19

Nitrogen Assessment and Management in Brackish-Water Aquaculture of India

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CHAPTER OUTLINE

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Introduction

Brackish-Water Aquaculture and Culture Systems

Brackish-water aquaculture (BWA) requires natural resources such as land, water, and biological resources such as seed and feed. Shrimp farming, a biology-based production activity, is synonymous with BWA in India. The quality and quantity of available resources and their management therefore plays a key role in the economic success and long-term sustainability of coastal aquaculture. Shrimp culture technology and the system of culture to be undertaken depend entirely on the site characteristics. The natural resources, namely land and water, if poorly planned and managed, can result in irreversible environmental damage and may lead to ultimate loss in economic gains. Shrimp farming in India till now has three distinct phases. First, the "rising phase" with *Penaeus monodon* culture from late 80s to 1995, second, the "falling phase" during 1995–2001 affected with viral diseases, predominantly the "white spot syndrome virus" (WSSV) and monodon baculo virus (MBV), and from 2002 onward, the third phase during which the farming is "sustainable" due to involvement of research and development (R&D) institutions in the country (Kumaran et al., 2003). Since 2009 after the introduction of *Penaeus* v*annamei*, India witnessed rapid expansion of shrimp culture activity. The inland production of marine shrimp provides an alternative to traditional coastal aquaculture where land costs and user conflicts can inhibit commercial development.

The culture systems practiced vary depending on the availability of inputs and farmers capacity to invest in the farming. In low input farming systems, due to adoption of scientific principles of farming, 500–1500 kg crop ha^{-1} production is predictable. Surendran et al. (1991) demonstrated the technology of semi-intensive shrimp farming with 4–6 tons ha^{-1} production.

Source Waters (Creek/Sea Water)

India has a long coastline of 8129 km, including the mainland, islands (Andaman and Nicobar, and Lakshadweep), 14 large river systems, and innumerable small seasonal coastal rivers draining into the seas. The main source waters for BWA are estuaries, tidal creeks, lagoons and backwaters, and mangrove swamps to a large extent. India has a rich resource of underground saline water that is not commonly used for agriculture and could be used to raise marine shrimp. Water quality is critical for survival, health, and growth of cultured organisms, especially in semi-intensive and intensive culture systems and for the production of good quality seeds in the hatchery. The physical, chemical, and biological properties of water should be kept within the safe levels to maintain good water quality.

N Flows in Coastal Water Ecosystems

Atmospheric deposition of nitrogen (N) onto land, freshwaters, and estuary, use of N fertilizers in agriculture and sewage wastewater are the predominant N sources into coastal ecosystems. As these sources are in close proximity to the coastal waters compared to open seas, N atmospheric deposition rates are higher into coastal systems. Rivers and groundwater interfering complicates the assessment of the impacts of atmospheric deposition of N into coastal water systems (Jickells, 1998; Paerl et al., 2002; Jickells, 2006). The coastal water ecosystems such as estuaries and lagoons that act as a link between land and sea receive substantial nutrients inputs, particularly N, phosphorus (P), and organic matter. Data from the Central Pollution Control Board (www.cpcb.nic.in) as well as the Central Water Commission (cwc.nic.in) indicate that most of the rivers of India carry dissolved N in the form of NO_3-N. Reactive nitrogen (Nr) has a profound impact in the coastal areas, though its residence time is little compared to terrestrial ecosystems.

N Flows in Brackish-Water Aquaculture Ponds

In shrimp aquaculture ponds, the application of external inputs into the pond such as fertilizer, feed, chemicals, probiotics, etc. along with good water quality not only results in increased shrimp production but also leads to changes in water quality. Nitrogen added into aqua ecosystem from the atmosphere through biological and industrial N fixation comes out of the system through aquatic produce harvest. The accumulated feed on the pond bottom is expected to increase the suspended solids, organic load, and nutrients concentration in pond water and changes the bottom soil condition (Boyd and Fast, 1992). The release of soluble forms of nutrients (N and P) from aquaculture sites has the potential of eutrophication of water bodies (GESAMP, 1991).

