NATIONAL REPORT

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Executive summary

The unique geographical setting of the Indian Ocean – the low latitude northern boundary and porous eastern boundary – results in unusual climate and oceanographic processes both in the surface and subsurface waters in its northern and eastern parts. The unique surface phenomena include a complete seasonal of atmospheric and upper ocean circulation associated with the SW and NE monsoons north of about 10^{o}S latitude, and the advection of the warmer, fresher Indonesian Throughflow in the upper water column from the Pacific Ocean to the Indian Ocean through the Indonesian seas. As a consequence of the altered circulations of both air and surface seawater, which is also affected by the uneven distribution of precipitation and river runoff (most of which occurs in the Northeastern Indian Ocean), and unlike the Pacific and the Atlantic Oceans, centres of the most intense upwelling and consequently highest biological productivity do not occur along the eastern boundary of the Indian Ocean (e.g. off Myanmar and Australia), but are located in the northwestern Indian Ocean (the Arabian Sea). The subsurface characteristics are affected by the lack of deep convection in the northern Indian Ocean because of which the subsurface layers are renewed predominantly by waters brought in from the south. The resultant sluggish circulation combines with moderately high oxygen consumption rates to produce one of the most intense mesopelagic oxygen minimum zones (OMZs) in the ocean. These zones are anomalously located in the north and not along the eastern boundary. The core of the OMZ in the Arabian Sea is distinguished by large scale microbially mediated reduction of nitrate to gaseous nitrogen forms (N_2 and N_2O) as also several other polyvalent elements (Mn, Fe, I, etc.) to their lower valencies, but such conditions do not occur in the Bay of Bengal, the OMZ of which, for reasons still not well understood, remains just above the threshold of anoxia. The oxygen-deficiency also extends to shallow water during the SW monsoon, especially over the western Indian shelf, which experiences the most intense anoxia in the coastal ocean anywhere on the planet, greatly affecting biogeochemistry and ecology.

The marine environment of the North Indian Ocean is extremely sensitive to human induced changes not only because of the delicate biogeochemical environment, principally arising from the acute deficiency in both coastal and open oceanic regimes, but also because the high population density in the surrounding States, especially in South Asia, means that the magnitude of human impact is also much larger here.

Regular monitoring of coastal waters has been done at several fixed locations since 1991 under a national programme called COMAPS (Coastal Ocean Monitoring and Prediction System). The results show that coastal waters in the vicinity of population centres, especially mega cities, suffer from degraded water quality especially within 1 km of the coast. The most common pollution is by pathogenic bacteria the counts of which often exceeded permissible limits. There are few cases of declining oxygen concentrations with time but an increasing trend in nitrate was noticed at most locations. Contamination of sediments with mercury has significantly declined over the years except at Sandheads in West Bengal. The water quality has improved considerably beyond 1 km at almost all the locations, the only exceptions being Bassein, Ennore and Visakhapatnam. The cause of low chlorophyll content and zooplankton counts along the coasts of Karnataka, Kerala and Orissa despite the availability of nutrients in fairly high concentrations and low turbidity (except at Kochi) is not clear. It is strongly recommended that land based effluents, especially domestic sewage, containing nitrate and bacteria must be properly treated before they are discharged to streams/rivers in order to ensure good water quality.

Previous reports of massive anthropogenic nitrogen loading to the ocean based on models using fertilizer consumption on land are not supported by the observed concentrations. Most Indian estuaries are still moderately eutrophied except during periods of high river runoff (e.g. in Godavari) or where the renewal is sluggish (e.g. Cochin Backwaters). Hypoxic conditions are generally not observed in Indian estuaries, except in Cochin Backwaters, and around Mumbai. Over the western Indian shelf, which houses the world's largest coastal hypoxic zone, there is some evidence of a shift in conditions as indicated by the appearance of hydrogen sulphide during late summer/early autumn since the late 1990s as compared to the data taken in 1970s. However, the 16-years long time series observations off Goa exhibit no secular trend, but large inter-annual (and intra-seasonal) variability.

Despite the hyper-sensitivity of oxygen-deficient environments (due to their naturally low pH), unfortunately there are no long term data to evaluate the effect of acidification on biogeochemistry and ecosystems in the northern Indian Ocean. Such work has just been initiated.

The sea level is being monitored with tide gauges at 18 locations along the Indian coast as a part of Global Sea Level Observing System (GLOSS). These data have been used to compute trends of sea level variability The rate of relative sea level change has been found to vary from -3.36 mm/yr (Sagar Island) to +5.16 mm/yr (Diamond Harbour) (positive and negative values indicate rise and fall of sea level respectively). Compared to the global sea level rise rate of ~3 mm/yr, these data imply probable subsidence of land at several places.

Harmful Algal Blooms (HAB) have long been known to occur in Indian waters, sometimes resulting in Paralytic Shellfish Poisoning. As elsewhere in the world, frequency of such blooms also seems to be increasing along India's coast, but it may in part be due to a closer watch on their occurrence under a programme initiated in 1998. Based on the observations made so far, a total of 452 species of bloom-forming micro algae have been identified from the Indian EEZ of which 45 species are toxic. Altogether 84 open ocean blooms were recorded from the Indian EEZ and 7 hotspots of HABs have been identified along the west coast of India.

Regular assessments related to food from the sea are being carried out by the Central Marine Fisheries Research Institute. These include quantification of marine fishery catch in 9 maritime states and 2 union territories through daily field observations at 1511 landing centres; national census of marine fishers, crafts and gears made once every 5 years; assessments of all major pelagic, demersal, crustacean and mollusc stocks; status of fished stocks; analysis of trawl catch and by-catch; fisheries ecosystem assessments using models involving trophic interactions; assessment of habitat degradation due to anthropogenic activities; extent of heavy metal contamination in marine finfishes/shellfishes; oceanic resource assessment; mariculture assessments; and assessment of climate change and other human activities on fisheries.

No systematic assessment of the Coastal and Marine Biodiversity (CMB) of the Northern Indian Ocean (NIO) has been carried out so far and there is considerable data and information gap both in spatial and temporal coverage. Reports of major regional/national programmes contain only group/taxa details and not the species details. On a regional scale, there is lack of clarity on the CMB as the formats adopted by various groups/authors, the number of species reported under each taxonomic group and the total number of species reported show considerable variation and inconsistency. Ocean Bio-geographic Information System [OBIS] has records of 34,989 valid species from the Indian Ocean consisting of plantae (1690 species), animalia (30,894 species), archaea (4 species), bacteria (864 species), chromista (773 species), fungi (75 species) and protozoa (689 species). Information on microbial diversity is particularly lacking. India's 7516 km-long coastline has several mangrove ecosystems (4663 km^2), coral reef ecosystems (2383.87 km^2) and mud flats (2961 km^2). There are 33 designated MPAs spread over 6271 km^2 area. More dependable and authentic information on the CMB and MPAs within the Indian EEZ has been synthesized using the available information.

The socio-economic studies related to the oceanic services and resources and the impact of human activities thereon have largely been restricted to the fisheries sector. These include assessments of demographic profile of fishers; role of microfinance in reducing indebtedness among marine fishers; labour migration in marine fisheries; nutritional status and health of women employed in fisheries sector; fishers' social status in India; impact of monsoon trawl ban on marine fisheries sector; and impacts of identification of Potential Fishing Zones, a remarkably useful service provided by the Indian National Centre for Ocean Information Services (INCOIS), Hyderabad.

It may be noted that while the work carried out so far have led to substantial advancement in scientific understanding of a number of important processes/issues, an integrated study linking them is yet to be undertaken. For example, eutrophication causes hypoxia which, in turn, affects living resources and biodiversity, thereby having a profound socio-economic impact. A holistic assessment of these inter-linked issues needs to be carried out.

