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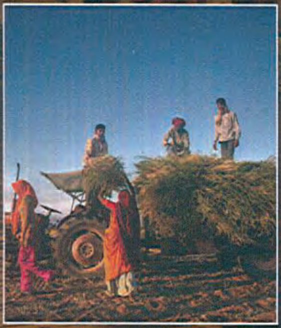
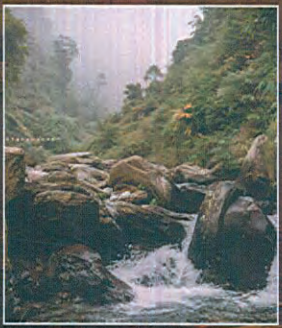
THE INDIAN NITROGEN ASSESSMENT

Sources of Reactive Nitrogen, Environmental and Climate Effects, Management Options, and Policies





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Reactive Nitrogen in Coastal and Marine Waters of India and Its Relationship With Marine Aquaculture

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CHAPTER OUTLINE

Introduction

India is bordered in the south, south-west, and south-east with Indian Ocean, Arabian Sea (AS), and the Bay of Bengal (BOB), respectively. Indian coast is 7517 km long comprising 5423 km in the peninsular India and 2094 km in Andaman and Nicobar, and Lakshadweep Islands. The Indian exclusive economic zone (EEZ) is spread in 2.02 million sq km (0.86 million sq km in west coast, 0.56 million sq km in east coast and 0.6 million sq km in Andaman and Nicobar Islands). The Indian marine environment

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consisting of adjoining coastal areas and EEZ directly sustains useful habitats and supports the livelihood of 3.9 million fishers. Nearly 25% of the country's population resides in these areas and about 340 communities are primarily occupied in marine and coastal fisheries (MoEF, 2009; SACEP, 2014).

Nitrogen (N) exists in various chemical forms, produced by marine biota through several chemical transformations during their growth and metabolism in the marine environment. Nitrogen as N_2 is generally unavailable in marine conditions and thereby, the equilibrium of the processes of N_2 fixation (conversion of atmospheric N_2 to organic nitrogen) and denitrification (conversion of nitrate to N_2) decides the bioavailable nitrogen supply and productivity (Gruber, 2008).

Potential for transfer of reactive nitrogen (Nr) to the coastal and marine waters is relevant, as it contributes to *new* production (primary production supported by external supply of nutrients) and forms the basis of energy transfer toward the higher pelagic trophic levels. Nitrogen assessment in the surface waters, as concentration of nitrite and nitrate was carried out in the Indian EEZ and the adjoining areas during the years 1998–2007 (Nair, 2010). The study revealed that the annual concentrations (μM) of NO_2 ranged from 0 to 0.4, 0 to 0.6, and 0 to 0.7 in the AS, BOB, and Andaman Sea, respectively. The corresponding values for NO_3 (μM) were 0–2.5, 0–3 and 0–3.5, respectively. The average marine fisheries production of the country during the period 2010–2015 has been estimated at 3.36 million tons consisting of approximately 667 different fish species inhabiting the neritic zone that depend on the productivity of marine ecosystem and in turn is influenced by the Nr available in the system.

Nitrogen Dynamics in Coastal and Marine Environment

Open ocean N-cycle seems to be unharmed, in comparison with that of coastal ecosystems although recent observations have indicated increasing anthropogenic influences (Purvaja et al., 2008a). Most marine organisms make use of nitrogen as nitrate (NO_3^-) and ammonium (NH_4^+). Combined nitrogen occurs in oxidation states ranging from −3 to +5. Its speciation in ocean is dependent on the redox potential of seawater influenced mostly by the ambient oxygen (O_2) levels. The bulk of oceanic water column is well oxygenated making NO_3^- the predominant species of N (Naqvi et al., 1998). In productive areas of the ocean surface, nitrification in the photic zone provides recycled nitrate that is used in primary production (Newell et al., 2011).

Export of Reactive Nitrogen Toward the Sea

Nr accumulation possibility is less in coastal ecosystems, being subject to rapid turnover. Potential for Nr transfer to continental shelf regions is large. However, the transport is only partial by means of high denitrification rates and the Nr transferred is generally denitrified to N_2 prior to its transport to the open ocean (Purvaja et al., 2008a). Transport of N to the ocean mainly occurs through river runoff, atmospheric deposition, and

N-fixation, while its loss is principally through conversion of the combined nitrogen to N_2. Oceanic currents supply enough O_2 at all depths to prevent the development of anoxic conditions in most oceanic areas (Naqvi and Jayakumar, 2000).

Most of the dissolved inorganic nitrogen (DIN) brought from rivers to the northern part of Indian Ocean (~81% in the case of AS and 96% in the case of BOB) is not transported to the coastal ocean and is consumed on the course of the rivers or in the estuaries; however, a considerable contribution (~13%, geometric mean) of this nitrogen to coastal new production is observed (Singh and Ramesh, 2011). Export of DIN by Indian rivers to coastal waters was estimated to be 0.22 ± 0.05 Tg year^{-1} (Krishna et al., 2016), which is almost similar to BOB (0.12 ± 0.03 Tg year^{-1}) and AS (0.10 ± 0.02 Tg year^{-1}).

In the south-west coast of India, in the Cochin estuary, export fluxes of nitrate were high during spring tide, whereas for ammonium during neap tide, because nitrate is mainly a riverine source and ammonium has other external sources in the estuary. During the spring tide, the Cochin estuary received 516×10^3 kg day^{-1} of DIN and exported 592×10^3 kg day^{-1} of DIN into the sea. Similarly, the neap tide input and export fluxes of the estuary varied from 383×10^3 to 468×10^3 kg day^{-1} DIN. Between successive spring and neap tides, there was an increase in the net fluxes of ammonium (25.8×10^3 to 43.1×10^3 kg day^{-1}) and DIN (76.4×10^3 to 85.8×10^3 kg day^{-1}) whereas nitrate flux showed a reduction (41.7×10^3–35.8×10^3 kg day^{-1}). Transports of nutrients were directed toward the sea during monsoon and post-monsoon months, and were directed toward river during pre-monsoon in the Chaliyar estuary in the south-west coast of India (Lallu et al., 2014; Xavier et al., 2005). It is mainly the benthic NH_4^+ efflux that sustains high estuarine productivity in the NO_3^- depleted dry season (Pratihary et al., 2009). The DIN transport to coastal areas can also occur through aerosol deposition (Srinivas et al., 2011) and eddies (Prasannakumar et al., 2007).

