of the farming is done by introduced SPF white shrimp, *P. vannamei*. Three kinds of intensive culture systems are in practice, depending on the quality of the water supply viz., open system. recirculation system. minimal water exchange system. Though *P. vannamei* is started in a semi-intensive culture system of late, it is usually cultured in the intensive and high and super-intensive system. Hence, the water management in coastal brackishwater aquaculture is paramount which starts with the identification of suitable water resources, water monitoring during culture, and discharge water treatment like screening, sedimentation, settlement, and bioremediation or phytoremediation before let into stream or waterbodies. Intensive coastal aquaculture is rapidly expanding which uses large water capacity and high protein content in feed which outcomes in a significant volume of nutrient-rich effluents. Therefore, the present review has reflected the innovative approaches targeted to have better water management in the three phases of brackishwater aquaculture practices toward an economic and sustainable production system.

Water management of shrimp farming includes three phases viz.,

- Influent/intake water management
- Pond water management
- Effluent/discharge water management

34.2 Intake Water Management

All aquaculture conveniences require a sufficient amount of quality water. It is imperative to have a dependable and efficient, good quality water source and equipment to transfer water to and within the facility of the farm site. The volume of water required depends on the facility size, the species, production system, and scale of operation. Accurate design and structure of the water inlet system are a complete necessity to avoid complications during the culture of shrimp farms. Brackishwater aquaculture utilizes saline water either from sea or estuary or creek (Fig. 34.1a, b). Water quality and quantity determine the success or failure of an aquaculture operation. The estimate of the quantity of water essential in a farm and the conducts and means to meet

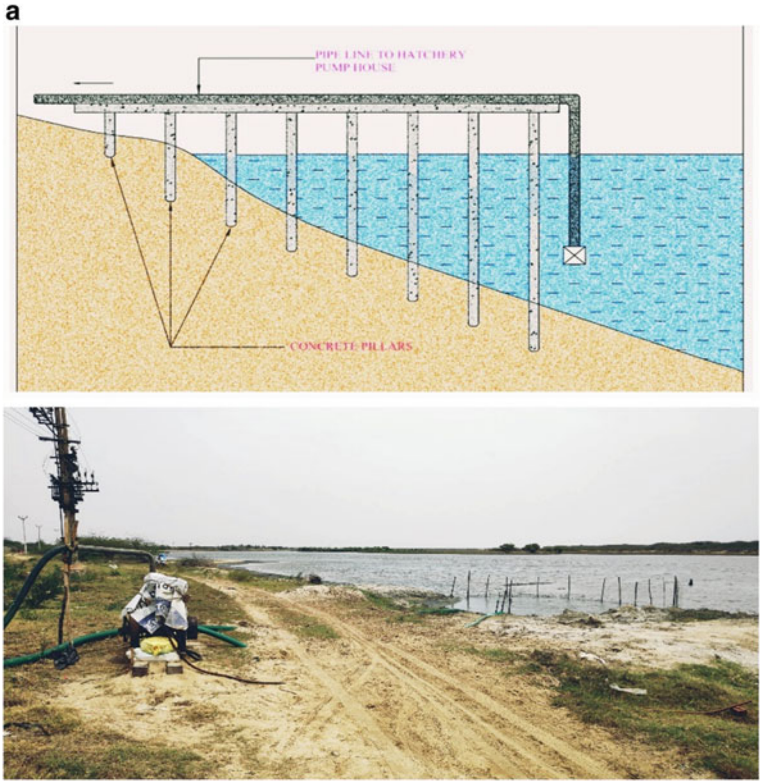

Fig. 34.1 **a** Intake of water from brackishwater resource. **b** Pumping water into culture pond