In terms of capacity building, India possesses necessary resources and expertise to spearhead a major regional initiative involving training and networking of researchers/institutions in the Indian Ocean Rim region such that an effective system can be put in place for regular reporting and assessment of the state of marine environment, including the socio-economic aspects, from the Indian Ocean. Such a networking is essential because, owing to its small size and tropical character of the northern Indian Ocean, processes in coastal region of one country are intimately linked to those of another, and so a complete understanding of these processes can only be achieved through collaborative efforts.

1. Introduction

There are two unique geographical features of the Indian Ocean that make its climate and oceanographic processes different from those in other oceanic areas. First, unlike the Pacific and Atlantic Oceans, the northern expanse of the Indian Ocean is limited by the landmass at low latitudes, and second, there exists a low latitude connection between the Indian Ocean and the Pacific Ocean through the Indonesian seas.

The first of these features greatly modifies physical processes in the northern Indian Ocean (Wyrtki, 1973; Shetye and Gouveia, 1998; Schott and McCreary, 2001). It causes complete reversals of atmospheric and surface oceanic circulations twice a year associated with the summer (Southwest) and winter (Northeast) monsoons. The SW monsoon circulation and hydrography are unique: instead of a west-flowing North Equatorial Current the Monsoon Current flows eastward while strong southwesterly winds drive a very strong but seasonal western boundary current (the Somali Current) and intense, widespread upwelling in the western Arabian Sea. Anomalies during the NE monsoon include strong poleward flow along the west coast of India, opposing local winds. As in the Arabian Sea, surface circulation in the Bay of Bengal also follows a general clockwise pattern during the SW monsoon and an anti-clockwise pattern during the NE monsoon. Strangely, the best organized (clockwise) flow occurs in spring when the winds are not very strong.

The confinement of the northern part of the Indian Ocean to the tropics and its small basin size ensure that the circulation at any given site is not controlled merely by local processes but is intimately linked to the large scale circulation including the equatorial Indian Ocean. For example, the westward propagating equatorial waves after hitting the coast in the eastern Indian Ocean get deflected and propagate along the coasts, reaching as far as the west coast of India. Westward propagating Rossby waves originate from these Kelvin waves. Thus, any perturbation in the equatorial Indian Ocean can affect circulation even over the western Indian shelf. This interlinking of coastal circulation implies that one cannot reach a complete understanding of the processes operating in this region, where a large area falls within the exclusive economic zones of the littoral countries, without coordinated and collaborative research involving these countries.

Within the northern Indian Ocean itself large geographical differences in oceanography and climate require its categorization into two hydrographically different regimes. Most of the major rivers of South Asia with the exception of the Indus flow into the northeastern region. This in conjunction with an excessive rainfall in the region results in a positive water balance (large excess of freshwater inputs over evaporation). The opposite holds for the northwestern Indian Ocean where evaporation far exceeds precipitation and runoff. The Bay of Bengal is, therefore, far more strongly stratified than the Arabian Sea.

Blocking of the Indian Ocean by land at low latitudes also means that unlike the Atlantic and Pacific oceans deep convection cannot occur here to cause rapid renewal of subsurface waters. Nevertheless, during the NE monsoon when the cool, dry northeasterly winds blow from the continent over the ocean, convective overturning does occur in the northern Arabian Sea (Banse, 1987; Madhupratap et al., 1996). However, since it does not extend beyond ~125 m, it can only erode the upper thermocline. While nutrient enrichment caused by this process leads to enhanced biological productivity, accounting for the winter blooms and contributing to the overall high biological productivity of the Arabian Sea on the annual scale, it does not ensure significant renewal of subsurface waters.

The Northwestern Indian Ocean is also connected to two Mediterranean-type marginal seas – the Persian Gulf and the Red Sea, which are highly saline. Winter cooling in these seas produces dense, high-salinity outflows that advect into the Arabian Sea along ~26.6 and 27.1 σ_Θ surfaces. While these water masses leave conspicuous signatures on the salinity structure, their contribution to oxygen flux to the mesopelagic zone is quite minor (Swallow, 1984; Naqvi et al., 2010). Thus, the waters that fill the mesopelagic zone, say between 150 and 1000 m, are largely derived from the south where they are formed close to the Polar Front. These waters reach the northern Indian Ocean through tortuous trajectories, as the direct trans-equatorial water exchange is limited only along the western boundary; as a result, their oxygen content is already low by the time they enter the region (Swallow, 1984). The restricted oxygen supply combines with moderately high oxygen demand for the degradation of organic matter sinking from the productive surface layer to produce one of the most intense and thickest oxygen minimum zones (OMZs) anywhere in the world (Warren, 1994). What distinguishes the Indian Ocean from other areas is that its OMZ is located in the northern basins and does not emanate from the eastern boundaries, as happens in the Pacific and the Atlantic.

While both the Arabian Sea and the Bay of Bengal suffer from acute oxygen deficiency at mid-depth, the OMZ of the Arabian Sea appears to be slightly more intense. The difference in minimum oxygen concentrations, close to detection limit in both basins, is close to analytical uncertainty of Winkler measurements, but it is large enough to result in different redox environments in the two OMZs (Naqvi et al., 2006a). The Arabian Sea OMZ provides reducing conditions where several polyvalent elements are reduced by bacterial action to their lower valencies [e.g. nitrate to N_2, a process called denitrification that is of great geochemical significance; Mn (IV) to Mn (II); Fe (III) to Fe (II); and iodate to iodide]. The zone where these reductive transformations take place (the “suboxic zone”) is fairly well-defined. Intriguingly, while these transformations are mediated by heterotrophic bacteria for the degradation of organic matter, the suboxic zone is located in the relatively oligotrophic central part of the Arabian Sea where the organic carbon supply from the surface is expected to be relatively small (Naqvi, 1991). The possible reasons for this apparent anomaly are still being debated; also, why the OMZ of the Bay of Bengal remains just above the threshold of suboxia is not fully understood.

Besides the open ocean OMZ, oxygen deficiency also develops on a seasonal basis in coastal areas of the Arabian Sea. Intuitionally it should happen more along the western margin where upwelling brings up low oxygen waters over the shelf and the productivity is high. However, that is not the case primarily because the residence water of water over the narrow shelf is very short. In contrast, on the other side of the basin – along the Indian west coast – severe anoxia occurs on a regular basis (Naqvi et al., 2006b). This is despite the fact that upwelling is much weaker here, but this actually allows the upwelled water, which has low oxygen content to begin with, to remain over the shelf long enough so that whatever little oxygen it contained is also completely lost. Presence of a low salinity lens also contributes to the development and sustenance of intense oxygen deficiency at very shallow depths. This lens is unique for an upwelling region: the eastern Arabian Sea is the only region where upwelling occurs in conjunction with high freshwater inputs. The capping of cold, saline waters by warm, fresher waters results in extremely strong stratification very close to the surface. It is therefore not surprising that anoxic, even sulphidic, conditions have been found to occur at depths as shallow as 5 m. The total area of the hypoxic zone (having dissolved oxygen <0.5 ml/l) at the peak of the upwelling season is around 200,000 km^2. This is an order of magnitude greater than the area of the famous “dead zone” in the Gulf of Mexico (Rabalais et al., 2001). In fact, it is the largest naturally formed low-oxygen zone in the world. Oxygen-deficient conditions begin with the onset of SW monsoon and gradually intensify. By July the near-bottom water over the mid- and inner-shelf turns practically anoxic allowing facultative bacteria to utilize other electron acceptors. Consequently, intense dentrification takes place in subsurface waters. Although N_2O is a minor product of denitrification, its production in the coastal low oxygen zone of the eastern Arabian Sea appears to be significantly higher than in other oxygen-deficient systems (Naqvi et al., 2000; Naqvi et al., 2006b), and so this region serves as a globally important source of atmospheric N_2O. By late summer/early autumn all available nitrate gets removed through denitrification below the pycnocline, triggering sulphate reduction over the inner shelf at least north of 12^oN latitude. However, with the reversal of coastal circulation in October/November mixed layer deepens and well-oxygenated conditions prevail over the entire western Indian shelf up to late spring. The prevalence of seasonal oxygen-deficiency, especially sulphidic conditions, has large impact on biodiversity and fisheries (Naqvi et al., 2006b, 2009).