Nutrient budgeting studies in shrimp farming (Phillips et al., 1993; Csavas, 1994) indicated that N and P from feed are major contributors to the deterioration of coastal waters quality. However, nutrient enrichment of coastal waters is improbable with the present level of coastal aqua farming in India. But accumulation of such nutrients is possible in semi-enclosed coastal water bodies with poor dilution rate and flushing capacity.

Role of N in Brackish-Water Ecosystems

Role as a Nutrient

N may limit the development of autotrophic food webs in ponds on which fish/shrimp yields are dependent. Productivity of BWA system depends on the nature and properties of bottom soils (Hickling, 1971; Mandal and Chattopadhyay, 1979). The main source of nutrient elements is the reserves in the bottom soil, which through the activity of several groups of microorganisms are transferred into the soluble forms (Mandal, 1962a). NH_4^+ and NO_3^- forms are primary available N sources to food organisms for aquatic species in ponds. Boyd and Munsiri (1997) predicted the availability of nutrients in aquaculture ponds from bottom soil properties.

N as Nutrient Through Manures and Fertilizers

Manuring and fertilization increase primary productivity by phytoplankton (Rao et al., 1982; Singh and Sharma, 1999) and ultimately increase the productivity of aquaculture ponds (Bhimachar and Tripathi, 1966; Chen, 1972; Apud et al., 1981). The availability of N for phytoplankton has to be increased through organic and inorganic fertilization programs (Schroeder et al., 1990; Knud-Hansen et al., 1991). Phytoplankton abundance of more than 300,000 to 400,000 cells mL^{-1} is usually considered sufficient.

Nitrogen fertilization is considered more important in brackish-water (BW) ponds than in freshwater (FW) ponds and application of nitrogen fertilizers is a common practice to increase the N:P ratio (Boyd and Daniels, 1994). An N:P ratio of 20:l in ponds favors diatoms, which is more preferable in BW ponds (Das and Jana, 1996). A diatom abundance of 20–30% of the total phytoplankton cells is considered adequate. Urea is more effective in stimulating diatoms compared to ammonium and nitrate fertilizers. Cyanobacteria typically dominate aquatic ecosystems in N-limited conditions to satisfy phytoplankton nutritional needs (Beversdorf et al., 2013). However, many non-diazotrophic cyanobacteria species, such as *M. aeruginosa*, also tend to dominate the phytoplankton community during periods of N-limitation (Paerl et al., 2011; Monchamp et al., 2014). Ayyappan et al. (1991) reported low primary production as the ponds did not receive any external nutrient input. Saraswathy et al. (2012) reported a positive correlation of phytoplankton density with nitrate ($r = 0.87$), phosphate ($r = 0.79$), silicate ($r = 0.97$), and chlorophyll *a* content ($r = 0.98$) in shrimp culture ponds.

N as Nutrient Through Feed

Feed alone accounted for almost 95% of the total N input in the form of crude protein in shrimp aquaculture. Protein levels in feed range from 10% to 50% depending on the nature of protein source. Native protein seems better hydrolyzed than processed ones (Zwilling et al., 1981). The recommended dietary protein level for *P. vannamei* varies from 20 to 48% (Kureshy and Davis, 2002; Cuzon et al., 2004). This wide variation in the reported values might be due to the protein quality, protein:energy ratios and a lower content of dietary protein could be compensated for by higher consumption. Changes in particular species biotic factors (weight gain, feed, and protein conversion efficiencies) and abiotic factors (temperature and salinity) determine the feed protein requirement (Guillaume, 1997).

Effect of dietary protein level variation on feed conversion and growth of aquatic species was evaluated. Aranyakananda and Lawrence (1993) reported the maximum dietary protein level of 15% and energy:protein ratio of 28.57 kcal g^{-1} protein for juvenile *P. vannamei.* Kureshy and Davis (2002) reported the dietary protein requirements per kg body weight per day (g DP kg^{-1} BWd) of 1.8–3.8 g for juvenile shrimp and 1.5–2.1 g for subadult shrimp. In addition to the above, the recycling of protein by natural productivity should also be considered for optimization of protein based on the stocking densities and farming systems.