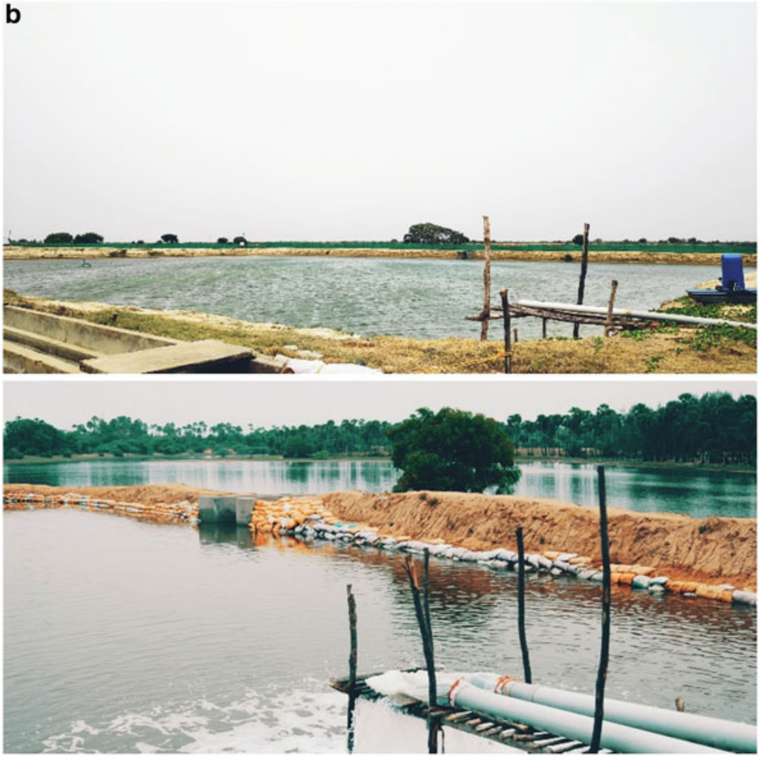

Fig. 34.1 (continued)

the requirements are the essential factors to be considered in selecting a suitable site. For farming, an estimation of evaporation and seepage losses is required in addition to water exchange during culture. In addition to that, a large supply of water should be on hand to flush ponds if needed or refill them after draining.

34.2.1 Site Selection and Pond Design

Identification of potential and suitable site for brackishwater aquaculture is necessary to expand aquaculture scientifically and sustainably. Therefore, the most important criteria for site selection are water source and its quantity and quality. Possible sites were defined after seeing the importance of ecosystems, soil and water quality, and coastal aquaculture authority (CAA) guidelines using GIS and remote sensing by coastal watershed approach. ICAR-CIBA has developed a methodology for demarking potential zones for Tamil Nadu coastal districts. viz., Chengalpattu and

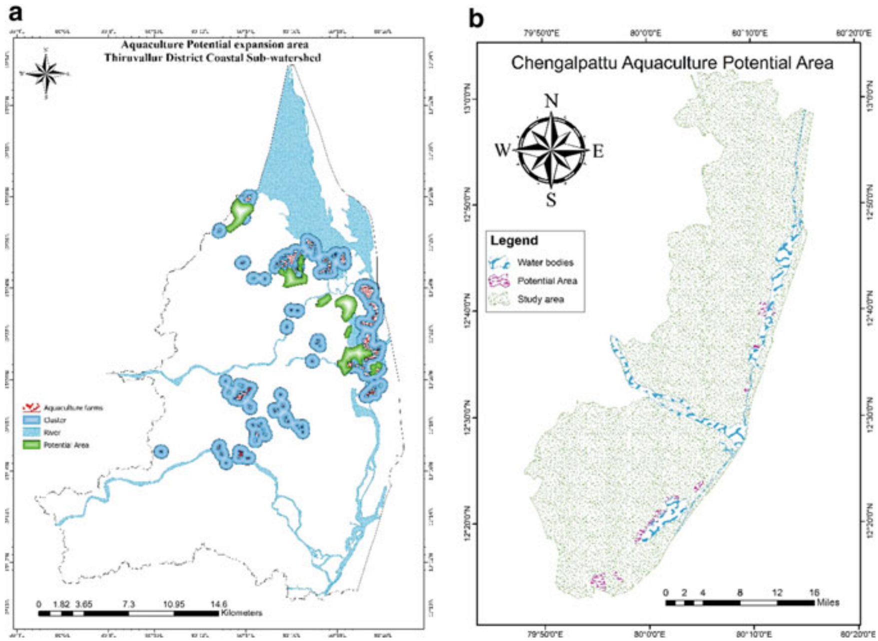

Fig. 34.2 **a** Aquaculture potential area for Thiruvallur district, Tamil Nadu. **b** Aquaculture potential area for Chengalpattu district, Tamil Nadu

Tiruvallur by coastal watershed-based geospatial modeling through analytical hierarchy process (AHP) (Fig. 34.2a, b). Site specific pond design should be made with engineering consideration so that water inlet and water draining during water exchange and harvest could be done with ease.

34.2.2 Water Pumping

The traditional and most economical method of water management for a coastal farm is through tidal flow, but nowadays, mostly in many cases of scientific farming, it is necessary to pump water. For *P. vannamei* culture usually, water is taken through pumping from canals, creeks, or sea. Monoblock or centrifugal pumps are used. Solar pumping is being encouraged. Evaluation study of solar pumping at ICAR-CIBA proved to be economical and efficient (Fig. 34.3).