Coastal hypoxia of intensity comparable to the Arabian Sea does not develop in the Bay of Bengal, apparently due to different hydrography and circulation (Naqvi et al., 2006a). Not only are winds less favourable for vigorous upwelling in the Bay of Bengal, accounting for lower primary productivity as compared to the Arabian sea, but the immense freshwater runoff also prevents the nutrient rich, oxygen depleted subpynocline waters from reaching the euphotic zone.

The eastern boundary of the Indian Ocean does not experience the kind of large scale upwelling that occurs in the Atlantic Ocean [off Mauritania (the Canary Current) and Namibia (the Benguela Current)] as well as the Pacific Ocean [off the west coasts of USA and Mexico (the California Current) and Peru and Chile (the Humboldt Current)]. The primary reason for this is the above-mentioned connection between the Pacific Ocean and the Indian Oceans through the Indonesian archipelago, which allows advection of low-salinity water at shallow depths from the Pacific to the Indian Ocean. Besides playing a key role in the global thermohaline circulation, this current – called the Indonesian Throughflow – leads to an anomalous (equatorward) flow off Western Australia which prevents intense upwelling and the associated development of an OMZ at mid-depth (Naqvi, 2008; Feng and Wild-Allen, 2010). The monsoonal circulation also does not allow significant upwelling in the Northeastern Indian Ocean (off Myanmar). However, some upwelling does occur along the east coast of Indonesia, especially during the Indian Ocean Dipole years (Murtugudde et al., 1999).

There are two major reasons that make the northern part of the Indian Ocean unusually sensitive to human induced changes in climate and environment. First, the landmass that surrounds it, especially the Indian Subcontinent, is very densely populated: approximately one quarter of the world's human population lives here. As a consequence, the potential human impact is much stronger here than elsewhere in the world. For example, the South Asian countries account for approximately one quarter of the global synthetic fertilizer consumption, and so the quantity of reactive nitrogen released to the environment through runoff from agriculture and other sources such as municipal discharge and fossil fuel combustion is very large. A large fraction of this is expected to enter aquatic bodies including coastal ocean, resulting in eutrophication and hypoxia. In addition to nutrient over-enrichment various developmental activities (especially urbanization, industrialization, reclamation of wetlands, etc.) are leading a great deal of environmental stress in coastal water bodies. Chemical as well as microbial (pathogen) pollution is a cause of concern in some aquatic ecosystems including the seas around India.

Secondly, the unusual conditions that distinguish the northern Indian Ocean region make it extremely susceptible to even minor changes in climate and anthropogenic forcings. For example, as much as 2/3 of the total global area of the continental margin that is exposed to bottom water oxygen concentrations below 0.2 ml/l (~9 µM) is found in the Indian Ocean (Helly and Levin, 2004). The biota that is adopted to cope with such low oxygen levels, especially benthic organisms, will be greatly impacted even by a minor change in environmental conditions. A very large volume of water in the Bay of Bengal is very close to the threshold of being reducing (denitrifying). A decrease in oxygen by as little as 2 µM will turn this system reducing. Such a decrease could be caused by a slight slow-down of renewal process or an increase in oxygen consumption rate. This issue is of great concern in view of the fact that the OMZs all over the world exhibit an intensifying trend over the past few decades (Stramma et al., 2008). With the ongoing increase in fertilizer runoff and considering the large river runoff into the Bay of Bengal it is quite possible, even likely, that oxygen decrease by a few µM may occur in the near future. Such a shift is going to have globally significant impact on biogeochemical fluxes besides affecting local ecology. Moreover, the low oxygen environments in both the open ocean and coastal areas are also characterized by naturally low pH. With the ongoing acidification due to incursion of anthropogenic CO_2 into the ocean, these oxygen poor environments are expected to be more affected by the projected decline in pH than a well-oxygenated marine system (Brewer and Peltzer, 2009). Furthermore, the effect of multiple stresses (deoxygenation and acidification) may be more than the sum of individual stress.

2. Assessments of the state of marine environment

There is a scarcity of formal assessments of the state of marine environment in the northern Indian Ocean and, where available, these are not very comprehensive. The available information for various sectors has been compiled and appended to this report. Brief summaries extracted from these reports are provided below. It may be noted that while substantial scientific understanding has been achieved pertaining to a number of important processes/issues, an integrated study linking them is yet to be undertaken. For example, eutrophication causes hypoxia which, in turn, affects living resources and biodiversity, thereby having a profound socio-economic impact. A holistic assessment of these inter-linked issues needs to be carried out.

2.1 Marine Pollution – COMAPS

Coastal waters of India face threat of pollution due to disposal of untreated sewage, industrial effluents and runoff from the land brought to the sea by rivers, lagoons, backwaters and creeks. The extent of contamination of seawater from these sources varies from location to location resulting in large spatial and temporal variations in distribution of pollutants in coastal waters. A long-term programme - Coastal Ocean Monitoring and Prediction System (COMAPS) – was initiated in 1991 and has since been in operation. The objective of this programme is to assess the quality of coastal waters for fisheries and other human related uses. COMAPS observations are carried out at selected locations along the Indian coast covering the following parameters: dissolved oxygen (DO), ammonia, nitrate, phosphate, chlorophyll *a*, and population of zooplankton, pathogenic bacteria such as *E.coli* and *S. faecalis* and mercury content of the sediments. Sampling sites are located at shore (0-1 km), nearshore (1-3 km) and offshore (5 km and beyond). Analysis of the data collected during this programme reveals the following trends in various coastal states:

Along the coast of Gujarat water quality is generally good in the Gulf of Kachhch and moderate along the coast of Porbander. Coastal waters off Veraval and in the Gulf of Khambat sometimes showed significant oxygen depletion, moderate to high nutrient concentrations and bacterial populations especially at stations close to the shore. The concentration of mercury in the sediments has decreased to non-detectable limits reflecting decrease in its concentration in the effluents originating from the land. The populations of biota mostly exhibited healthy trends except at Hazira-Daman probably due to high turbidity. From the results, it could be concluded that the impact of land based effluents is at present not very significant except at Veraval and Hazira. However, it is likely to increase in future due to higher quantity of wastes that are expected to be generated.

In Maharashtra, assessment of water quality has been made along the coast off Bassein (Mumbai), which is influenced by the Ulhas Creek that carries partially treated sewage, and effluents from various industries. The oxygen content varies widely (3-7 mg/l). Elevated nutrient levels seem to arise from sewage. However, very high nitrate levels of ~ 150 µM (associated with high phosphate of ~15 µM) that occurred in the early 1990s have decreased significantly in the recent years, even though concentrations up to 50 µM still occur occasionally close to the shore. Mercury content of sediments also declined in recent years and is presently ~0.1 µg/g. The chlorophyll *a* values are generally below 2 mg/m^3 indicating modest phytoplankton biomass probably limited by high turbidity as evident from the suspended sediment concentration of up to 554 mg/l. Accordingly, the zooplankton population is also low.

Observations in Goa are being made in the Mandovi Estuary. The water of the estuary remains well oxygenated and showed a significantly increasing trend with time. Concentrations of nutrients have decreased slightly in the recent years and are not abnormal. The chlorophyll *a* also showed a significantly decreasing trend over the years at the shore unlike the nearshore site where fluctuations were observed. The decreasing trend could be attributed to grazing by the high population of zooplankton in the coastal and nearshore waters. The population of pathogenic bacteria was marginally higher. Excepting this, the results obtained showed that the impact of land based effluents on the environmental characteristics of waters of Goa is small.