N as Toxicant

Nitrogenous compounds such as ammonia and nitrite were high during extensive shrimp culture, which was due to the shrimp feed protein catabolism and subsequent nitrification. Ammonia is the major end product of protein metabolism in most aquatic animals (Hartenstein, 1970) and is also produced upon decomposition of organic waste by bacteria. Free or unionized form of ammonia (NH_3) is toxic, while the ionized form $(NH_4{}^+)$ has little toxicity (Burkhalter and Kaya, 1977; Armstrong, 1978). Concentrations of unionized ammonia above 1 mg/L are potentially lethal for shrimps, while concentrations greater than 0.1 mg/L may adversely affect growth. At pH 9 and 20 ppt salinity, about 25% of total ammonia is unionized. Therefore, total ammonia concentrations above 0.4 mg/L could negatively affect the growth when pH is high (Boyd and Fast, 1992).

Timmons et al. (2002), based on the quantity of feed applied, calculated the amount of ammonia-nitrogen generated per day in aquaculture ponds.

$$\mathrm{PTAN} = \mathrm{F} * \mathrm{PC} * 0.092$$

where PTAN (kg day^{-1}) = total ammonia nitrogen production rate; F (kg day^{-1}) = feed rate; and PC = protein concentration in the feed.

In the above equation, the constant is arrived based on the assumptions of 16% protein N, 80% N assimilated by aquatic species, 80% of assimilated N as excreta, 90% excreted N as TAN, and 10% as urea. It is also assumed that N in unutilized feed and feces is removed quickly from the system by sedimentation and sludge removal. In zero water exchange–based aquaculture production systems with dominant heterotrophic bacteria, it is not possible to remove the solids from the system and hence there is a requirement of a modified formula.

Ammonia (NH_3) volatilization from aquatic system can be a source of atmospheric NH_3. Only 25 to 30% of the N applied in feed is recovered in the cultured animals at harvest and the remaining is converted to NH_3 that enters the water (Boyd, 1990; Boyd and Tucker, 1995) that can be lost by volatilization. The dominant factors controlling volatilization are NH_3 concentration in solution, pH, and atmospheric conditions such as temperature, wind speed, and solar radiation (Jayaweera and Mikkelsen, 1991). Fox et al. (1996) reported an average loss of 40 kg ha^{-1} NH_3 in 25 day in fish ponds with onetime application of fertilizer urea @ 134 kg ha^{-1} during one growing cycle.

Nitrifying bacteria oxidize ammonia nitrogen and utilize it as energy source for their metabolism and growth resulting in the formation of nitrite-nitrogen (NO_2-N), which upon accumulation is toxic to fish. Another byproduct nitrate-nitrogen $(NO_3{}^- - N)$, produced by nitrifying oxidizing bacteria that utilize nitrite as an energy source, is less toxic. In shrimp ponds nitrite is seldom at concentrations great enough to kill them, but growth may be adversely affected by concentrations above 4 or 5 mg L (Boyd and Fast, 1992). Nitrite is toxic to fish and causes brown blood disease, a condition in which the hemi ion in blood is oxidized from the ferrous to ferric state resulting in the formation of methemoglobin which gives blood a brown color and kills fish by hypoxia. The toxicity of nitrite is significantly reduced in seawater due to high concentration of chloride and calcium (Lewis and Morris, 1986).

N Role in Eutrophication

Gowen and Bradbury (1987) termed the increase in dissolved nutrients concentration from shrimp farms into receiving water body as "hyper-nutrification" and the increase is mainly due to feed-related N and P (Phillips et al., 1993; Csavas, 1994). Increased accumulation of Nr inputs leads to increased growth of algae in tropical coastal systems (Corredor et al., 1999). The consequences of hyper-nutrification, such as increase in phytoplankton production, and turbidity, and decrease in oxygen levels and biodiversity are becoming frequently reported (Nixon, 1995; Cloern, 2001; Rabalais, 2002).