Fig. 34.3 Solar water pumping

34.2.3 Reservoir/Disinfection

Water treatment is necessary for the maintenance of good water quality during culture which ultimately decides the success of the crop. Before stocking seeds, water from the source should be filtered through 60μ filters to prevent the entry of parasites and crustaceans that are carriers of diseases. A reservoir pond is necessary for most of the farming systems. Chlorination should be done in a reservoir pond to sterilize the water by applying enough chlorine (approximately 30 ppm). Chlorine dosage varies with pH, concentrations of organic matter, and ammonia. Water must be pumped in the grow out pond when the permissible levels of chlorine residuals are less than 0.001 ppm. Aeration, adding of 1 mg L^{-1} of sodium thiosulfate for every mg L^{-1} of chlorine, and contact with sunlight are some of the management measures for dechlorination**.** In addition to chlorination, ozonation, and UV disinfection also can be applied based on the necessity and requirement of the production system.

34.3 Water Monitoring and Management during Culture

34.3.1 Pond Preparation

Pond preparation includes pond bottom soil conditioning by tilling, liming, and fertilization. Fertilization of pond water for phytoplankton and zooplankton blooms is by either with organic or inorganic fertilizers. A stable pH, algal bloom which is brown with a yellowish hue in color, and water temperature above 25 °C are the major indicators to ensure that the pond is prepared for stocking. Culture must be initiated with at least 1.2–1.5 m of water. Ponds should be constructed to prevent dike erosion, to enable complete drainage of water, to minimize the area of sludge accumulation, and to facilitate ease of draining of sludge. Drainage and harvesting openings should be constructed in low-lying locations and coordinated with the water flow regime.

34.3.2 Pond Lining

Ponds used for aquaculture are mostly earthen ponds in India. The sandy areas and wastelands in many parts of the country can also be utilized effectively if proper seepage reduction systems are in place. The development of intensive farming system warrants ponds lining. Polythene lining, clay compaction, the lean mixture of sand cement, etc., are used to reduce the seepage rate. In sandy soils, one can mix cement with a top layer of soil and obtain a stable lining (Rekha et al. 2005). When considering the cost economics of different lining materials, high-density polythene lining is feasible (Fig. 34.4).

34.3.3 Water Monitoring and Maintenance

Aquaculture ponds are living active systems that show constant and continual fluctuations. Water quality comprises all the essential physico-chemical and microbiological characteristics of water. pH is normally measured as one of the most vital parameters. In any selected site, the pH of the water rather ranges from 7.5 to 8.5. The other similarly important chemical characteristic of water is dissolved oxygen (DO). The water must not be too turbid. Consistent monitoring of water quality is very crucial. The optimum range for water quality parameters is given in Table 34.1.

Fig. 34.4 High-density polythene lining

Table 34.1 Optimum range for water quality parameters

S. No:	Parameter	Optimum range
1	Temperature (°C)	28–32
2	pH	7.5–8.5
3	Salinity (ppt)	15–25
4	Total dissolved solids (TDSs) (ppm)	< 100
5	Dissolved oxygen (DO) (ppm)	4.0–7.0
6	Total ammonia-N (ppm)	< 3.7
7	Free ammonia (ppm)	< 0.1
8	Nitrite-N (ppm)	< 0.25
9	Nitrate–N (ppm)	0.2–0.5
10	Dissolved-P (ppm)	0.10–0.20
11	COD (ppm)	< 70
12	BOD (ppm)	< 10
13	Hydrogen sulfide (ppm)	0.002

34.3.4 Aeration

Aeration is necessary for oxygenation (DO) which is the main factor controlling the pond dynamics. DO levels should be maintained above 4 ppm and paddle wheel/long