Nitrogen Dynamics in the Regional Seas

The northern Indian Ocean is separated into BOB and AS, by the Indian landmass. During the oligotrophic inter-monsoon period, surface waters are depleted of combined nitrogen thus restricting the production of phytoplankton (Bhattathiri et al., 1996). In April–May and September–November, *Trichodesmium* spp. blooms occur in the eastern and central AS when bioavailable nitrogen is relatively scarce at the surface due to denitrification. In the AS, conditions favor denitrification as the dominant N-loss pathway (Ward et al., 2009) and may be predominantly stimulated by dissolved organic matter. The rate of denitrification (Naqvi et al., 2009) in the coastal hypoxic zone is less than that in the open ocean oxygen-minimum zones (OMZ). The hypoxia along the Western Indian continental shelf might have increased by augmented nitrogen input from runoff and atmospheric deposition through anthropogenic activities (Naqvi et al., 2009).

The NO_3^- concentrations within the OMZ are about two times higher in the BOB in contrast to that of AS (Naqvi et al., 2006a). The DIN from rivers exported to the BOB is less (<0.5 Tg N a^{-1}) compared to AS (Naqvi et al., 2010). In BOB, upwelling is very weak and does not rise close to the surface. In the AS, oxygen-depleted waters ascend to very shallow depths (Naqvi et al., 2006a).

The N_2 fixation rates in the eastern AS varied from $\sim 0.1-34$ mmol $Nm^{-2}day^{-1}$. These higher N_2 fixation rates were consistent with higher chlorophyll *a*. N_2 fixation by *Trichodesmium* spp. takes place mostly in the upper ocean (within 10 m from the surface) whereas carbon uptake happens throughout the euphotic zone. N_2 fixation is the most important process among all the nitrogen gain processes and the AS gains ~92% of its "new" nitrogen through this process. Lower values of d^{15} N of particulate organic nitrogen (PON) associated with higher fixation rates confirm the presence of N_2 fixing bacteria (Gandhi et al., 2011). Gandhi et al. (2010) reported that around ~79% of the nitrogen in suspended particles of surface waters in the northeastern AS was contributed from recently fixed nitrogen by *Trichodesmium*. Denitrification and recurrent occurrence of N_2 fixing microorganisms in the AS makes it a suitable global basin for testing marine nitrogen equilibrium (Naqvi, 1987).

Productivity of the Regional Seas in Terms of Nitrogen Availability

In the south-west coast of India, high concentrations of urea and ammonia-N were observed prior to the formation of mudbanks. The variability of nitrite concentration here is brought about by the nitrification–denitrification process. The marked increase in the concentration of organic nitrogen as compared to a non-mudbank area is indicative of the presence of organically webbed forms of nitrogen. This organic form acts as a "reserved nutrient" (or inducer) for upcoming utilization following the assimilation of inorganic nitrogen forms. The sediments play an active role in nitrate uptake and its regeneration, which is related to forms of nitrate in the overlying water (Nair et al., 2013).

Eutrophication in Coastal/Marine Scenario

In South Asia, the estuarine and coastal systems were recognized for their N limitation. Any kind of Nr input into these systems can cause algal blooms and eutrophication. Mandovi–Zuari and Cochin estuaries on the west coast, and Godavari and Hoogly estuaries on the east coast were reported to be nitrogen limiting (SACEP, 2014). The rate of application of synthetic N-fertilizers in the agricultural fields in India is around 17.66 Tg per annum (Jaga and Patel, 2012) and the rate of transport of DIN to the northern Indian Ocean is 1.62 ± 0.32 Tg $year^{-1}$, which results in the retention and/or elimination of around 91% of anthropogenic N before its transport to the sea. In the watershed of the west-flowing rivers, both natural and anthropogenic processes direct the export of DIN to the AS (Krishna et al., 2016).

As a typical case study, Cochin backwaters (CBW) were reported to change from a river-dominant system during summer monsoon to a tide-dominant system during premonsoon season affecting N and P stoichiometry (Martin et al., 2010). Increase was well marked in the levels of NO_3 and PO_4 in the CBW (Martin et al., 2013) after 1975 (av. 15 μM and 3.5 μM, respectively) compared to the period before (av.2 μM and 0.9 μM, respectively).

Algal bloom predominates along west coast of India especially in southern part. Major causal organism was reported to be dinoflagellate. Along the east coast, diatom blooms were reported to prevail. The Centre for Marine Living Resources and Ecology (CMLRE) worked on algal blooms formation, their spread and ecological consequences on marine ecosystems (Padmakumar et al., 2012) and documented the records of 80 algal blooms (of which 27 were by Cyanobacteria) in the Indian EEZ during 1998–2010. A comprehensive overview of historical harmful algal blooms in the AS, their causes and impact, and seasonal variability was presented by Al Shehhi et al. (2014). Blooms mostly occurred during withdrawal of south-west monsoon and/or in pre-monsoon period (D'Silva et al., 2012; Raghukumar and Anil, 2003; Patil and Anil, 2008). Enhanced phytoplankton growth and blooms usually occur just after the south-west to north-east monsoon transition in the BOB (Prasannakumar et al., 2007). Secondary production is highest from October–January and lowest from June–September (Desai and Bharghava, 1998). In BOB, NO_3^- entrained in water column during January contributed to the development of blooms during late February–early March (Kumar et al., 2010).

Increase in the nitrogen species in the coastal surface waters (SACEP, 2014) was indicated from the assessment by Coastal Ocean Monitoring and Prediction Systems (COMAPS). Prema et al. (2014) observed that between 2002 and 2012, there was an increase in the annual mean DIN in the inshore waters, off Kochi, but the concentrations remained in the "good" grading, well within the water quality indexing criteria for DIN (<0.1 mg L^{-1}) by USEPA (2006) without reaching the excess limits.

Nitrogen in Coastal/Marine Habitats and Food Webs

In the northern Indian Ocean, primary production in the bright upper ocean is mainly limited by the availability of DIN (Prasannakumar et al., 2002; Madhupratap et al., 2003). Since the contribution of DIN by atmospheric deposition is relatively less in the northern Indian Ocean (Srinivas et al., 2011; Singh et al., 2012), the riverine DIN input to this area is important for primary production. Export of 1.84 ± 46 Tg year^{-1} of DIN from rivers would support ~12.2 ± 3.1 Tg year^{-1} of new carbon production (11.5 ± 2.9 and 0.66 ± 0.17 Tg C year^{-1} in BOB and AS, respectively). The N/P ratios in the Central and West BOB were lower than 16, indicating nitrate deficiency, whereas N:Si ratio was <1 (Paul et al., 2008).

In the surface ocean, N is present mostly as dissolved organic nitrogen (DON), but only a little fraction of it is chemically characterized in surface ocean waters (Purvaja et al.,2008a). It is estimated that the Indian monsoonal estuaries transfer ~0.41 ± 0.08 Tg of DON during wet season to the northern Indian Ocean. The BOB receives around three times higher DON (0.30 Tg) than AS (0.11 Tg). DON in the estuaries located in the southwest was found to be higher, and this may be due to higher soil organic carbon, biomass carbon, and heavy rainfall (Krishna et al., 2015).