Along the Karnataka coast, observations have been made off Mangalore and Karwar. In the coastal waters of Mangalore, dissolved oxygen has declined after 2000, but remained above 4 mg/l. Nitrate and phosphate concentrations increased significantly over the years at the shore and nearshore sites, but the concentrations were normal offshore. An increase in the population of pathogenic bacteria occurred over the years which in conjunction with increasing trends of nutrients point to significant influence of disposal of untreated wastes from land based sources on the water quality. Chlorophyll *a* exhibited a decreasing trend over the years with values often below 2 mg/m^3. The low to moderate zooplankton population also showed decreasing trends. Coastal waters of Karwar, relatively less influenced by land run off, showed normal quality in terms of DO and nutrients that remained within their normal ranges, although the concentrations of nitrate and phosphate have been gradually increasing in recent years. The concentration of Chl *a* and the population of zooplankton were low at shore and increased offshore. In both cases the levels were higher as compared to Mangalore. Populations of the pathogenic bacteria were also low. Thus, in terms of water quality coastal waters of Karwar are quite healthy. Along both Mangalore and Karwar coasts, concentrations of mercury in sediments also showed decreasing trends over the years.

Varying trends in water quality were observed along the Kerala coast. The waters of Kochi were well oxygenated with increasing trend over the years. However, nitrate and phosphate concentrations also exhibited increasing trends with time. Chlorophyll *a* concentration was low as was the zooplankton population with a decreasing trend over the years. Despite high DO, high water turbidity at shore, increasing concentrations of nitrate and phosphate and higher pathogenic bacteria populations are indicators of considerable contamination of coastal waters from the land based discharges especially the untreated sewage. The waters of Calicut and Neendakara showed similar trends as off Kochi except the decreasing trend of DO. Also, the high nutrient concentrations were observed less frequently. Overall the data indicate lesser contamination of coastal waters by the land based discharges.

The coastal zone off Veli receives acidic effluents from the industry. However, there has been an improvement in water quality over the years as the pH values increased from 2 to 5, at times reaching normal levels, since 2006. In the offshore region, pH was rarely less than 8. Chlorophyll *a* was exceptionally low with low population of zooplankton at shore but, in general, the nutrients were within normal ranges. Paravur, a fishing village which experiences least contamination from the land based discharges, showed normal water characteristics except for pathogenic bacteria. Marginally increasing trends in nutrients were noticed in recent years. At all locations, pathogenic bacteria counts indicated disposal of untreated sewage but the water quality improved considerably offshore. Concentrations of mercury in sediments were low at all locations, exhibiting decreasing trends over the years. In general, the data revealed that relatively degraded water quality at Kochi, Calicut and Neendakara is confined to 0-1 km zone in the sea. Despite presence of good levels of nutrients, the reasons for low chlorophyll and low population of zooplankton are not clear. It might be due to active predation by the higher organisms.

Coastal waters of Tamil Nadu exhibited different characteristics especially on the biological parameters, though the levels and trends of chemical parameters were almost similar to those for Kerala and Karnataka. The coast off Ennore that is influenced by sewage generated by the city of Chennai and also the industrial effluents from neighbouring industrial estates showed some oxygen depletion and decreasing trends with time especially at the shore and nearshore stations. Nutrients displayed decreasing trends from very high values falling down to 5 µM for nitrate, 1.5 µM for phosphate and 2 µM for ammonia. However, large seasonal variations were observed (e.g. 1–15 µM in the case of nitrate). Copious nutrients resulted in occurrence of blooms as evident from high chlorophyll values. High zooplankton counts even at shore with increasing trends indicate high productivity. Though the high nutrient concentrations occur seasonally and do not necessarily reflect poor water quality, the presence of pathogenic bacteria in large numbers with increasing trends with time shows deterioration of near shore water quality. The coastal region off Cuddalore and Tuticorin exhibited almost similar features and trends; the only difference was in the levels of nutrients and bacteria. While off Cuddalore phosphate concentration often exceeded 1.5 µM, such was not the case off Tuticorin. Both regions were affected by high populations of *E. coli* and *S. faecalis* at shore which decreased offshore. The waters of Cuddalore at shore showed more than 2 mg/m^3 Chl *a* at shore, but such levels were not observed along the Tuticorin coast. However, in the waters of Cuddalore and Tuticorin, the population of zooplankton showed rising trends and with counts exceeding 5000 nos/m^3 occurring during the recent years. In conclusion, coastal waters of these industrialized and urbanized locations show deteriorated water quality in terms of high population of pathogenic bacteria and occasionally high nutrient levels. The problem is significant at shore and nearshore waters in Ennore but is restricted to the shore waters at Cuddalore and Tuticorin.

The coastal and offshore waters of Arumuganeri, Nagapattinam, Vembar and Mandapam are known for fishing activities and Nagapattinam has more population and agricultural activity compared to the other locations. All the locations showed almost same levels of DO, with values above 4 mg/l, except at Arumuganeri. The concentrations of the three nutrients were almost within normal ranges with trends of decrease except the phosphate in the case of Nagapattinam which showed increasing trends presumably due to agricultural runoff. All the three locations showed more or less normal levels of chlorophyll with high population of zooplankton. The water quality in these zones is normal except for bacterial populations that exceeded 10 CFU/ml. At all the locations along the coast of Tamil Nadu, the concentration of mercury in the sediments was low (<0.1 µg/g) which reflects decrease in its concentration in effluents discharged from the land. Further, the nutrient levels were normal at the nearshore and offshore sites, except at Ennore where normal concentrations were restricted to the offshore station. In general, the coastal waters of Tamil Nadu suffers from the adverse level of population of pathogenic bacteria and the problem is more serious off Ennore with a decrease of DO and an increase of nitrate, moderate at Cuddalore and Tuticorin and less at other locations.

Coastal zone of Puducherry city showed moderate degradation of water quality with the DO decreasing occasionally below 4 mg/l and also exhibiting decreasing trends with time. Seasonal variations in all parameters were large. Nitrate concentrations were uniformly elevated, but ammonia and phosphate concentrations were largely within the normal ranges with trends of decrease with time. The concentration of mercury in sediments was < 0.01 µg/g and showed a decreasing trend. Chlorophyll *a* levels were moderately high but exhibited large seasonal variations. The zooplankton population was high. The contamination by pathogenic bacteria was also moderate. Thus, the waters off Puducherry were of normal water quality except for moderate bacterial contamination.

Along the coast of Andhra Pradesh, large scale development is mostly around the port city of Visakhapatnam. The main sources of pollution are sewage and the port activities especially spillage of fertilisers and chemicals during the handling of cargo. The DO at shore has been around 4 mg/l in recent years, but it increased to 5 mg/l at the nearshore and offshore sites. Nitrate, ammonia and phosphate concentrations were high earlier but have now decreased to 1-10 µM for nitrate, 1-3 µM for ammonia and 1-5 µM for phosphate. High levels were also recorded at the nearshore site, although the concentrations of these nutrients decreased over the years with intermittent higher values. While the Chl *a* levels have been around 2 mg/m^3, the zooplankton population reached up to 5000 nos/m^3 and showed a significantly increasing trend with time. The pathogenic bacteria counts are very high at shore, but mercury content of sediments has declined drastically to reach a minimum of < 0.1 µg/g. High concentrations of nutrients and high pathogen counts show that sewage discharge and port activities have led to significant deterioration of water quality in this region.