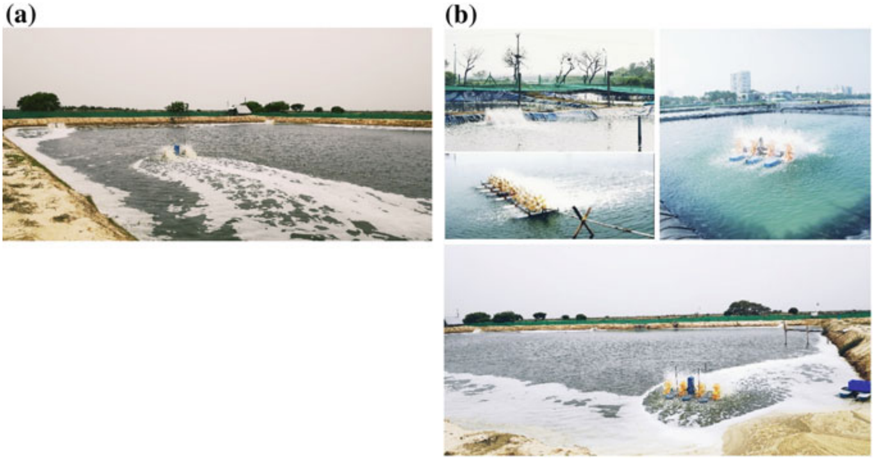

Fig. 34.5 Aerators used in intensive prawn culture systems **a** paddlewheel aerator and **b** longline aerator

arm aerators are commonly used (Fig. 34.5a, b). The location of the aerators should be adjusted in such a way the sedimentation occurs at the center of the pond, which will help in its easy removal. With the intensive culture system, this has become a prime necessity in *P. vannamei* farming. The number of aerators essential is about 1 HP per every 300 kg of biomass.

34.3.5 IoT-Based Water Quality Monitoring System

Real-time monitoring of water quality is highly essential for ensuring better management practices in shrimp aquaculture (Zhang et al. 2011). Internet of things (IoT)-based sensors for wireless water quality monitoring (Lim et al. 2010) using an android application and Web application for pH, turbidity, temperature, and DO have been fabricated and evaluated in the experimental farm at ICAR-CIBA, Chennai (Fig. 34.6). Evaluation of their sensing capability, data storage, and the alert system was carried out. Three types of sensor pH, temperature, and turbidity are integrated and used for monitoring water quality automatically. It would send an alert system if the water quality crossed the threshold which helps the farmers to take remedial action, then and there.

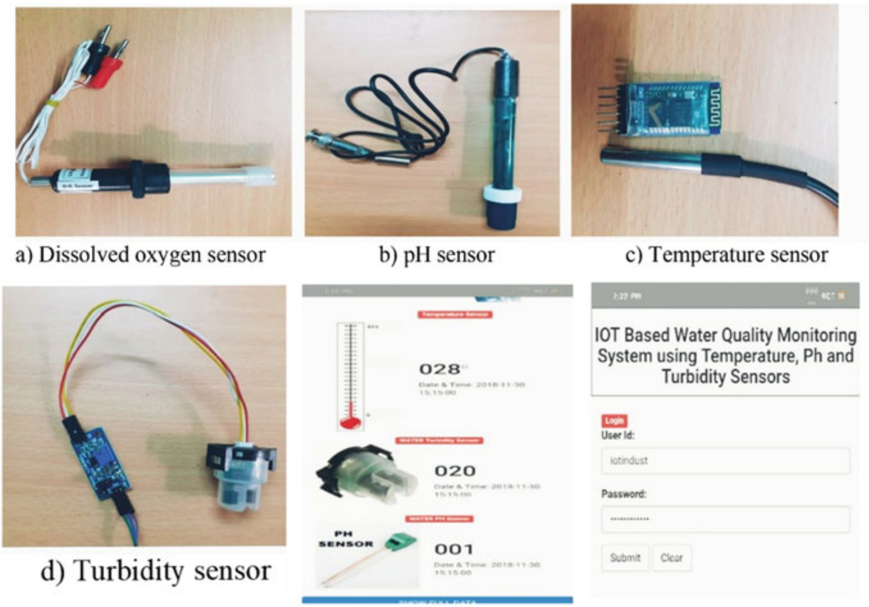

Fig. 34.6 IoT sensors

34.3.6 Feeding and Water Quality

The major challenge in scientific shrimp farming is to provide artificial feeds in proper quantity at the right time as per requirement, which is best done by automatic feeder in addition, there are other potential advantages such as maintenance of better water quality, clear pond bottom, and better feed conversion ratio (FCR) by using an auto feeder. Feeding frequency is usually dependent on farm size, as well as the species and size of the species being cultivated. But mostly, it has been observed that to a greater extent, the feeding and feeding frequency depend on labor availability. Automatic feeders are found to be suitable for *P. vannamei* culture owing to its feeding behavior, which is a column dweller, A solar-powered 125 kg capacity timer-controlled automatic feeder has been designed and developed by ICAR-CIBA and demonstrated in the farmer's field (Fig. 34.7). Results show auto feeder installed ponds provide a better growth rate and low FCR compared to manual feeding. This auto feeder was found to be highly suitable for *P. vannamei* farms with a water spread area ranging from 0.8 to 1 ha (Rekha et al. 2017).