Increased Nr in coastal waters harms seagrass, macroalgae, and coral reefs affecting ecosystem, habitat structure, trophic dynamics, and human health (Purvaja et al., 2008b). In the seagrass ecosystem, variation of nitrate (0.62 ± 0.45–5.47 ± 0.25 μM) and nitrite ($0.14 + 0.03$–0.69 ± 0.08 μM) was noted in different islands waters of Lakshadweep (Nobi et al., 2016). Higher nitrite–nitrate concentration in the seagrass environment is common as N-fixation is generally more in seagrass bed sediments than the carbonate sediments of the adjacent coral reef environment (Qasim, 1970).

In oceanic Lakshadweep waters, DIN accounted for less than 10% and DON for more than 90% of the total dissolved N in the euphotic zone. Urea formed 17–18% of total dissolved N and 19–20% of DON. The phytoplankton in these waters is nitrogen limited. Production associated with NO_3 assimilation varied from 11% to 60% (average 37%) of the observed primary production. Zooplankton regenerated NH_4 at an average rate of 0.59 μg-at N (mg dry wt)$^{-1}$day^{-1}. Assimilation of this quantity of NH_4 would account for 9–50% (average 23%) of the measured primary production (Wafar et al., 1986). NO_3 production rates were equal to NO_3 uptake rates by the zooxanthellae, suggesting a close coupling between these processes. Wafar et al. (1993) suggested that the algae would be limited by N if there is no regenerative N supplied.

Rajkumar (1997) reported that in coral reef ecosystems in Lakshadweep, there was sufficient *new* nitrogen input (NO_3) in monsoon; while in post-monsoon, regenerative flux (Ammonium and Urea) were dominated. There was no indication of either *new* or regenerative fluxes in pre-monsoon. Heterotrophic biomass buildup was not interfered even at low concentrations of available nitrogen. Nitrogen uptake was dependent not only on the substrate availability but also on the prevailing weather conditions. Production of N and its transformation proceeded at appreciable rates. Reefs export particulate organic matter and dissolved inorganics in measurable quantities. There is a predominance of heterotrophy over autotrophy in nitrogen flux in reef waters.

Prema et al. (2015) assessed biogeochemistry and ecosystem processes in the Ashtamudi Lake in the south-west coast of India, in clam beds as well as in no clam regions. Total ammonia-N in water in the clam bed was three times that of no clam region, whereas the nitrate and nitrite concentrations were similar in both. The benthic region of clam beds, due to bioturbation by clams showed higher amount of nitrite and nitrate, compared to the no clam region. Ammoniacal N in the benthic region in the clam bed was around twice of that of no clam region.

The environmental features including nitrogenous nutrients of seawater in the mudbank region of Purakkad, Alleppy, Kerala indicated considerable reduction in the more oxidized forms of nitrogenous nutrients in the surface and bottom waters in the mudbank after a gap of 30 years (CMFRI, 1984, 2014). This is in conformity with the earlier reports that the organic nitrogenous forms act as reserved nutrients and control the periodic variability of nitrate in the mudbank area (Nair et al., 2013). During the post- and premonsoon seasons, flocks of sea birds migrate to the mudbank region of Purakkad, Alleppy. Analysis of the leachable nutrients from this bird area beach sediment indicated that the leachable DIN was four times that of non-bird area sediment (CMFRI, 2014).

The covariation of nitrate in surface layers in the northern AS, chlorophyll *a* and primary production in its euphotic zone with mixed-layer depth, and wind are all indicative of carbon fixation mainly controlled by physical forcing (Prasannakumar et al., 2001). A swarm of pelagic tunicate (*Pyrosomas spinosum*) was found in surface open waters of AS (Gauns et al., 2015) during late south-west monsoon, associated with surface concentrations of 2.5 μM nitrate, 0.3 μM phosphate, 0.9 μM silicate, and 5.0 μM ammonium. Lower molar C/N ratio (5) in *P. spinosum* suggests that the growth of these organisms is carbon-limited. In CBW, rotifers showed significant positive correlations with nitrite, chlorophyll *a*, total suspended solids, phosphate, and biochemical oxygen demand (Varghese and Krishnan, 2011). *Brachionus rotundiformis* was found to dominate (85.76%) among the 13 species of *Brachionus* and showed significant positive correlations with nitrite, biochemical oxygen demand, chlorophyll *a*, and total suspended solids (Varghese and Krishnan, 2013).

In BOB, the subsurface maximum (2.0–3.51 $\mu\text{mol dm}^{-3}$) of ammonium in the euphotic zone is attributed to the regeneration of ammonium by zooplankton excretion associated with stratification of water column during summer. The spatial distribution of recycled nitrogen (ammonium) showed an increasing trend from inshore to offshore regions in the northern Bay (Satyanarayana et al., 1991).

In the seagrass beds of Gulf of Mannar, high positive correlation was noticed (CMFRI, 2014) between chlorophyll, nitrate, and silicate concentrations in seawater ($p < .001$). Sulochanan et al. (2011) observed highly significant influence of nitrite, ammonia ($p < .001$) seasonally in seagrass beds in Palk Bay and Gulf of Mannar. Inorganic phosphate and total organic nitrogen were considered as most important limiting factors for the growth and reproduction of seagrass (Govindasamy et al., 2012, 2013).

Nitrogen in Coastal Aquaculture/Mariculture

There are reports of pollution due to shrimp aquaculture when the ponds are emptied and the problem of algal overgrowth in receiving waters is indicative of nutrients sourced from aquaculture wastes (Aquaculture Authority, 2001; Rajitha et al., 2006). Prema et al. (2012) reported high nutrient imbalance (N/P) in the water, with excess phosphate in the traditional shrimp farms at Vypin, Kochi due to direct release of domestic wastewater containing detergents.

Marine fisheries are an important traditional livelihood along coastal India and also contribute to the protein component of food. The marine fisheries sector has high population along the Indian coast. Traditional fishermen have their habitations very close to the shoreline. Information regarding the marine fishing sector along the east and west coast is provided in Table 20.1. Coastal aquaculture/mariculture activities are presently limited to farming of fishes, crustaceans, bivalves, and seaweed, but adverse effects are still possible on coastal water quality, by enrichment of nitrogen from uneaten feed or waste products, other inputs for aquaculture, and suspended solids (SACEP, 2014).