The coast of Orissa was studied at three locations namely Rushikulya (an ecologically sensitive area), Puri (a moderately urbanized area) and Paradip (port and industrial area). Consistently high DO levels (~6 mg/l) and steady or declining concentrations of nitrate, phosphate and ammonia, which are well within the normal ranges, show that the waters of Rushikulya are minimally influenced by human activities. As in other areas the concentration of mercury in sediments has also decreased to 0.1-0.2 µg/g. The pathogenic bacteria counts were < 10 CFU/ml. The waters of Puri also showed almost similar characteristics with slightly elevated levels in nutrients with increasing trends with time. However, the concentrations remained within the normal ranges. The population of pathogenic bacteria was slightly higher than that off Rushikulya. The waters of Paradip also showed similar characteristics as those of Rushikulya except in the case of phosphate which showed an increasing trend with concentrations exceeding 1.5 µM. The population of pathogenic bacteria was moderately high at shore and decreased to less than 10 CFU/ml at nearshore, revealing low level of contamination by sewage at Rushikulya and Paradip and effectiveness of treatment of sewage at Puri. The concentrations of Chl *a* at all the three locations were mostly < 2 mg/m^3 at the shore, but increased towards offshore. The zooplankton population was less than 100 nos/m^3. Despite normal concentrations of nutrients, the cause of low chlorophyll concentration and zooplankton biomass is not clear but it could be due to active predation by higher organisms in the fishery rich waters of Orissa.

The coast of West Bengal sampled at Sandheads is affected by runoff from land containing sewage and industrial effluents from Kolkata City transported by the Hooghly River. The water remained well oxygenated throughout. Nitrate and phosphate showed significant increasing trends at shore and offshore and their concentrations exceeded 5 µM and 1.5 µM, respectively. Ammonia concentrations were < 2 µM with significant seasonal fluctuations. The concentrations of all nutrients decreased offshore. In contrast to other segments of the coast, mercury content of sediments in this region showed marginal increasing trend over the years both at the shore and nearshore waters. Recent values reaching up to 0.3 µg/g suggest continued release of industrial wastes containing mercury. However, the concentration of mercury decreased offshore. The population of *E. coli* and *S. faecalis* were close to 10 CFU/ml. Chlorophyll *a* values were by and large within the normal range with marginal increasing trend with time. In contrast, moderate zooplankton counts (around 100 nos/m^3) showed a decreasing trend over the years. The lower values of zooplankton despite the presence of normal levels of phytoplankton are not easily explainable but an active predation by higher organisms in the fishery rich zones of Sandheads might account for this anomaly. The high nutrient concentrations indicate that the land based effluents especially the sewage need to be treated.

India has two major groups of islands namely the Andaman & Nicobar and Lakshadweep groups. Assessment of water quality has been made near the capitals of these union territories. Water quality around Kavaratti (Lakshadweep) is influenced mostly by the sewage generated by the human population of 11,000 on the island. The lagoon of Kavaratti has recovered from low DO of earlier years to ~5 mg/l in the recent years. Nitrate and phosphate showed increasing trends, but their concentrations are below 5 µM and 2 µM, respectively. Chlorophyll *a* showed a significant increasing trend with time while the zooplankton showed a marginally decreasing trend. In recent years, Chl *a* concentration has risen to 2 mg/m^3 but the zooplankton population remained as low as 100 nos/m^3. In a coral rich environment, the abundance of fishes is common and the low population of zooplankton might be due to active predation by the higher organisms. The high phosphate levels and high population of pathogenic bacteria (~100 CFU/ml) clearly point to an anthropogenic influence. Barring the high pathogenic population and phosphate levels, the water quality of Kavaratti lagoon is normal.

The Andaman islands are one of the least developed regions and the major settlement is mostly at Port Blair in South Andaman. The data collected at Minnie Bay showed well oxygenated conditions with a significantly increasing trend with time. Concentrations of nutrients were moderately high: >5 µM (nitrate), 2 µM (ammonia) and 1.5 µM (phosphate). Chlorophyll *a* showed a marginal decreasing trend with recent values being < 1 mg/m^3. Such low levels of chlorophyll *a* with further decreasing trend could be attributed to the grazing by zooplankton, whose population was high with rising trends over the years. Both *E. coli* and *S. faecalis* showed wide fluctuations in their abundance and at a few occasions their population exceeded the normal limit of 10 CFU/ml indicating the impact of discharge of untreated sewage. In general, the coastal water of Port Blair at Minnie Bay is fairly normal in terms of quality with no immediate threat of major pollution.

In conclusion, coastal waters in the vicinity of population centres, especially mega cities, suffer from degraded water quality especially within 1 km of the coast. The most common pollution is by pathogenic bacteria whose counts often exceeded permissible limits. There are few cases of declining oxygen concentrations but an increasing trend in nitrate was noticed at most locations. Contamination of sediments with mercury has significantly declined over the years except at Sandheads in West Bengal. The water quality improved considerably beyond 1 km at almost all the locations, the only exceptions being Bassein, Ennore and Visakhapatnam. The cause of low chlorophyll content and zooplankton counts along the coasts of Karnataka, Kerala and Orissa despite the availability of nutrients in fairly high concentrations and low turbidity (except at Kochi) is not clear. One possible explanation is active grazing of phytoplankton by zooplankton and predation of the latter by the higher organisms. It is strongly recommended that land based effluents, especially domestic sewage, containing nitrate and bacteria must be properly treated before they are discharged to streams/rivers in order to restore the sea water quality.

As a caveat, it may be pointed out that the COMAPS observations have an inherent bias in that almost all the data come from fair weather periods. Thus, there is a near-complete absence of data for the crucial SW monsoon period from the Arabian Sea. This is the period when the nutrient-rich, oxygen-depleted subsurface waters are brought up to the shelf through upwelling. Upwelling and consequent anoxia are most intense during the late SW monsoon and early autumn. While post SW monsoon observations have been made at all COMAPS sites, the exact timing of the observations may vary from year to year. This together with the large inter-annual variability in upwelling/anoxia intensity and duration would introduce uncertainties that must be considered while extracting long-term trends from the COMAPS data.

2.2 Eutrophication and hypoxia

Going by the magnitude of fertilizer consumption and other human activities such as fossil fuel consumption and municipal discharges in the region, large nutrient loading is expected to occur in the seas around India through river runoff and atmospheric deposition. In fact, based on the data on fertilizer use in 1990 Seitzinger et al. (2002) estimated the flux of dissolved inorganic nitrogen (DIN) to the ocean by the South Asian rivers to be 4.2 Tg N/y (1 Tg=10^{12} g). Synthetic N consumption in the region has since more than doubled. However, as described in the above section, while the nutrient levels at several sites monitored under the COMAPS programme exhibit an increasing trend, the observed concentrations are nowhere near those expected from the large runoff predicted by the model used by Seitzinger et al. Subsequent estimates of DIN fluxes using all available data are lower by an order of magnitude (Naqvi et al., 2010; Singh and Ramesh, 2011). It may be noted that a large fraction of fertilizer consumption in India occurs in regions (e.g. NW India) that are not well drained and hence the excess fertilizers accumulate in terrestrial water bodies, and in case of nitrogen substantial loss may occur through denitrification. Therefore, most of the excess N may not actually reach the coastal ocean. In support of this view, the COMAPS data from coastal sites rarely show unusually high chlorophyll levels that are characteristic of eutrophied environments.