Fig. 34.7 Solar-powered auto feeder

34.4 Effluent Water or Discharge Water Management

Shrimp aquaculture wastewater/released during the culture period is high in volume but moderately dilute in nature. whereas during harvest, discharge is of substantial amounts mainly suspended solids, containing uneaten feed, fecal matter and plankton, and dissolved nutrients such as ammonia, nitrite, phosphorus, carbon dioxide, and hydrogen sulfide. The organic enrichment leads to environmental deterioration of the receiving water bodies especially nitrogen and phosphorous. In general, 52–92% of the nitrogen and 85% of the phosphorus enter the aquatic environment which may easily induce eutrophication and algal bloom leading to anoxia. Intensive coastal aquaculture is rapidly expanding which uses large water volume and high protein content in feed which results in a significant number of nutrient-rich effluents. The national fisheries policy concerning aquaculture is to enhance production and product diversity, but also to enhance product quality to recover the competitive position of the sector and encourage environmental, economic, and social sustainability.

34.4.1 Waste Management—Central Drainage

The topography of the land determines the type and shape of ponds to be constructed. A well-made pond will enable easy management of water transfer, harvesting of the fish/shrimp, and waste collection. It would allow circulation of the water such that wastes will be gathered at the center of the pond. The construction of the dike for the pond including the height, slope, and width of the dike should be pre-determined for effective water recirculation. A central drain is in the center, operated using a standpipe or a valve. Drainage and sludge removal are important parts of pond operation (Fig. 34.8). Ensuring proper slope and water release capacity of the drainage canals toward the final outlet should be encompassed in the planning process.

34.4.2 Discharge Water Treatment Management

The discharge water from shrimp farms should be treated by screening, sedimentation, settlement pond before discharging into an adjacent aquatic ecosystem to avoid the issue of pollution.

34.4.3 Mangroves as Biological Filters

The adaptability of mangrove species (*Rhizophora*) as a biological filter in the shrimp farm discharge water under different types of soils prevailing in coastal areas in Tamil Nadu viz., sandy loam, loamy sand, and clay loam was studied. The study revealed that the mangroves can be developed as a biofilter in the buffer zone along the coast. The mangroves planted along the coast acts as shelterbelts during natural calamities viz., storms cyclones and tsunami in addition to the nutrient sequestering of the shrimp farm discharge water.