Table 20.1 Marine Fisheries Related Statistics in the East and West Coast of India

State/Union Territory		Average Landings (Lakh tonnes)	Landing Centers	Fishing Villages	Fisher Families	Traditional Fisher Families	Fisher Population
West coast	Kerala	5.76	187	222	118,937	116,321	610,165
	Karnataka	4.74	96	144	30,713	28,533	167,429
	Goa	1.53	33	39	2189	2,147	10,545
	Maharashtra	3.45	152	456	81,492	74,203	386,259
	Gujarat	7.12	121	247	62,231	59,469	336,181
	Daman & Diu	0.46	5	11	7374	7,181	40,016
East coast	West Bengal	0.77	59	188	76,981	53,532	380,138
	Odisha	1.39	73	813	114,238	87,541	605,514
	Andhra Pradesh	3.42	353	555	163,427	161,039	605,428
	Tamil Nadu	6.65	407	573	192,697	185,465	802,912
	Puducherry	0.65	25	40	14,271	14,248	54,627

Central Marine Fisheries Research Institute [CMFRI], 2014. Central Marine Fisheries Research Institute Annual Report, 2013–14. pp. 174–178; MoA, CMFRI, 2012. Marine Fisheries Census 2010 Part I India. Ministry of Agriculture, KrishiBhavan, New Delhi and Central Marine Fisheries Research Institute, Kochi. Available from: http://eprints.cmfri.org.in/id/eprint/8998.

Live feeds are mainly used as diet for cultured fish larvae. Microalgae form the basic requirement for live feed culture. Using marine grow-out effluents as culture media for the live feed *Nannochloropsis salina* it was found that more than 95% of total NH_3-N and NO_3-N, and more than 90% of NO_2-N of the effluents were used within 50 days (Prema et al., 2006).

No significant alterations in the levels of nitrate, phosphate, and silicate in seawater were observed by cage culture fisheries at Munambam, off Kochi (Prema et al., 2010), nor the cage culture activity influenced the plankton population (Varghese et al., 2010). No significant difference was observed between the total ammonia-N of the cage and reference sites ($p > 0.05$), but they differed significantly between culture periods in cage site ($p < 0.05$) at Karwar, west coast of India (Philipose et al., 2012). No significant difference was observed in the nitrite and nitrate levels of the cage and reference sites and also between the two harvests.

Oysters in fish–oyster integrated farming stimulate the bacterial process of nitrification and denitrification, helping the escape of nitrogen gas, thus, lowering the ammonia content in culture water. The lower eutrophication index (E) value evidenced that oysters can control eutrophication in an integrated aquaculture system. The filter-feeding oysters process the DIN and DIP pool, improve water quality and the growth of fish (Viji et al., 2014a,b). In oyster farm sites, lower ammonia-N levels and chlorophyll *a* values were recorded by Ramalinga (2006). The ammonia-N generated by oysters was taken up by rapidly regenerating phytoplankton in the water column which in turn accounted for increased chlorophyll *a*.

In the outdoor culture of agar-yielding seaweed *Gracilaria edulis*, crop growth rate increased with proportionate supply of nutrients including nitrogen (Kaliaperumal et al., 2003). Higher phosphate and nitrate contents in the water accelerated the growth of

G. edulis in nearshore waters of Gulf of Mannar during November to March. The green seaweed *Ulva reticulata* cultured along with shrimp was found to be an effective eliminator of ammonical nitrogen from 249.5 to 17.39 μmol N L^{-1} (94%). The nitrate nitrogen came down from 28.39 to 24.21 μmol N L^{-1} (5%) and nitrite nitrogen from 14.51 to 9.03 μmol N L^{-1} (22%). The total N removal from the aquaculture system was 45%. The toxic nitrogenous wastes were always found to come down in the integrated system in comparison to the monoculture system (Seema and Jayasankar, 2005). The removal of nitrogenous species showed a gradation in the effluent treated with *U. lactuca* > *G. corticata* > control (Seema et al., 2005).

Atmospheric Nitrogen Contribution and Sea to Air Exchanges in the Indian Seas

Based on the chemical analysis of ambient aerosols, collected from the marine atmospheric boundary layer during the continental outflow (January–April), Srinivas and Sarin (2013) quantified that dry-deposition fluxes (μmol m^{-2} day^{-1}) of N (2–167) to the BOB are significantly higher compared to those over the AS (N: 0.2–18.6).

The AS is an active site for N-fixation (Devassy et al., 1978). The predicted N_2 fixation rate for the AS is 3.3 Tg N $year^{-1}$ (Bange et al., 2005). Significant amount of nitrogen is fixed (~11% of the global N_2 fixation) during a *Trichodesmium* bloom in the AS. Later, Parab and Matondkar (2012) observed that in the AS, *Trichodesmium* species fixed a total of 0.2976 Tg N $year^{-1}$. Higher consumption ratios suggest possible underestimation of N_2 fixation or presence of additional microbes that are incapable of fixing N_2 (Gandhi et al., 2011). *Trichodesmium erythraeum* is abundant in high ($\geq$300 μatm) pCO_2 concentrations. The N: P ratios almost doubled (~10) at high pCO_2 regions of BOB leading to enhanced productivity in this N-limited region and increased biological carbon sequestration (Shetye et al., 2013). Estimates of N_2 fixation are helpful in lessening the ambiguity in the marine N budget.

The OMZ of AS is responsible for a loss of up to 40 Tg $year^{-1}$ (30–50%) of fixed N (Naqvi, 2008) by denitrification. The AS seems to explain for at least one-third of the global oceanic water column denitrification (Naqvi, 2002). When extrapolated to the entire AS, the overall denitrification rate was 41 ± 18 Tg N $year^{-1}$ (Devol et al., 2006). Removal of ammonia and methylamines was mostly observed to happen through wet deposition, contributing less than 1% to the new production (Naqvi, 2002). Emissions of N_2 and N_2O to the atmosphere from the AS are globally significant. The AS appears as a net sink for combined nitrogen of approx. 3×10^{13} g N $year^{-1}$ and a significant source for atmospheric N_2O. The distribution of N_2O indicates considerable losses to reducing zones, pointing to a very rapid turnover of N_2O within the region (Naqvi et al., 1993). Isotope enrichment in the combined NO_3 and NO_2 pool and in N_2O in reducing waters seems to be noticeably lesser in the coastal region than in the open ocean, implying more varied sources/sinks and/or different isotopic fractionation factors (Naqvi et al., 2006a). The isotopic data are indicative of multiple pathways of N_2O production, i.e., nitrification, denitrification, and the coupling of the two processes (Naqvi et al., 1998). Out of the total amount of denitrified nitrogen ~7% was lost to the atmosphere (Somasundar et al., 1990).

Upwelled waters from the AS to Cochin backwaters leads to anoxia due to weak flushing along with high organic input from anthropogenic loadings, causing denitrification and formation of N_2O in the bottom waters (Martin et al., 2010). Annual emissions of N_2O in the AS ranged from 0.33 to 0.70 Tg N_2O and are dominated by fluxes from coastal regions during the south-west and north-east monsoons (Bange et al., 2001). During the north-east monsoon, N_2O concentrations are low and less variable (<25 nM to a depth of 100 m). But the onset and amplification of O_2 deficiency during south-west monsoon causes changes in the N_2O field (Naqvi et al., 2006b, 2009).