Nitrogen Transformation/Dynamics and Budgeting

N Forms, Sources and Emissions in Brackish-Water Aquaculture Ponds

Major portions of N remain locked in the atmosphere as gaseous form of N (N_2) and only a fraction of N as Nr goes to plants (plankton in aquaculture ponds), animal, and ultimately to human beings (Velmurugan et al., 2008). N compounds in nature are both nonreactive (N_2) and reactive. Photochemically, biologically, and radiatively active N compounds in the earth's atmosphere and biosphere (reduced forms—NH_3 and $NH_4{}^+$; oxidized forms—nitrogen oxides [NO_x], HNO_3, N_2O, and NO_3; organic compounds—urea, proteins, nucleic acids, and amines) fall under Nr group (Galloway, 1998; Galloway et al., 2002).

Fractions of soil nitrogen, namely amino acid, peptide, and easily decomposable proteins are known as easily available forms of nitrogen. This form of nitrogen is lower in BW ponds than FW ponds. However, the productivity of BW ponds (Pillay et al., 1962) was directly related to the amount of soil nitrogen in this form. The amount in the NH_4 form was in general higher than that in the NO_3 form due to the prevailing reducing condition in the soils (Moritimer, 1941). This form of N is mainly adsorbed on the soil exchangeable complex and is beneficial for benthic algae in BWA (Mandal, 1962a), which obtain the nutrients for their growth directly from the pond bottom soil.

N loss can take place through several ways in aquaculture ponds. During the periods of high pond water pH and heavy aeration, ammonia escapes into atmosphere through volatilization from the surface of water column (Reeves, 1972). Biological oxidation of ammonia N to nitrite and nitrate forms does not result in N loss from the ponds. Denitrification of NO_2 to N_2 and N_2O production are possibly more significant pathways for N loss (Seitzinger et al., 1984). Nishio et al. (1983) reported that N_2 production by denitrification in pond sediments quickly moves to the overlying water due to biological and physical turbulences near sediment–water interface. Nitrate can be converted back to ammonia through denitrification, but the quantity of ammonia produced by this process is mostly small compared to other N compounds (Vanderborght et al., 1977). Generally, active sites for both nitrification and denirification initiated from ammonia are limited mainly to shallow depth pond sediment. Loss of N through water seepage is an important pathway in sandy porous soils (Krom et al., 1985).

Nitrous oxide (N_2O), an important greenhouse gas has the largest concentration in the atmosphere among the trace nitrogenous species, and contributes to global warming potential. N_2O emission into the atmosphere is conspicuous from natural water bodies and soils, and also from aquaculture—an anthropogenic activity. To increase the aquaculture production globally, use of aquaculture feed has to be increased, which may result in the increased N_2O emission. Schlesinger et al. (2012) reported that N use efficiency reduces N_2O emissions, which indirectly reduces greenhouse gas emissions from N fertilizer use. N use efficiency can also be increased by minimizing the N loss through volatilization and leaching, which indirectly reduces N_2O emissions. Adjustments in feed application rates based on the actual requirements through check tray observations in aquaculture ponds may reduce surpluses in N balance.

Factors Affecting the Mineralization of Organic N in Brackish-Water Fish/Shrimp Pond Soils

Transformation of nutrients in pond soil depends considerably on the widely fluctuating salinities of water in ponds during different seasons of the year (Johnson and Guenzi, 1963). Muralidhar et al. (1999) reported maximum available nitrogen at 20 ppt and the higher salinities had some adverse effect on the microbial population responsible for the process of mineralization (Mandal, 1962b). A decrease in available nitrogen content was observed with increase in salinity level as compared to initial values. The increase of available nitrogen in the water with a corresponding decrease of nitrogen content in the soil at the initial stages of increasing salinity can be explained due to the replacement of NH_3 from the soil complex by sodium.