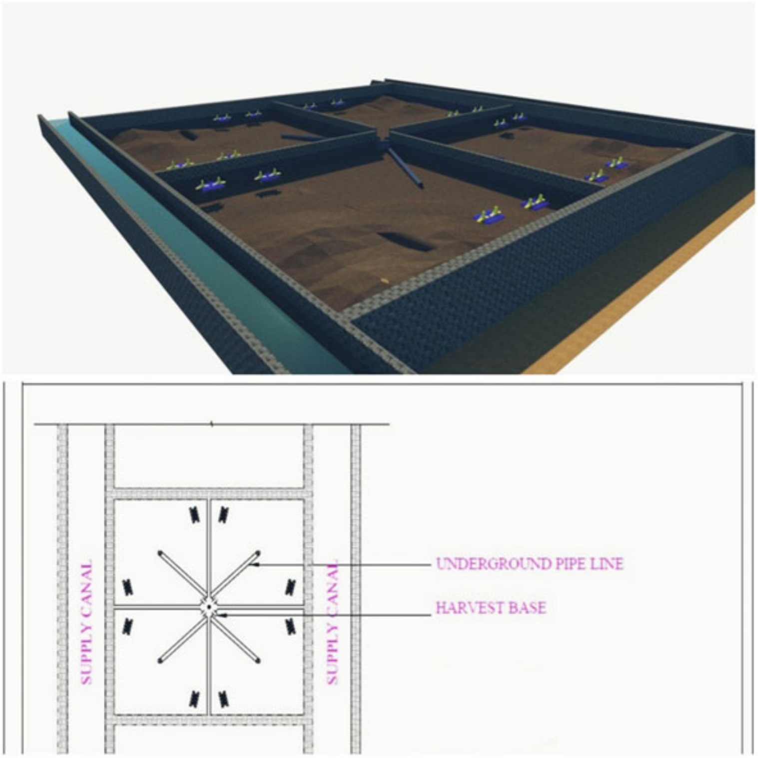

Fig. 34.8 Three-dimensional view of a pond with central drain

34.4.4 Seaweed Bioremediation

Macroalgae well known for the name seaweed can utilize the availability of nutrients viz., nitrogen and phosphorus and makes them an effective instrument for bioremediation (Marinho-Soriano et al. 2009). Algae, particularly seaweeds, are the most appropriate for biofiltration because they probably have the highest production of all plants and can be economically cultured (Neori et al. 2004). The red algae *Gracilaria* spp. and the green algae *Ulva* spp. are effective biofilters. *Gracilaria* spp. has been examined for their usefulness in laboratory using tank (Zhou et al. 2006; Marinho-Soriano et al. 2009; Skriptsova and Miroshnikova 2011, Marinho-Soriano et al. 2014), outdoor pond, and field cultivation experiments (Zhou et al. 2006; Yang et al. 2006, 2015). The bioremediation potential of macroalgae would help to sequestrate the nutrient nitrogen and phosphorus (Marcella et al. 2011). The faster expansion of high-density brackishwater shrimp farming increases the importance of phytoremediation. Based on studies at ICAR-CIBA, it is proved that *Agarophyton tenuistipitatum* could be utilized as a potential species to improve water quality at a biomass density ranging from 3.5 to 4.5 g L^{-1} as this species showed better growth in the brackish water salinity regime (Sarkar et al. 2021).

34.5 Integrated Multi-trophic Aquaculture (IMTA)

Integrated multi-trophic aquaculture (IMTA) includes the cultivation of fed species with extractive species that use the inorganic and organic wastes from aquaculture for their growth. A combination of species from different trophic levels in the same system is called multi-trophic. It involves more intensive cultivation of the different species in the nearness of each other, linked by nutrient and energy flow-through water. Filter-feeding organisms as nutrient extractors have proven to be an effective system that reduces extreme pollution from fed farming. The most frequently used organisms are mollusks, which filter organic particles and phytoplankton and macroalgae, which can absorb inorganic nutrients. IMTA provides utilization of nutrients at all trophic levels effectively (Troell et al. 2009).

Seaweed-based co-culture finds significant importance in this context (Castelar et al. 2015). *Agarophyton tenuistipitatum* had notable nutrient bioremediation efficiency and assimilative capacity. Its co-culture with shrimp *P. vannamei* could be an environment-friendly method that reduces nutrient loads from shrimp culture. Economic utilization of seaweed biomass is also possible. *Agarophyton tenuistipitatum* is potentially a fast-growing species with higher specific growth rate (SGR) compared to *Holothuria edulis* in the brackishwater culture system and hence, multiple crops may be obtained from an IMTA system with lesser input. An outdoor trial was conducted to arrive at the effective biomass density of seaweed *A. tenuistipitatum* for efficient bioremediation as well as growth and survival of *P. vannamei* in brackishwater system (Annual Report CIBA 2019). An experiment with five treatments (different biomass intensity, (0, 0.5, 1.5, 2.5, and 3.5 g L^{-1})) revealed that at a biomass density of 3.5 g L^{-1}, NH_4-N, and PO_4-P significantly reduced by 95.71% and 95.74%, respectively, in three weeks. Specific growth rate and average body weight of *P. vannamei* were not significantly increased but survival (99.17%) was significantly higher. The total bacterial count was also significantly reduced. IMTA of seaweed (3.5 g L^{-1}) and shrimp improves the water quality and has bioremedial benefits in the culture system (Fig. 34.9).

34.6 Biofloc

Biofloc production systems can be used for improving environmental control over production. More intensive forms of aquaculture with biofloc can be practiced in places where water is scarce, or land is expensive. A basic criterion in developing a biofloc system is the species to be cultured. Direct consumption of floc gives nutritional benefits to cultured species. Only a few types of biofloc systems are

Fig. 34.9 Seaweed-based IMTA

presently using commercially and are not much evaluated in research. The two basic types are system exposed to natural light and without exposure to natural light. Biofloc systems exposed to natural light include lined ponds or tanks outdoor, for the culture of shrimp and lined raceways in greenhouses. A complex mixture of bacterial and algal processes control water quality in such "greenwater" biofloc systems. Green water biofloc systems are commercially used. However, some biofloc systems (raceways and tanks) are operating in closed buildings with no exposure to natural light. These systems are operated as "brown-water" biofloc systems, where only bacterial processes control water quality (Panigrahi et al. 2018). This is indeed a zero water exchange system with monitoring and managing the water quality by developing bioflocs.

34.7 Aquaponics

Aquaponics is the combination of traditional aquaculture with hydroponics in a symbiotic environment enabling sustainable food production. Fish, prawns, or shrimp can be reared in tanks, and the water is directed into separated raceways of hydroponics, in which salt-tolerant vegetables can be grown. The aquaponics can be integrated with brackishwater fin fishes and small-scale seaweed farming. The fecal matter, feed remains, etc., will be turned into a rich nutrient system that supports plant growth.