The total emission of N_2O from the Indian shelf is calculated to be 0.05–0.38 Tg for the upwelling season. Surface saturations (89–214%) and atmospheric fluxes (−0.10–10.67 $\mu mol\ m^{-2}\ day^{-1}$) from BOB are much lower. The upwelled water does not rise to very shallow depths (Naqvi et al., 2006a), and maximal N_2O concentrations over the shelf are much lower compared to AS (Narvekar et al., 1998; Naqvi et al., 2006a). The AS N-cycle can have an impact on climate change by means of its N_2O emission and denitrification modules (Bange et al., 2005; Naqvi et al., 2010). Nutrient ratios in the AS suggest that nitrogen is limiting and denitrification dominates N-fixation (JGOFS, 2002).

Conclusion

The nitrogen dynamics, especially the oceanic nitrogen transformations, in the surface water of coastal and marine environment in India has been studied. However, the productivity of the coastal and marine ecosystem in relation to nitrogen is in its infancy, as the link among nutrients, primary, secondary, and territory production is yet to be established through modeling. Studies on nitrogen and/or nutrient transfer into the coastal and marine habitats and food web are rare in India and the explorations already done in this line are location specific, while an ecosystem-based approach needs to be followed. Research on nitrogen and/or nutrient management/environment feasibility/environmental impacts in coastal aquaculture and mariculture also needed to be strengthened. The nitrogen budget in the coastal and marine ecosystem including sea to air exchanges and vice versa, needs updating due to its relevance in the present scenario of climate change.

Specific Research Needs/Gaps From the Works Reviewed

- It is not yet obvious how the suboxic ecosystem of AS will respond to anthropogenic changes. Future work must therefore focus on prediction of the magnitude and direction of these impacts (Naqvi and Jayakumar, 2000).
- A meaningful quantitative prediction of increase in N_2O emission in coastal and marine environment is not possible at present because of continuing uncertainties

concerning the formative pathways to N_2O as well as insufficient data from key coastal regions (Naqvi et al., 2010).

- The role of N-fixation in the AS is still complex to appraise because of less database availability (Bange et al., 2005).
- Reports on pollution of coastal waters with effluents from the fertilizer industries are many. But, whether quantification of such pollution loads from material managing in ports or from the industries is yet to be established (SACEP, 2014).
- Further investigations are needed for estimation of the impact of riverine DIN fluxes on primary production in the Indian coastal waters (Krishna et al., 2016).
- Total input of DON fluxes will provide better insight on the contribution of riverine nitrogen inputs toward coastal productivity in the BOB and the AS (Singh and Ramesh, 2011) and alterations in the freshwater discharge due to natural or anthropogenic events and their impact on microbial food web dynamics needs further appraisal (Krishna et al., 2015).

Policy Issues

Effective ecosystem-based policy actions and recommendations integrating social, economic, and environmental concerns, coastal and marine ecosystem sustainability to abate anthropogenic nutrient pollution are suggested by SACEP (2014) and CPCB (2009) also strongly advocates waste water treatment, before its disposal, both of which still needs implementation.

References

Al Shehhi, M.R., Gherboudj, I., Ghedira, H., 2014. An overview of historical harmful algae blooms outbreaks in the Arabian Seas. Marine Pollution Bulletin 86 (1), 314–324.

Aquaculture Authority, 2001. Shrimp Aquaculture and the Environment – an Environment Impact Assessment Report. Aquaculture Authority, Chennai, India, p. 114.

Bange, H.W., Andreae, M.O., Lal, S., Law, C.S., Naqvi, S.W.A., Patra, P.K., et al., 2001. Nitrous oxide emissions from the Arabian Sea: a synthesis. Atmospheric Chemistry and Physics 1, 61–71. http://dx.doi.org/10.5194/acp-1-61-2001.

Bange, H.W., Naqvi, S.W.A., Codispoti, L.A., 2005. The nitrogen cycle in the Arabian Sea. Progress in Oceanography 65, 145–158. http://dx.doi.org/10.1016/j. pocean.2005.03.002.

Bhattathiri, P.M.A., Pant, A., Sawant, S., Gauns, M., Matondkar, S.G.P., Mohanraju, R., 1996. Phytoplankton production and chlorophyll distribution in the eastern and central Arabian Sea in 1994–95. Current Science 71, 857–862.

Central Marine Fisheries Research Institute [CMFRI], 1984. Ecology of Mudbanks – hydrography in: coastal zone management: Mudbanks of Kerala coast. Central Marine Fisheries Research Institute Bulletin 31, 25–27.

Central Marine Fisheries Research Institute [CMFRI], 2014. Central Marine Fisheries Research Institute Annual Report, 2013–14, pp. 174–178.

Central Pollution Control Board [CPCB], 2009. Status of Water Supply, Wastewater Generation and Treatment in Class-i Cities and Class-ii Towns of India. Control of Urban Pollution Series, CUPS/70/2009 – 10.

Desai, B.N., Bharghava, R.M.S., 1998. Biological production and fishery potential of the exclusive economic zone of India. In: Sherman, K., Okemwa, E., Ntiba, M. (Eds.), Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability and Management. Blackwell Science Inc, Cambridge, MA, pp. 297–309.

Devassy, V.P., Bhattathiri, P.M.A., Qasim, S.Z., 1978. *Trichodesmium* phenomenon. Indian Journal of Marine Science 7, 168–186.

Devol, A.H., Uhlenhopp, A.G., Naqvi, S.W.A., Brandes, J.A., Jayakumar, A., Codispoti, L.A., et al., 2006. Denitrification rates and excess nitrogen gas concentrations in the Arabian Sea oxygen deficient zone. Deep Sea Research Part I 53, 1533–1547. http://dx.doi.org/10.1016/j.dsr.2006.07.005.

D'Silva, M.S., Anil, A.C., Naik, R.K., D'Costa, P.M., 2012. Algal blooms: a perspective from the coasts of India. Natural Hazards 63, 1225–1253.

Gandhi, N., Ramesh, R., Srivastava, R., Sheshshayee, M.S., Dwivedi, R.M., Raman, M., 2010. Nitrogen uptake rates during spring in the NE Arabian Sea. International Journal of Oceanography 2010, 127493. http://dx.doi.org/10.1155/2010/127493.

Gandhi, N., Singh, A., Prakash, S., Ramesh, R., Raman, M., Sheshshayee, M.S., 2011. First direct measurements of N_2 fixation during a *Trichodesmium* bloom in the eastern Arabian Sea. Global Biogeochemical Cycles 25, GB4014. http://dx.doi.org/10.1029/2010GB003970.

Gauns, M., Mochemadkar, S., Pratihary, A.K., Roy, R., Naqvi, S.W.A., 2015. Biogeochemistry and ecology of *Pyrosoma spinosum* from the Central Arabian Sea. Zoological Studies 54 (3). http://dx.doi.org/10.1186/s40555-014-0075-6.