An assessment of eutrophication in Indian estuaries is included in this report. For those estuarine systems where long-term data are available (e.g. Mandovi-Zuari estuaries and Cochin Backwaters), the results are variable. In the case of the Goan estuaries, there has not been a discernible change in nitrate levels in the past three decades (Maya et al., 2011), but in the case of Cochin Backwaters, nutrient loading has definitely increased (Martin et al., 2013). Along the east coast of India, where most of the discharge occurs, sustained daily observations for 15 months in 2007-2008 in the Godavari Estuary revealed large variability in the DIN and dissolved inorganic phosphorus (DIP) fluxes (Sarma et al., 2009). Peak values (65 µM for DIN and 22 µM for DIP) occurred during the peak discharge period of SW monsoon. During the dry season, the concentrations were generally low (3-10 µM). By and large, well-oxygenated conditions prevailed in the estuary, but oxygen depletion (down to a minimum of ~40% saturation, but still not low enough to be classified as hypoxic) was occasionally noticed during the post SW monsoon period. Plankton blooms causing high chlorophyll *a* (up to 28 mg/m^3) have been recorded in this estuary (Acharyya et al., 2012). Thus, although this estuary is eutrophied, it is not excessively so. Such blooms may be principally responsible for the observed oxygen depletion in the estuary. However, it may be noted that prevalence of suboxic or anoxic conditions is rare in Indian estuaries. The Cochin Backwaters, and the inland waters around Mumbai, are perhaps the only estuarine systems where hypoxia has been recorded so far. This also shows that Indian estuaries are only moderately eutrophied.

As stated earlier, the western Indian shelf houses the world's largest coastal hypoxic zone in the ocean. However, unlike the other 400-plus sites experiencing hypoxia in coastal waters (Diaz and Rosenberg, 2008), this system is primarily formed as a result of natural processes described above. The earliest historical data collected prior to the large increase in fertilizer consumption in India (by Banse who carried out a time series study off Cochin in 1958-1960) show exactly the same pattern of seasonal variability in oxygen as do recent observations (Banse, 1968). Off Mumbai, occurrence of low oxygen conditions and its effect on demersal fisheries was reported by Carruthers et al. (1959). With the subsequent increase in nutrient loading in coastal waters, an intensification of the coastal oxygen-deficient zone is expected to have occurred. Indeed, Naqvi et al. (2000) reported the occurrence of hydrogen sulphide in bottom waters, and even though sulphide was not measured by earlier workers, they argued that its presence could not have gone unnoticed. Therefore, they concluded that its appearance was an indicator of an intensification of the coastal oxygen-deficient zone. Subsequently, Naqvi et al. (2006b) provided evidence showing that oxygen levels in subsurface waters were lower in the 1990s in comparison with sustained observations made during 1971-1975 under the UNDP/FAO-sponsored Integrated Fisheries Project. Regular monitoring at a time series site off Goa (the Candolim Time Series, CATS) has since confirmed the recurrence of sulphidic conditions almost every year during late summer/early autumn. However, these data sets do not show a secular change (i.e. ongoing intensification of anoxic conditions). Instead, they indicate large inter-annual (and even intra-seasonal) variability (Naqvi et al., 2009).

Sedimentary record from the region provides some insights into past changes in biogeochemical conditions off the central west coast of India. Going on biomarker measurements in a sediment core collected off Goa, it appears that not only the productivity during the last few decades has been the highest ever in the last 700 years, but there has also been in a shift in phytoplankton community (viz increasing importance of dinoflagellates) (Kurian et al., 2009). This shift could have been caused by the high N:P ratio in anthropogenic nutrient fluxes. It may however be noted that the flux of nutrients through runoff from the Indian coast does not seem to be very large (<0.1 Tg N/y). This is, in fact, smaller than the estimated deposition of nitrogen from the atmosphere (~0.2 Tg N/y; Naqvi et al., 2009). Although the combined N inputs of anthropogenic origin are still quite is modest, they do have the potential for having triggered a shift from natural suboxic to anthropogenic anoxic conditions (Naqvi et al. 2009). Nevertheless, the possibility that the observed changes are, at least in part, caused by longer-term natural variation, or that there has been a slight alteration of local hydrography and circulation cannot be ruled out.

2.3 Ocean Acidification

Ocean acidification (http://oceanacidification.net/) is one of the most serious threats being faced by marine ecosystems today. This phenomenon is occurring largely due to the incursion of anthropogenically released carbon dioxide, an acidic molecule, from the atmosphere to the ocean. Presently the rate of this incursion is around 2.5 giga tons C/yr. As a result of this incursion the seawater pH has already declined by 0.1 pH units and is likely to decrease by 0.3 pH units by the end of this century. The pH decrease of this magnitude is likely to have a profound impact on ocean biogeochemistry and ecology as it will make it increasingly difficult for marine organisms such as corals to biologically precipitate CO_2 from seawater.

Although there are no records showing a decrease in seawater pH in the Indian Ocean, it has been established that the Indian Ocean serves as a sink for anthropogenic CO_2 (Sabine et al., 1999; Goyet and et al., 2009). The most challenging aspect of the anthropogenic carbon in the Indian Ocean is its uneven distribution. At shallow depths of 250 m the Arabian Sea contains ~33 μmol/kg of anthropogenic carbon than in the Bay of Bengal (~17 mol/kg) but is much higher (53 μmol/kg) in the south Indian Ocean (east of 80^{o}E and between 25^{o}S and 50^{o}S. Its concentration decreased with depth. At 1200 m it is ~25 μmol/kg but occurred only in the southeast Indian Ocean. Below 3000 m the anthropogenic carbon could only be found in the Indian Ocean south of 55^{o}E. The Indian Ocean carbon sink has been found to strengthen between 1990 and 2009 by 0.01 Pg C/decade, which exhibits faster Indian Ocean pCO_2 growth rate that that of atmospheric growth (Sarma et al., 2013). The resultant enhanced acidity has resulted in the shallowing of aragonite saturation depths by 100 and 200 m, respectively, in the Arabian Sea and Bay of Bengal than in preindustrial times (Sabine et al., 1999). Sarma et al. (2002) estimated that the aragonite saturation depth due to anthropogenic carbon in the Indian Ocean shallowed in the range 4- 44 m.

A climate profile evaluation by Attri and Tyagi (2010) indicated a pH of 7 or above in rain water at 10 Global Atmospheric Watch stations before 1980. But a large data in 2000 at these stations showed it to range between 5 and 6, which clearly indicates acidification of rain water. This is consistent with significant increases in rain water sulphate and nitrate concentrations in the last two decades. The INDOEX campaign provided unequivocal evidence for polluted sulphate aerosol transport to the south Indian Ocean from the Indian subcontinent (Alexander et al., 2005). Extensive investigations under ISRO-GBP programme (ICARB) have provided clear evidence for pollutant sulphate and nitrate transport to the Arabian Sea and Bay of Bengal (Reddy et al., 2008; Kumar et al., 2008). Deposition of these aerosols over the Arabian Sea and Bay of Bengal (Rengarajan and Sarin, 2004) will contribute to seawater acidification.

Given the complete lack of data and also considering the fact that the northern Indian Ocean contains large volume of water (within OMZs) that has naturally low pH, and a number of sensitive ecosystems especially coral reefs that are supported by biological $CaCO_3$ precipitation, it is imperative that a long-term programme be initiated for high precision measurements of ocean carbon variables including pH together with in situ impact experiments involving ocean biota.

2.4 Sea level rise

Global warming caused by the increases in greenhouse gases in the atmosphere is arguably the most serious issue faced by mankind today. An important consequence of this phenomenon is the rise in sea level. The factors largely responsible for sea level rise are ocean thermal expansion and melting of polar ice. The most recent scientific assessments indicate that the global sea level may go up by up to one meter by the end of this century (Church et al., 2013). The sea level rise by this magnitude will have tremendous socio-economic impact considering that as many as 600 million people (around 10% of the current global population) live on low-lying land (0-10 meters above sea level (ASL)). Such effects include operating difficulties in ports and harbours and adverse effects on access to the coast and ocean; coastal flooding; loss of wetlands important to fisheries; loss of fresh water supplies from possible salt water intrusion into the coastal aquifer; and a possible increase in coastal erosion. Coastal and fishing populations and countries dependent on fisheries are particularly vulnerable to climate change.