34.8 Recirculatory Aquaculture System

A recirculating aquaculture system (RAS) can be defined as an aquaculture system where the water is treated and re-used with less than 10% of total water volume exchanged per day. Based on system water exchange, it is possible to distinguish between flow-through (>50 $m^3 kg^{-1}$ feed), reuse (1–50 m^3 kg^{-1} feed), conventional recirculation (0.1–1 $m^3 kg^{-1}$ feed), and "next generation" or "innovative" RAS (<0.1 m^3 kg^{-1} feed). RAS is a potential solution for the increasing environmental restrictions in countries with restricted access to water and land Badiola et al. (2012). Treatment of aquaculture water for its reuse purposes is a sensible means to support the further growth of the aquaculture industry without extreme water demands that are environmentally unsustainable. Water and area savings, reduced risk of contamination, and better environmental control can be achieved by the development of simple, cost-effective, water reuse systems using quite basic techniques without much technical sophistication (Martins et al. 2010). The treated discharge water would be suitable and ideal for recirculation within the farm, making the farming practice conform to the zero discharge norms. Use of nitrifying trickling filters in recirculating aquaculture is preferred (Eding et al. 2006).

Different models of RAS exists for fish culture for more than a decade, whereas the application for shrimp culture and that too maturation is not in vogue due to practical problems. But the intensive *P. vanamei* culture heralded many customized RAS models starting from a small capacity for hatchery use to grow out culture models of industrial production capacity. The initial investment is high, but the production is high if managed properly. Thus, the customized design of the RAS system can be fabricated as per the affordability, need, and requirement of the species being cultured.

34.8.1 RAS for Shrimp Maturation—Single Pair Mating

The concept of single pair mating of *Penaeus monodon* was evaluated in a prototype recirculation system designed in the experimental station of ICAR-CIBA which consists of 8 no's cylindrical tanks of capacity 500 ml liters connected in series with two filter units, reservoir tank, sedimentation tank, settlement tank, and half HP pump. The filter unit was designed after a series of trials to screen the best combination of materials for effective biofiltration, like oyster shell, bio balls, plastic balls which

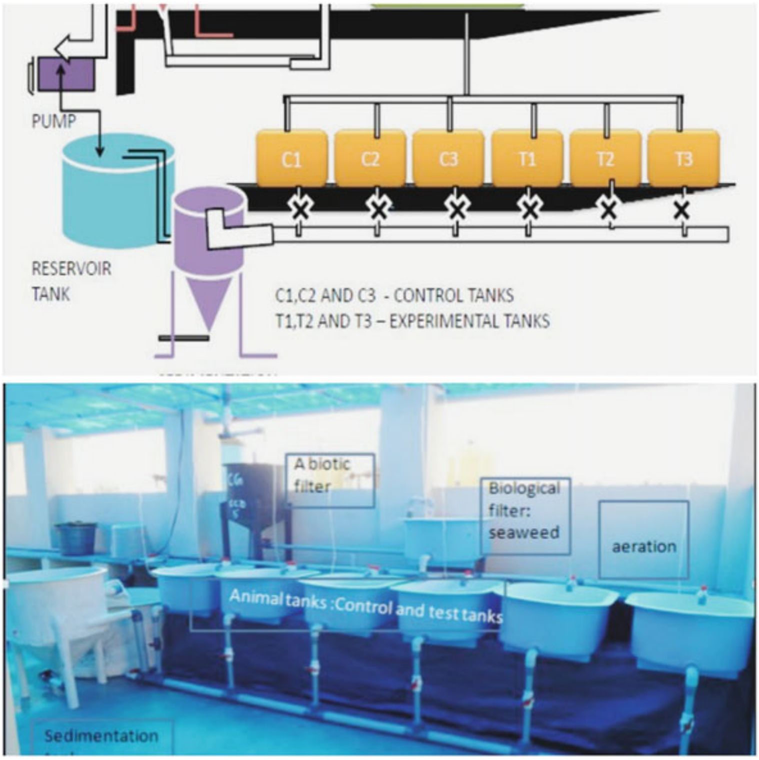

Fig. 34.10 RAS for single pair mating

have a more specific surface area. The study proved the efficacy of RAS for shrimp maturation (Fig. 34.10).