Role of Manuring, Fertilization, and Feeding on N Dynamics

Accumulation of the inorganic N forms ($NH_4^+ - N$ and $NO_2^- - N$) in intensive aquaculture pond waters is responsible for the deterioration of water quality. Nutrient concentration (NO_3-N) has been observed more with fertilizer treatment which might be because of immediate release of nutrients from fertilizer. A steady increase in nutrient concentration has been recorded with progress of time. Nitrate-nitrogen concentration was significantly more in treatments whenever chemical fertilizer was applied (Muralidhar et al., 2001). Average nitrate *N* values of 0.008–0.009 ppm were observed with chemical fertilizers compared to 0.001 ppm with manure treatments. Nitrogen in manure occurs largely in organic forms and the C:N ratio in FYM is 15:30. Primary production and plankton numbers were significantly high in manure and fertilizer combination compared to other treatments. Ammonia *N* values did not vary among the manure and fertilizer treatments, and nitrite-N concentration was more in poultry manure and fertilizer tanks compared to cattle manure and manure plus fertilizer treatments.

N Budgeting

Nitrogen budgeting is a prerequisite to achieve nitrogen reduction in waste and increase nitrogen recovery in the aquatic animal. N budgeting is usually expressed as a mass-balance approach, where total N inputs plus generation is equal to total N outputs plus consumption. N input into the pond (quantity and quality), aquatic species under culture, water-exchange frequency, and other environmental parameters determine the magnitude and rates of N fluxes.

Many studies on N budget revealed that feed nitrogen contributes 90–98% of the total nitrogen input. Other minor contributors are intake water (1.54%–3.04%) and post-larvae stages. Nitrogen recovery in shrimp was high (34.2–43.6%) under zero water–exchange *Penaeus monodon* culture systems (Fig. 19.1) (Xia et al., 2004; Saraswathy et al., 2013) compared to water-exchange system (22–31%). Under zero water–exchange system, nitrogen is accumulated in the sediment whereas under water-exchange system, before fixing in the soil, nitrogen is removed through discharge water. The nitrogen in discharge water varied between 11.2% and 14% and the lowest was recorded under zero water–exchange system. Unaccounted loss (volatilization of ammonia and denitrification) varied between 15% and 57% and this variation is due to stocking density, aeration intensity, and culture practices. Under water-exchange system, the discharge water contained 14–35% of N and only 3% of N was unaccounted and assumed to be lost through denitrification and voltalization into atmosphere (Briggs and Funge-smith, 1994; Jackson et al., 2003; Thakur and Lin, 2003). Generally, unaccounted loss is high under zero water–exchange and aided by aeration (Reeves, 1972) under high stocking density. Accumulation of organic sludge may sequester some of the unaccounted nitrogen in the pond sediment (Briggs and Funge-Smith, 1994).

In ponds where aquatic species are fed with commercial feeds, N fixation was minor but an important contributor to the N budget. In tropical fish ponds, N fixation in mg N

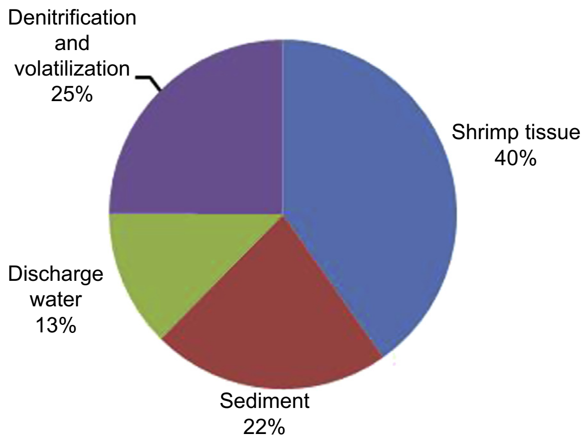

FIGURE 19.1 N budgeting in *P. monodon* culture ponds (own unpublished data).

m^{-2} day^{-1} was 6–23 and 21–57 during dry and rainy seasons, respectively (Lin et al., 1988). NH_4-N concentration in the pond water and phytoplankton species composition largely determine the N fixation and ammonia concentration is inversely related to inhibition of N fixation (Lin et al., 1988).