In India sea level is being monitored with tide gauges at 18 locations along the coast as a part of Global Sea Level Observing System (GLOSS). These data have been used to compute trends of sea level variability by the linear fit method. Further correction is required for the Global Isostatic Adjustment to remove the errors due to vertical land movement and to compare with the global values (Unnikrishnan and Shankar, 2007). The results will be used as one of the input for generation of the coastal multi-hazard vulnerability mapping so that the impacts of the sea level rise due to the climate change will be added into the multi-hazard vulnerability mapping. The rate of relative sea level change along the Indian coast has been found to vary from -3.36 mm/yr to +5.16 mm/yr (positive and negative values indicate rise and fall of sea level respectively). The sealevel is showing rising trend at Chennai (0.33 mm/yr), Kolkotta (1.13 mm/yr), Diamond Harbour (5.16 mm/yr), Gangra (2.00 mm/yr), Haldia (2.89 mm/yr), Kandla (3.18 mm/yr), Kochi (1.30 mm/yr), Mangalore (3.00 mm/yr), Mamugoa (0.22 mm/yr), Mumbai (0.74 mm/yr), Paradip (1.03 mm/yr), Tangachimadam (0.31 mm/yr) and Visakhapatnam (0.97 mm/yr). Fall in sea level is recorded at Karwar (-1.22 mm/yr), Nagapatnam (-1.95 mm/yr), Sagar (-3.36 mm/yr) and Tuticorin (-2.70 mm/yr). Compared to the global sea level rise rate of ~3 mm/yr, the above data imply probable subsidence of land at several places.

2.5 Harmful Algal Blooms

The first ever record of Harmful Algal Bloom (HAB) in the Indian waters was made by Hornell in 1908 (Hornell, 1917), thereafter many records have emerged on recurrent occurrences of HABs in the Indian exclusive economic zone (EEZ). Major recorded incidences of Paralytic Shellfish Poisoning (PSP) in the Indian EEZ occurred in 1981 from coastal Tamilnadu, Karnataka, and Maharashtra (Devassy and Bhat, 1991) and during September 1997 from Vizhinjam, Kerala (Karunasagar et al., 1998).

The Centre for Marine Living Resources and Ecology (CMLRE), Ministry of Earth Sciences has made extensive studies on HABs since 1998 till now. Based on the studies, a total of 452 species of micro algae have been identified from the Indian EEZ which include 229 diatoms, 198 dinoflagellates, 16 blue green algae and 9 other groups (silicoflagellates, chlorophytes, coccolithophorids, raphidophytes, prymnesiophytes and prasinophytes). 86 bloom forming species and 45 toxic species were also identified. Altogether about 84 open ocean blooms were recorded from the Indian EEZ, of which 32 were dinoflagellates, 27 cyanophyceans, 20 diatoms, 4 raphidophycean and 1 haptophycean bloom. A total of 7 hotspots of HABs were noticed along the west coast of India: (1) Green *Noctiluca scintillans* in the northeastern Arabian Sea (NEAS) during winter monsoon (WM) and spring intermonsoon (SIM), (2) Red *Noctiluca scintillans* along the southeastern Arabian Sea (SEAS) during summer monsoon (SM), (3) *Dinophysis* sp. in the SEAS during WM, (4) Dinoflagellates mainly *Gonyaulax* spp. and *Gymnodinium* spp. in the SEAS during WM, (5) *Pseudo-nitzschia* spp. in the coastal waters of NEAS during WM (6) *Trichodesmium* spp.in the SEAS during SIM, and (7) *Pseudo-nitzschia* spp. in the SEAS during SM. In the Bay of Bengal, major blooms observed were caused by *Trichodesmium erythraeum*, green *Noctiluca*, *Microcystis aeruginosa* and diatoms like *Thalassiosia partheneia* and *Rhizosolenia* spp. Some of the potentially toxic dinoflagellates of Indian EEZ are *Alexandrium catenella*, *A. tamarense*, *Protocentrum lima*, *P. Concavum*, *Gonyaulax polyedra* and *Coolia monotis.* Few potentially toxic diatoms observed were *Pseudo-nitzschia australis, P. multistriata., P. pseudo delicatissima, P. seriata etc.*

Cysts of 53 species of harmful micro algae e.g., *Lingulodinium polyedrum*, *Gonyaulax spinifera, Protoperidinium leonis* etc were isolated so far from harbours, coastal waters and near shore environments of southwest coast of India. Also, 1320 bacterial strains were isolated from coastal and open ocean waters. *Micrococcus, Flavobacterium, Vibrio* and *Pseudomonas* were the predominant bacterial genera associated with algal blooms. The bloom regions have shown higher load of total heterotrophic bacterial count than the non-bloom areas. A gradual increase in percentage abundance of bacterial genera associated with blooms is evidently seen during their crashing stage.

Globally, the occurrences of HABs are increasing (Anderson et al., 2002) and the HABs in the Indian EEZ have also been found to increase during the last century. However, it is pertinent to note that reporting HABs started only about two decades ago following increased awareness about their ill-effects and implementation of dedicated programmes to monitor them along the Indian EEZ; so, their lower incidences prior to this period could have been due to lack of awareness and lack of monitoring/reporting. Nevertheless, increasing urbanization and anthropogenic inputs along the Indian coast and probably climate change effects in the last few decades could have influenced in rising frequency of HAB occurrences in the northern Indian Ocean.

Apart from HABs along the eastern Arabian Sea (EAS), the blooms are also noticed in the upwelling systems of Oman and Somalia along the western Arabian Sea (WAS), which are much stronger and extend up to central Arabian Sea (CAS), during SM (Resplandy et al., 2011). The WAS blooms were dominated by diatoms represented by *Chaetoceros curvisetus*, *C. lorenzianus*, *Thalassiosira mala*, *Fragilaria oceanica*, *Fragilariopsis cylindrus*, *Skeletonema costatum*, *Coscinodiscus* spp., *Asterionella japonica*, *Proboscia alata, Pseudo-nitzschia* spp., *Biddulphia* spp., *Thalassiothrix frauenfeldii, Thalassionema nitzschioides, and Pleurosigma normanii.* Dinoflagellates blooms were mainly observed during the waning phase of SM upwelling and are represented by *Noctiluca scintillans, Gonyaulax polygramma, Gymnodinium* spp., *Karenia mikimotoi*, *Protoperidinium* sp. *Ceratium* spp., *Ceratium furca, C. fusus*, *C. Tripos* and *Pyrophacus steinii*. Besides these toxic raphidophyte *Chattonella marina* was also reported to bloom in the WAS.

The recurrence of the summer and winter blooms in the Arabian Sea have a greater role in defining the system biogeochemistry. The advected/exported nutrients and primary produced organic matter contribute to formation of intense oxygen minimum zones (OMZ) in the CAS.

These anoxic/sub-oxic waters extend towards coastal systems as upwelling watermass, in turn, have cascading effects like nitrous oxide production, evacuation of demersal fishery, etc. Nevertheless, under the growing concerns of increasing algal blooms and expansion of OMZ, in-depth understanding on HABs and their effects on biogeochemistry and food-web dynamics in the northern Indian Ocean need closer attention.

3. Food Security

The Central Marine Fisheries Research Institute (CMFRI), Kochi, has been carrying out assessments related to food from the sea, which are summarized below:

<u>Marine Fishery Catch Assessment</u>**:** A regular assessment of the Indian marine fishery landings from 9 maritime states and 2 union territories is made through daily field observations at 1511 landing centres. The national estimate is based on stratified multistage random sampling design made on spatio-temporal basis. The observations cover about 25 craft-gear combinations and resources are recorded as per a code. There are 1155 coded species in the database. The database from 1959 is available in digital format.

<u>National census of marine fishers, crafts and gears</u>: National level enumerations of the marine fishermen households were carried out in 1980, 2005 and 2010. The details on marine fishing villages, fish landing centers and fishermen population, infrastructure available, the number of fishing craft and gear with individual fishermen and other details were collected through trained enumerators. Database of marine fisheries census 2005 and 2010 are available in digital format. Assessment is made once every 5 years.