Govindasamy, C., Arulpriya, M., Ruban, P., Meenakshi, V.R., 2012. Hydro-chemical evolution of Palk strait region, Bay of Bengal. Journal of Tropical Life Sciences 2 (1), 1–5.

Govindasamy, C., Arulpriya, M., Anantharaj, K., Ruban, P., Srinivasan, R., 2013. Seasonal variations in seagrass biomass and productivity in Palk Bay, Bay of Bengal, India. International Journal of Biodiversity and Conservation 5 (7), 408–417. http://dx.doi.org/10.5897/IJBC12.132.

Gruber, N., 2008. The marine nitrogen cycle: overview of distributions and processes. In: Capone, D.G., Bronk, D.A., Mulholland, M.R., Carpenter, E.J. (Eds.), Nitrogen in the Marine Environment, second ed. Elsevier, Amsterdam, pp. 1–50.

Jaga, P.K., Patel, Y., 2012. An overview of fertilizers consumption in India: determinants and outlook for 2020-a review. International Journal of Scientific Engineering and Technology 1, 285–291.

JGOFS, January 2002. Report of the Indian Ocean Synthesis Group on the Arabian Sea Process Study. JGOFS REPORT No. 35.

Kaliaperumal, N., Jayasankar, R., Ramalingam, J.R., 2003. Outdoor culture of agar yielding red alga *Gracilaria edulis* (Gmelin) Silva. Seaweed Research and Utilisation 25 (1 & 2), 159–162.

Krishna, M.S., Prasad, M.H.K., Rao, D.B., Viswanadham, R., Sarma, V.V.S.S., Reddy, N.P.C., 2016. Export of dissolved inorganic nutrients to the northern Indian Ocean from the Indian monsoonal rivers during discharge period. Geochimica et Cosmochimica Acta 172, 430–443.

Krishna, M.S., Prasad, V.R., Sarma, V.V.S.S., Reddy, N.P.C., Hemalatha, K.P.J., Rao, Y.V., 2015. Fluxes of dissolved organic carbon and nitrogen to the northern Indian Ocean from the Indian monsoonal rivers. Journal of Geophysical Research (Biogeosciences) 120 (10), 2067–2080.

Kumar, S., Ramesh, R., Dwivedi, R.M., Raman, M., Sheshshayee, M.S., D'Souza, W., 2010. Nitrogen uptake in the northeastern Arabian Sea during winter cooling. International Journal of Oceanography. http://dx.doi.org/10.1155/2010/819029, 819029.

Lallu, K.R., Fausia, K.H., Vinita, J., Balachandran, K.K., Naveen Kumar, K.R., Rehitha, T.V., 2014. Transport of dissolved nutrients and chlorophyll a in a tropical estuary, south west coast of India. Environmental and Monitoring Assessment 186 (8), 4829–4839.

Martin, G.D., Muraleedharan, K.R., Vijay, J.G., Rejomon, G., Madhu, N.V., Shivaprasad, A., et al., 2010. Formation of anoxia and denitrification in the bottom waters of a tropical estuary, southwest coast of India. Biogeosciences Discussions 7, 1751–1782. http://dx.doi.org/10.5194/bgd-7-1751-2010.

Martin, G.D., Jyothibabu, R., Madhu, N.V., Balachandran, K.K., Nair, M., Muraleedharan, K.R., et al., 2013. Impact of eutrophication on the occurrence of *Trichodesmium* in the Cochin backwaters, the largest estuary along the west coast of India. Environmental Monitoring and Assessment 185, 1237–1253.

Madhupratap, M., Gauns, M., Ramaiah, N., Kumar, S.P., Muraleedharan, P.M., deSousa, S.N., et al., 2003. Biogeochemistry of the Bay of Bengal: physical,chemical and primary productivity characteristics of the central and western Bay of Bengal duringsummer monsoon 2001. Deep Sea Research Part II 50 (5), 881–896.

MoA, CMFRI, 2012. Marine Fisheries Census 2010 Part I India. Ministry of Agriculture, KrishiBhavan, New Delhi and Central Marine Fisheries Research Institute, Kochi. Available from: http://eprints.cmfri.org.in/id/eprint/8998.

MoEF, 2009. State of Environment Report India-2009. Environmental Information System (ENVIS). Ministry of Environment and Forests, Government of India. Available from: http://www.moef.gov.in.

Nair, K.K.C., 2010. Atlas on Environmental Parameters and Productivity (Primary and Secondary) on the Indian EEZ and Adjoining Areas. A technical publication of the Centre for Marine living Resources and Ecology, Kochi. CMLRE, Ministry of Earth Sciences< Government. of India, 296 pp.

Nair, S.M., Balchand, A.N., Prashob, P.K.J., Anu, G., 2013. Phenomenal changes in the forms of nitrogen: results from a coastal zone of south west India. Chemical Speciation & Bioavailability 25 (2), 89–96.

Naqvi, S.W.A., 1987. Some aspects of the oxygen deficient conditions and denitrification in the Arabian Sea. Journal of Marine Research 45, 1049–1072. http://dx.doi.org/10.1357/002224087788327118.

Naqvi, S.W.A., 2002. Air-sea interactions and exchanges. In: Watts, L., Burkill, P., Smith, S. (Eds.), Arabian Sea Process Study. JGOFS International Planning Office, Bergen, Norway. JGOFS Report No. 35.

Naqvi, S.W.A., 2008. The Indian Ocean (chapter 14). In: Capone, D.G., Bronk, D.A., Mulholland, M.R., Carpenter, E.J. (Eds.), Nitrogen in the Marine Environment, second ed. Elsevier Press.

Naqvi, S.W.A., Jayakumar, D.A., 2000. Ocean biogeochemistry and atmospheric composition: significance of the Arabian sea. Current Science 78, 289–298.

Naqvi, S.W.A., Sengupta, R., Dileepkumar, M., 1993. Carbon dioxide and nitrous oxide in the Arabian Sea. In: McBean, G.A., Hantel, M. (Eds.), Interactions Between Global Climate Subsystems: The Legacy of Hann, pp. 85–92.

Naqvi, S.W.A., Yoshinari, T., Jayakumar, D.A., Altabet, M.A., Narvekar, P.V., Devol, A.H., et al., 1998. Budgetary and biogeochemical implications of N_2O isotope signatures in the Arabian Sea. Nature 394, 462–464.

Naqvi, S.W.A., Naik, H., Pratihary, A., D'Souza, W., Narvekar, P.V., Jayakumar, D.A., Devol, A.H., Yoshinari, T., Sainoet, T., 2006a. Coastal versus open-ocean denitrification in the Arabian Sea. Biogeosciences 3, 621–633. http://dx.doi.org/10.5194/bg-3-621-2006.

Naqvi, S.W.A., Narvekar, P.V., Desa, E., 2006b. Coastal biogeochemical processes in the north Indian Ocean. In: Robinson, A., Brink, K. (Eds.), The Sea, vol. 14. Harvard University Press, pp. 723–780.