As nitrification rate measurements are not available in aquaculture ponds, 15–25 mg N m^{-2} day^{-1} of nitrification rate in estuarine sediments (Henriksen and Kemp, 1988) is likely to be representative for pond sediment. Assuming the sediment oxygen demand of 5–10% for nitrification, about 25–50 mg N m^{-2} day^{-1} is oxidized, which is equivalent to 5–10% of N input per day. In order to get energy from the reduced forms of N, oxygen is required for nitrifying bacteria. The oxygen half-saturation concentration (K) values were 0.3–0.9 mg L^{-1} and are directly proportional to temperature (Painter, 1970).

Nitrogen Management

Better Management Practices to Maintain Nitrogen Metabolites Levels

The best method for preventing nitrogen metabolites accumulation in aquaculture ponds lies in the selection of good site with availability of high quality water, following optimum stocking densities and aiming at modest levels of shrimp production. Providing aeration, liming, and pond bottom treatments to improve the decomposition of organic matter helps in the maintenance of optimum soil and water parameters in aquaculture ponds. Aquaculture sustainability depends on the adoption of better management practices, which in turn reduce the nutrients concentration and pollution potential of pond discharge water.

In case of high levels of ammonia detected in pond water, feeding should be reduced or stopped immediately followed by flushing with the new water, aerating the water, and reducing the stocking density in the pond. The other pathways to reduce the metabolites load are:

- Use of photoautotrophic algae–based systems (green water systems)
- Autotrophic bacterial conversion: In intensive recirculating aquaculture production systems, bioreactors are routinely used that rely on the nitrification of ammonia nitrogen to nitrate-nitrogen by ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) (Timmons et al., 2002).
- Heterotrophic bacterial conversion: Controlling inorganic nitrogen by manipulating carbon/nitrogen ratio is a potential method for aquaculture systems. This approach offers a practical and inexpensive means to reduce the accumulation of inorganic nitrogen in culture ponds. In case of increased ammonium concentration, addition of cheap sources of carbonaceous substrate such as cassava meal and flour can control the N metabolites concentration. Bacteria and other microorganisms use carbohydrates (sugar, starch, and cellulose) as a food to generate energy and produce proteins and new cells (Avnimelech, 1999). The resulting heterotrophic

bacterial production (single cell protein) may be utilized as a food source for fish and shrimp (Beveridge et al., 1989; Rahmathulla and Beveridge, 1993; Burford et al., 2004), thus lowering the demand for supplemental feed protein (Avnimelech, 1999).

- Periphyton-based aquaculture: The whole complex of aquatic biota attached to the substratum including the associated detritus and microorganisms is termed as Periphyton. Thus, the periphyton community comprises bacteria, fungi, protozoa, phytoplankton, zooplankton, benthic organisms, and a range of other invertebrates and their larvae. Any material with high surface area such as tree branches, bamboo, higher aquatic plants, PVC pipes can be used for the production of periphyton.
- Use of chemicals: Fast ammonia removal by zeolites is a well-known process in freshwater aquaculture (Sand and Mumpton, 1977) and shrimp ponds in South East Asia (Boyd, 1990). Joseph et al. (2002b) reported that zeolite reduced the ammonia concentration only to a maximum of 10.5% by 5th day. Poly allyl amine hydrochloride (PAA·HCl) polymer hydrogels efficiently remove nitrate (NO_3), nitrite (NO_2), and orthophosphate (PO_4) anions from the aquaculture wastewater.
- The feed protein levels are to be adjusted to avoid the inorganic N forms load in the pond water. In intensive ponds with high water exchange and aeration, this method of decreasing the protein levels without compromising the production was successful. Avnimelech (1998) reported that intensive culture of aquatic species in these ponds is like biotechnological reactors.

After the harvest, pond sludge, if not removed regularly during culture period, comprises about 15–22% of the total N inputs, and about 42% of the total N inputs may be lost through denitrification. Re-aeration of pond sludge generally minimizes the denitrification. Regular removal of pond sludge during culture period significantly reduces the concentration of inorganic N forms in the pond water column. The disposal of harvested pond sludge on high lands not only reduces the impact of discharge water on the receiving water bodies, but also improves soil fertility and in turn increases the yield of terrestrial crops.