34.8.2 RAS for Shrimp Maturation—Community Mating

Similarly, the study on community mating for shrimp maturation was also evaluated by a series of statistically designed experiment trials of shrimp maturation in both the RAS system and traditional water exchange system with 1:2 male; the female ratio in 5 t capacity tanks. It was conclusively shown that the RAS for shrimp maturation is on par with the traditional water exchange system. The circular tanks with central drainage were appropriate for RAS. In the case of rectangular tanks, the central drainage system was efficient when compared to lateral drainage in removing the metabolites in rectangular tanks as about 37% showed maturation in the central drainage system.

34.8.3 Algal Bioreactor-based Recirculation System

The construction of recirculating aquaculture system with seaweed-based bioreactors for intensive shrimp culture is one of the advanced approaches to solve problems related to discharge water treatment. Different models were developed and field tested. Raceway type model (Fig. 34.11) is found to be very efficient in managing water quality followed by tubular model (Fig. 34.12). Raceway reactor was found to be reducing a significant amount of NH_4-N, NO_2-N, NO_3-N, and PO_4-P. It also helped to maintain alkaline pH throughout the entire culture cycle. The system does not require any degasser to remove CO_2 as algae can absorb CO_2 for photosynthesis and produce an ample amount of O_2. A quite impressive growth rate (4.63% day^{-1}) was recorded in the system with almost 100% survival. Feed was also utilized quite efficiently with an FCR value of 1.4.

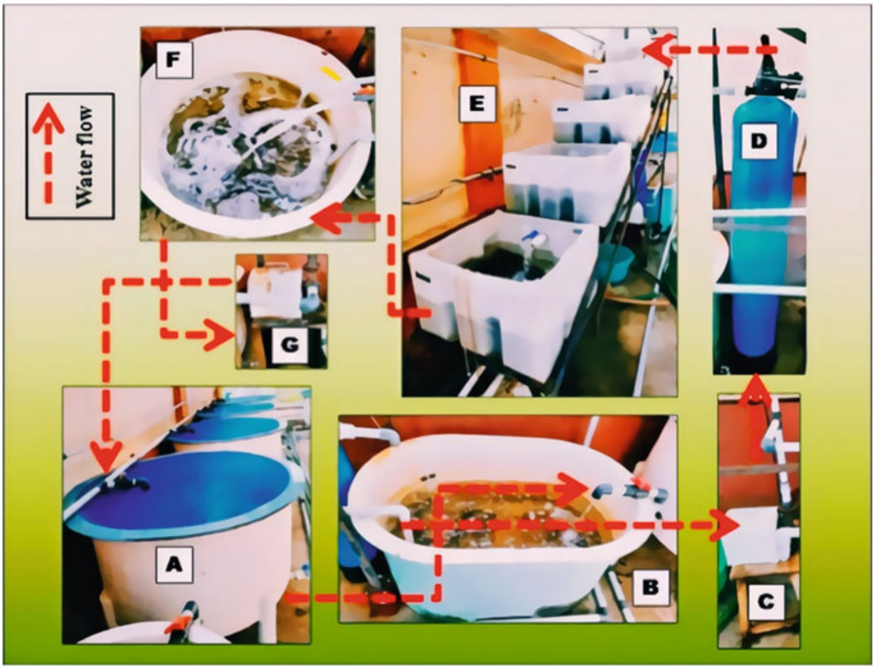

Fig. 34.11 RAS with raceway type bioreactor **a** shrimp culture tanks, **b** Sump, **c** Pump, **d** pressure sand filter, **e** seaweed bioreactor. Red color arrow indicates the flow cycle of water in the system

Fig. 34.12 RAS with tubing bioreactor **a** shrimp culture tanks, **b** sump, **c** pump, **d** pressure sand filter, **e** seaweed bioreactor. Red color arrow indicates the flow cycle of water in the system

34.9 Conclusions

Water management in coastal brackish water aquaculture is paramount which needs innovation in all three phases viz., influent, during culture, and effluent of water management. The concepts of delivering high production with a sustainable approach through evolving eco-friendly technologies started getting momentum worldwide viz., development and advancement of RAS, raceways, IMTA, zero water exchange systems with biofloc, seaweed bioremediation, and aquaponics. The research efforts by ICAR-CIBA as discussed above starting from site selection using GIS and remote sensing, water intake by solar pumping, disinfection protocols, cost-effective lining materials for pond, water monitoring using IoT, feed management by auto feeder, central drainage for managing the waste inside the pond, seaweed bioremediation, IMTA model, zero water exchange system with biofloc offer scope for higher productivity with better water management practices that maintain the serenity of coastal ecosystems.

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