Naqvi, S.W.A., Naik, H., Jayakumar, D.A., Pratihary, A., Narvenkar, G., Kurian, S., 2009. Seasonal anoxia over the western Indian continental shelf. In: Wiggert, J.D., Hood, R.R., Naqvi, S.W.A., Brink, K.H., Smith, S.L. (Eds.), Indian Ocean: Biogeochemical Processes and Ecological Variability, Geophys. Monogr. Ser, vol. 185. AGU, Washington, D.C, pp. 333–345.

Naqvi, S.W.A., Naik, H., D' Souza, W., Narvekar, P.V., Paropkari, A.L., Bange, H.W., 2010. Carbon and nitrogen fluxes in the north Indian Ocean. In: Liu, K.K., Atkinson, L., Quinones, R., Talaue-McManus, L. (Eds.), Carbon and Nutrient Fluxes in Continental Margins: A Global Synthesis. Springer-Verlag, NewYork, pp. 180–192.

Narvekar, P.V., Naqvi, S.W.A., Dileepkumar, M., 1998. CO_2 and N_2O fluxes from the northern Indian Ocean. In: Parashar, D.C., Sharma, C., Mitra, A.P. (Eds.), Global Environment Chemistry, pp. 128–140.

Newell, S.E., Babbin, A.R., Jayakumar, A., Ward, B.B., 2011. Ammonia oxidation rates and nitrification in the Arabian Sea. Global Biogeochemical Cycles 25, GB4016. http://dx.doi.org/10.1029/2010GB003940.

Nobi, E.P., Dilipan, E., Thangaradjou, T., 2016. Ecosystem perspective of seagrass environments of Lakshadweep islands, India. International Journal of Applied Science Innovation 2016 (1), 42–51. ISSN: 2458-6501.

Padmakumar, K.B., Menon, N.R., Sanjeevan, V.N., 2012. Is occurrence of harmful algal blooms in the exclusive economic zone of India on the rise? International Journal of Oceanography 2012. Available from: http://dx.doi.org/10.1155/2012/263946.

Parab, S.G., Matondkar, S.G.P., 2012. Primary productivity and nitrogen fixation by *Trichodesmium* spp. in the Arabian Sea. Journal of Marine Systems 105-108, 82–95.

Patil, J.S., Anil, A.C., 2008. Temporal variation of diatom benthic propagules in a monsoon influenced tropical estuary. Continental Shelf Research 28, 2404–2416.

Paul, J.T., Ramaiah, N., Sardessai, S., 2008. Nutrient regimes and their effect on distribution of phytoplankton in the Bay of Bengal. Marine Environmental Research 66 (3), 337–344. http://dx.doi.org/10.1016/j.marenvres.2008.05.007. Elsevier.

Philipose, K.K., Sharma, S.R.K., Loka, J., Damodaran, D., Rao, G.S., Vaidya, N.G., et al., 2012. Observations on variations in physico-chemical water parameters of marine fish cage farm off Karwar. Indian Journal of Fisheries 59 (1), 83–88.

Prasannakumar, S., Ramaiah, N., Gauns, M.U., Sarma, V.V.S.S., Muraleedharan, P.M., Raghukumar, S., et al., 2001. Physical forcing of biological productivity in the northern Arabian Sea during the northeast monsoon. Deep Sea Research Part II: Topical Studies in Oceanography 48 (6), 1115–1126.

Prasannakumar, S., Muraleedharan, P.M., Prasad, T.G., Gauns, M.U., Ramaiah, N., de Souza, S.N., et al., 2002. Why is the Bay of Bengal less productive during summer monsoon compared to the Arabian Sea? Geophysical Research Letters 9 (24), 2235. http://dx.doi.org/10.1029/2002GL016013.

Prasannakumar, S., Nuncio, M., Ramaiah, N., Sardesai, S., Narvekar, J., Fernandes, V., et al., 2007. Eddy-mediated biological productivity in the Bay of Bengal during fall and spring inter-monsoons. Deep-Sea Research I 54, 1619–1640.

Pratihary, A.K., Naqvi, S.W.A., Naik, H., Thorat, B.R., Narvenkar, G., Manjunatha, B.R., et al., 2009. Benthic flux in a tropical estuary and its role in the ecosystem. Estuarine, Coastal and Shelf Science 85 (3), 387–398.

Prema, D., Kuriakose, S., Thomas, V.J., 2006. Culture of *Nannochoropsissalina* in different marine grow-out effluents. In: Pandey, P.K., Vasudevappa, C., Ayyappan, S., Kumar, D., Mukherjee, S.C. (Eds.), The Sixth Indian Fisheries Forum, Proceedings. AFSIB, Mangalore and IFA, Mumbai, India, pp. 1–5.

Prema, D., Sobhana, K.S., Laxminarayana, A., Joseph, I., Joseph, S., Ignatius, B., et al., 2010. Observations on selected characteristics of water and sediment at the open sea cage culture site of Asian seabass *Lates calcarifer* (Bloch) off Cochin, south-west coast of India. Indian Journal of Fisheries 57 (4), 53–59.

Prema, D., Khambadkar, L.R., Anilkumar, P.S., Remya, R., Kripa, V., 2012. Scientific Advisory on Water Quality Management for Traditional Fish Farms. Marine Fisheries Information Service, pp. 7–8. T&E Ser. No. 212.

Prema, D., Jeyabaskaran, R., Kaladharan, P., Khambadkar, L.R., Anilkumar, P.S., Nandakumar, A., et al., 2014. Water Quality Indexing of Coastal Waters off Cochin. Technical and Extension Series 219. Marine Fisheries Information Service, pp. 15–16.

Prema, D., Mohamed, K.S., Kripa, V., Jenni, B., Alloycious, P.S., Sajikumar, K., et al., 2015. Assessment of Biogeochemical Processes of Ashtamudi Lake Ecosystem in Relation to Clam Fishery. Technical and Extension Series 225. Marine Fisheries Information Service, pp. 8–12. ISSN 0254-380 X.

Purvaja, R., Ramesh, R., Shalini, A., Rixen, T., 2008a. Nitrogen cycling: a review of the processes, transformations and fluxes in coastal ecosystems. Current Science 94, 1419–1438.

Purvaja, R., Ramesh, R., Shalini, A., Rixen, T., 2008b. Biogeochemistry of nitrogen in seagrass and oceanic systems. Memoirs of the Geological Society of India (73), 435–460.

Qasim, S.Z., 1970. Some characteristics of a *Trichodesmium* bloom in the Laccadives. Deep-Sea Research 17 (3), 655–660.

Raghukumar, S., Anil, A.C., 2003. Marine biodiversity and ecosystem functioning: a perspective. Current Science 84, 884–892.

Rajkumar, R., 1997. Aspects of Nitrogen Recycling in a Coral Reef Ecosystem. PhD Thesis. Goa University.