Characteristics of Brackish-Water Aquafarms Discharge Water with Reference to Nitrogen

N in discharge waters from aquaculture ponds may deteriorate the quality of receiving waters. The intrinsic N use efficiency determines the quantity of N released into the environment. The N discharge to the environment from intensive raceways and cages is more than the fishponds.

Increased levels of NO_3-N, NH_3-N, and NO_2-N were reported by Joseph et al. (2002a) in pond and discharge waters as compared to intake water. However, discharge water quality during culture as well as harvest time is within the permitted limits of Ministry of Environment and Forests (MOEF, 1993) and guidelines of Ministry of Agriculture/

Department of Agriculture and Cooperation (MOA/DAC, 1995). Comparison of sea and creek (Kandaleru) water–based shrimp farms indicated high organic and nutrient loading in creek water–based ponds, and the likely impact of discharge water from these ponds is comparatively higher than seawater-based farms (Joseph et al., 2002a). As the farmers practiced extensive system of shrimp culture, discharge water from these ponds could not pollute the natural creek, though same source water serves as source and sink.

Adverse changes in environmental parameters of receiving water body will occur only when the pollution load in pond discharge water exceeds the assimilative/flushing capacity of water body. Site location, tidal amplitude variation, flushing/dilution rates, volume of water body during high and low tides, creek morphology, type of culture system, and the management practices determine the environmental impact of aquaculture farm's discharge water. There is a likely risk of eutrophication in the water body when semi-intensive shrimp farming is practiced (Fig. 19.2) and Joseph et al. (2003) suggested the guidelines to prevent this problem.

In most of the shrimp farming countries, use of settlement ponds is recommended as a treatment option to remove the suspended solids and particulate material effectively from discharge water, but it is not effective for nutrients removal (Jackson et al., 2003).

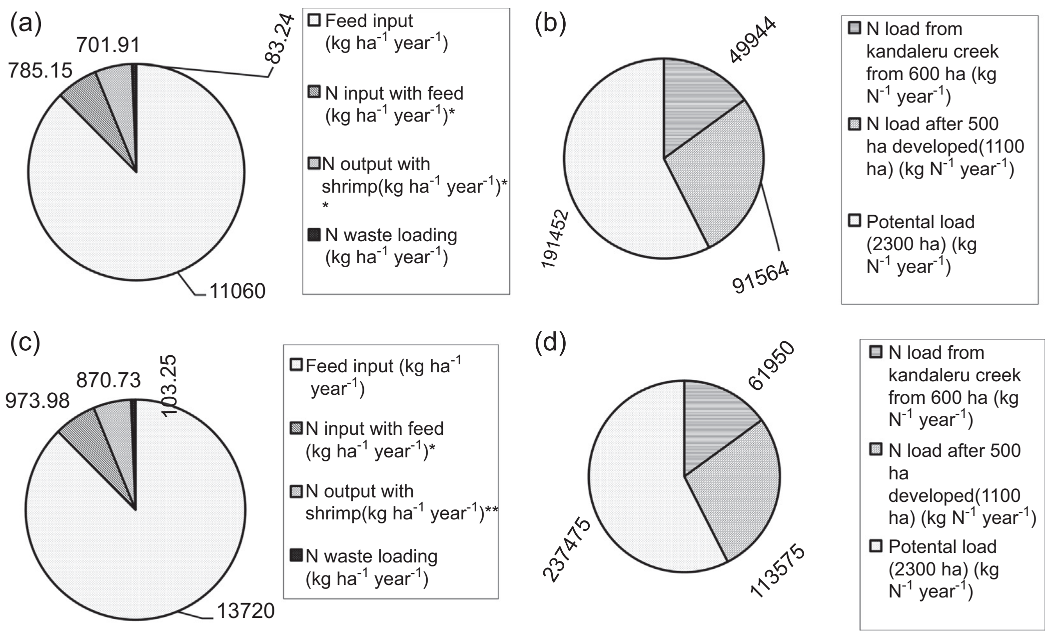

FIGURE 19.2 Nitrogen budget (A, B low range and C, D high range) for shrimp production (7900–9800 Kg ha Year^{-1}) in the Kandaleru creek, Nellore District of Andhra Pradesh. *, Assumes feed quality of 7.099% Nitrogen; **, N content of shrimp 8.885%; FCR 1.4:1. *Joseph, K.O., Gupta, B.P., Thirranavakkarrassu, A.R., Muralidhar, M., Krishnani, K.K., 2003. Effect of shrimp farming on nitrogen levels in the waters of Kandaleru creek, Andhra Pradesh. Indian Journal of Fisheries 50, 291–296.*

In shrimp hatcheries, though there was an increase in N and its metabolites concentration due to biological activity, practically there was no difference in the quality of water at intake and outfall area due to the mixing of discharge water with large volume of seawater (Muralidhar and Gupta, 2007). Hatchery discharges depend on the size of the facility and its water utilization efficiency. Treatment methods for the water discharge of the hatcheries mostly include sedimentation/oxidation/percolation of the ponds before the water is released back to sea/backwaters.

Research Needs/Gaps

The synthesis of existing knowledge on N dynamics in aquaculture ponds and coastal ecosystems indicated a lack of understanding in many aspects. Biome-level integrated studies on N cycling inputs, collection of reliable data on the large scale, and processes of Nr uptake by plankton and fish/shrimp are needed to fulfill this gap. Biotic and abiotic factors governing the availability of N in aquaculture ponds need to be studied. Aquatic species that are assimilating the N need to be effectively identified to increase the feed N use efficiency and also for the modeling studies on N dynamics for particular species. There are gaps in our knowledge of atmospheric N effects on coastal ecosystems. The spatial and temporal variations in emission of the dominant Nr trace gases from aquaculture ponds and coastal ecosystems of India have to be documented. Currently, there are no sector-wise and regional N budgets for the country. Quantitative estimations of various Nr emissions are required to clearly understand the nitrogen cycle at country level.

N exchange across the sediment–water interphase in aquaculture ponds plays an impotant role in N cycling of coastal waters because of lesser volume of water compared to higher surface area of the sediment. New pathways and transformations in N cycle are to be discovered. At the broader scale, more attention is required on specific functional groups of organisms that play key roles in overall N biogeochemistry coupling them with ecosystem modeling. Research over the next decade will likely concentrate more intensively on such groups particularly with respect to their role in the response of the aquaculture ponds to climate change.

The following research gaps requires to be addressed with the latest modern tools such as molecular techniques, remote sensing and GIS, ^{15}N tracer techniques, etc.

- Accurate measurement of inputs of Nr to the coastal ecosystems.
- Dependable data on larger scale and pathways of Nr uptake from aquaculture ponds and coastal ecosystems.
- Aquatic organisms effectively assimilating N are to be identified.
- Complete accounting of the N cycle in aquaculture ponds and coastal ecosystems to understand the overall changes in N cycling and productivity.
- Quantification of spatial and temporal variation in the emission of Nr gases from aquaculture ponds and coastal ecosystems.

Conclusion

Proper management of feed N will remain at the forefront of issues to improve the global Nr balance over both short and long terms. Collaborative multidisciplinary effort can help the aquaculture sector's contribution to reduce the global Nr load. Research on improvements in nitrogen utilization and simultaneous reduction of nitrogen loss is highly desirable for sustainable aquaculture development. In this context, it is essential to identify the optimum protein requirements of a species that will assure higher growth and lower nitrogen waste to the environment. Quantitative estimations of Nr emissions not only give the database and the related impacts, but also provide strategies to formulate and evaluate mitigation options. In spite of impressive and rapid advances in our understanding of many important aspects of the marine nitrogen cycle, there are a number of fundamental issues that remain unresolved. In order to understand the ecosystem response to changes in N cycle, investigations have to be carried out for the sustainable management of the vulnerable coastal ecosystems for future generations. Interactions and feedbacks between atmospheric, terrestrial, and aquatic systems are important aspects to be studied. To decrease N export to coastal systems, an array of innovative methodologies is required. Modeling and synthesis of data at a greater magnitude along with policy and economic studies in the country will be required to minimize environmental deterioration of coastal ecosystems and to meet the food and energy demands of society through sustainable aquaculture simultaneously.

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