Rajitha, K., Mukherjee, C.K., Vinu, C.R., 2006. Application of Remote Sensing and GIS for Sustainable Management of Shrimp Culture in India. Aquacultural Engineering. http://dx.doi.org/10.1016/j.aquaeng.2006.05.003.

Ramalinga, 2006. Environmental Impact Assessment of Suspended Oyster, Crassostreama Drasensis (Preston) Culture. PhD Thesis. Central Institute of Fisheries Education, Mumbai.

SACEP, 2014. Nutrient Loading and Eutrophication of Coastal Waters of the South Asian Seas – a Scoping Study. Available from: www.sacep.org/pdf/Scoping_study_ on_Nutrient_loading_in_SAS_Region.pdfpp56.

Satyanarayana, D., Sahu, S.D., Panigrahy, P.K., Sarma, V.V., Suguna, C., 1991. Subsurface ammonium maxima in northern Bay of Bengal. Marine Environmental Research 31, 123–136.

Seema, C., Jayasankar, R., 2005. Removal of nitrogen load in the experimental culture system of seaweed and shrimp. Journal of the Marine Biological Association of India 47 (2), 150–153.

Seema, C., Jayasankar, R., Mathew, G., 2005. Influence of physicochemical parameters on the removal of nitrogenous compounds during treatment of fish effluent with seaweeds. Seaweed Research and Utilisation 27 (1 & 2), 99–104.

Shetye, S.S., Sudhakar, M., Jena, B., Mohan, R., 2013. Occurrence of nitrogen fixing cyanobacterium *Trichodesmium* under elevated pCO_2 conditions in the western Bay of Bengal. International Journal of Oceanography. Available from: http://dx.doi.org/10.1155/2013/350465.

Singh, A., Ramesh, R., 2011. Contribution of riverine dissolved inorganic nitrogen flux to new production in the coastal northern Indian Ocean: an assessment. International Journal of Oceanography. http://dx.doi.org/10.1155/2011/983561.

Singh, A., Gandhi, N., Ramesh, R., 2012. Contribution of atmospheric nitrogen deposition to newproduction in the nitrogen limited photic zone of the northern Indian Ocean. Journal of Geophysical Research 117, C06004. http://dx.doi.org/10.1029/2011JC007737.

Somasundar, K., Rajendran, A., Dileepkumar, M., Sengupta, R., 1990. Carbon and nitrogen budgets of the Arabian Sea. Marine Chemistry 30, 363–377.

Srinivas, B., Sarin, M.M., 2013. Atmospheric deposition of N, P and Fe to the northern Indian Ocean: implications to C- and N-fixation. Science of the Total Environment 456–457, 104–114.

Srinivas, B., Sarin, M.M., Sarma, V.V.S.S., 2011. Atmospheric dry deposition of inorganic and organic nitrogen to the Bay of Bengal: impact of continental outflow. Marine Chemistry 127, 170–179.

Sulochanan, B., Kumaraguru, A.K., Korabu, L.S., 2011. Hydrological conditions in seagrass beds in Palk Bay and Gulf of Mannar, southeast coast of India. Journal of Marine Biological Association of India 53 (1), 108–115.

USEPA, 2006. National Coastal Assessment, Alabama 2000–2004. Final Report. Alabama Department of Environment Management and United States Environmental Protection Agency, Office of the Research and Development, Gulf Ecology Division, Gulf Breez, p. 37. F1 32561.

Varghese, M., Joseph, S., Joseph, I., Boby, I., Manisseri, M.K., Thomas, V.J., et al., 2010. Preliminary studies on the impact of open sea cage culture of *Lates calcarifer* (Bloch) on the planktonic and benthic fauna off Cochin, Kerala. Indian Journal of Fisheries 57 (3), 75–77.

Varghese, M., Krishnan, L., 2011. Ecology of rotifers in Cochin backwaters, Kerala, India. Indian Journal of Fisheries 58 (3), 109–115.

Varghese, M., Krishnan, L., 2013. *Brachionus* species distribution in relation to environmental characteristics in Cochin backwaters, Kerala, South India. Indian Journal of Fisheries 60 (1), 133–138.

Viji, C.S., Chadha, N.K., Kripa, V., Prema, D., Prakash, C., Sharma, R., et al., 2014a. Can oysters control eutrophication in an integrated fish-oyster aquaculture system? Journal of the Marine Biological Association of India 56 (2), 67–73.

Viji, C.S., Mohamed, K.S., Kripa, V., Prema, D., Sharma, R., Jenni, B., 2014b. Oysters Improve Growth of Fish in an Integrated aquaculture System in a Tropical Estuary. Marine Fisheries Information Service, pp. 10–14. Technical and Extension Series 220.

Wafar, M.V.M., Wafar, S., Devassy, V.P., 1986. Nitrogenous nutrients and primary production in a tropical oceanic environment. Bulletin of Marine Science 38, 273–284.

Wafar, M.V.M., Wafar, S., Rajkumar, R., 1993. Nitrogen uptake kinetics of freshly isolated zooxanthellae. Indian Journal of Marine Science 22, 83–88.

Ward, B.B., Devol, A.H., Rich, J.J., Chang, B.X., Bulow, S.E., Naik, H., et al., 2009. Denitrification as the dominant nitrogen loss process in the Arabian Sea. Nature 461, 78–81.

Xavier, J.K., Joseph, T., Paimpillii, J.S., 2005. Fluxes of nitrogen in Chaliyar river estuary India. International Journal of Ecological and Environmental Science 31 (3), 223–229.

THE INDIAN NITROGEN ASSESSMENT

Sources of Reactive Nitrogen, Environmental and Climate Effects, Management Options, and Policies

Edited by

Yash P. Abrol, Tapan K. Adhya, Viney P. Aneja, Nandula Raghuram, Himanshu Pathak, Umesh Kulshrestha, Chhemendra Sharma, and Bijay Singh

The Indian Nitrogen Assessment: Sources of Reactive Nitrogen, Environmental and Climate Effects, Management Options, and Policies provides a reference for readers interested in reactive nitrogen – from researchers and students to environmental managers. Although the main processes that affect the N cycle are well known, this book focuses on the causes and effects of disruption in the N cycle, specifically in India.

This book helps readers gain a precise understanding of the scale of nitrogen use, misuse, and release through various agricultural, industrial, vehicular, and other activities, also including discussions on its contribution to the pollution of water and air. Drawing upon the collective work of the Indian Nitrogen Group, this reference book helps solve the challenges associated with providing reliable estimates of nitrogen transfers within different ecosystems, also presenting the next steps that should be taken in the development of balanced, cost-effective, and feasible strategies to reduce the amount of reactive nitrogen in the environment.

Key features

- Identifies all significant sources of reactive nitrogen flows and their contribution to the N cycle on a national, regional, and global level
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