<u>Stock assessments</u>: Assessments of all major pelagic (29 stocks); demersal (32 stocks); crustacean (6 stocks) and mollusc (5 stocks) stocks on regional and maritime state platform have been made. Length Based Micro Models are used for these assessments.

<u>Status of fished stocks</u>: On a national basis the fish stocks have been classified into abundant, less abundant and collapsed) of different resource groups based on last three years (2008-10) average landings and maximum annual landings observed during the period 1950-2010.

<u>The trawl catch and by-catch</u>**:** An analysis made in 2011 has shown that the edible portion of trawl catch was 62%, landed low-value by-catch as 25% and discarded by-catch as 13%. Assessments of low-value by-catch is made at a national level.

<u>Fisheries Ecosystem Assessments</u>: The Gulf of Mannar, Northwest Coast (NWC) and the Arabian Sea off Karnataka have been modeled using trophic interactions (Ecopath Models).

<u>Environment & Habitat Assessments</u>**:** Habitat degradation due to anthropogenic activities has been assessed. Coding of marine litter as per UNEP guidelines has been initiated. Mercury and arsenic in the tissue of 68 species of marine finfishes/shellfishes covering all trophic levels were analyzed and the fishes were found to be safe for consumption.

<u>Oceanic Resource Assessment</u>: Fishery for oceanic resources not established. The potential of oceanic resources including tuna, billfishes and allied species, was estimated as 208,000 t. This comprises of yellow fin tuna (80,000 t), skipjack tuna (99000 t), big eye tuna (500 t), billfishes (5900 t), pelagic sharks (20800 t) and other species (1800 t).

Mariculture Assessments: The ecological and environmental impacts of commercial and experimental mariculture activities are assessed through planned projects or opportunistically. Socio-economic impacts are also assessed.

Socio-economic Assessments: Craft/gear economic efficiency assessments are made annually at a regional level. Other assessments include the income analysis, market network surveys, price analysis fish consumption assessment and factor productivity analysis for assessment of sectorial investment.

Climate Change Impact Assessments : Vulnerability of coastal states, fish phenology and fish distribution have been made based on past biological data and fishery observations. Estimates of carbon foot print of fishing industries ad estimates of carbon sequestration potential of seaweeds have also been made

Other one-off Assessments: As and when required specific assessments have been made such as impact assessment of seasonal fishing/trawling bans, impact assessment of destructive fishing practices and manmade mishaps (eg oil pollution)/ natural disasters (tsunami)

4. Coastal and Marine Biodiversity

No systematic assessment of the Coastal and Marine Biodiversity (CMB) of the Northern Indian Ocean (NIO) has been carried out so far and there is considerable data and information gap both in spatial and temporal coverage. Reports of major Regional/ National programmes such as the International Indian Ocean Expedition (IIOE) conducted in the Northern Indian Ocean during 1960 to 65, The Indian Joint Global Flux studies (I-JGOFS) conducted in the North Eastern Arabian Sea during 1992 to 97, the Marine Living Resources Programme (MLRP) conducted in the Indian EEZ during 1998 to 2003, 2003 to 07 and 2008 to 2012 and the Bay of Bengal Process Studies (BoB-PS) conducted in the Bay of Bengal during 2001 to 2006 contain only group/ taxa details and not the species details. The available information is summarized below:

On a Regional scale, there is lack of clarity on the CMB as the formats adopted by various groups/ authors, the number of species reported under each taxonomic group and the total number of species reported show considerable variation and inconsistency. Ocean Bio-geographic Information System [OBIS] has records of 34,989 valid species from the Indian Ocean consisting of plantae (1690 species), animalia (30,894 species), archaea (4 species), bacteria (864 species), chromista (773 species), fungi (75 species) and protozoa (689 species).

India's 7516 km-long coastline has several mangrove ecosystems (4663 km^2), coral reef ecosystems (2383.87 km^2) and mud flats (2961 km^2). There are 33 designated MPAs spread over 6271 km^2 area of the coastline; of these, 18 are under marine environment and the rest are partly terrestrial. More dependable and authentic information on the CMB and MPAs within the Indian EEZ has been synthesized from the available information.

4.1 Diversity of flora and fauna other than microbes

Marine Microalgae**:** Wafar et. al. (2011) reported 200+ diatom and 90+ dinoflagellate species from the Indian EEZ. However, recent (1998 to 2012) surveys conducted under the Marine Living Resources Programme (MLRP) of the Ministry of Earth Sciences (MoES) have recorded 392 species of marine microalgae within the EEZ of India consisting of 164 species of dinoflagellates, 206 species of diatom, 16 species of cyanobacteria and 6 species belonging to other groups such as silicoflagellates, parsionophycae and chrysophyceae**.** Taylor (1976) based on IIOE collections, reported 201 dinoflagellate species from the Indian Ocean. Updated in present report: 392+ species.

Macro algae: India's National Report to the Convention of Biological Diversity (CBD) 2001 reports 624 species of macro algae. However, more recent reports of Wafar et. al. (2011) and Saxena (2012) indicates to 844 species consisting of 434 species of Rhodophytes, 216 species of chlorophytes, 191 species of phaeophytes and 3 species of xanthophytes. Important species are *Enteromorpha compresa, Ulva lactuca, Acetabularia cremulata, Dictyosphaeria cavernosa, Chaetomorpha media, Caulerpa corynephora, C.paltata, Odium iyengarii, Halimeda macroloba, Dictyota atomarica, Ectocarpus breviarticvulatus, Grateloupia indica and Sargassum duplicatum.* Updated in present report: 844 species. Area estimates of sea weed dominated ecosystems have not been carried out except for Palk Bay and Gulf of Mannar.

Sea grass**:** 14 species of sea grass mostly associated with coral reefs have been reported by Wafar et. al. (2011) and Saxena (2012). These include species such as *Cymodocea serrulata, C. rotunda Halophila ovalis, H.beccarii , H.deecipiens, H.avata, H.stipulacea, Halodule pinifolia*, H.uninervis, H.wightid, *Syringodium isoetifolium*, *Thalasia hemprichii*, *Enhalus acoradies*.,etc. Updated in present report: 14 species. Area estimates of sea grass dominated ecosystems have not been carried out except for Palk Bay and Gulf of Mannar.

Mangroves: India has only 2.66% of world's mangroves. As per the 2009 assessment report to CBD the total mangrove vegetation cover of India is 4662.56 km^2, an increase by 15% from the 1987 assessment (4046 km^2). Substantial increase in mangrove coverage is reported for the states of Goa (from 0 km^2 in 1987 to 22 km^2 in 2011), Gujarat (from 427 km^2 in 1987 to 1058 km^2 by 2011) and West Bengal (from 2076 km^2 in 1987 to 2155 km^2 by 2011) whereas, a decrease in the mangrove coverage is reported for Andhra Pradesh (from 495 km^2 in 1987 to 352 km^2, by 2011) and Andaman & Nicobar islands (from 686 km^2 in 1987 to 617 km^2 by 2011). Considerable uncertainties in the number of true mangrove species exist in our present knowledge on mangroves. Untawale (1978) reported 33 true mangrove species from the west coast and 47 species from the east coast of India. Wafar et al. (2011) reported the occurrence of 39 species of true mangroves whereas Saxena (2012) report 69 species of mangrove vegetation in India. The report by Bhatt et al. (2011) gives the total number of true mangrove species as 68 species and mangrove associated species as 86, whereas Mathew et. al. (2010) reported 72 species of exclusive mangroves and 165 species of mangrove associated species**.** Sunderbans has 30 of the 50 species of true mangroves in the world. Whereas, a decrease in the mangrove coverage is reported for Andhra Pradesh (from 495 km^2 in 1987 to 352 km^2, by 2011) and Andaman & Nicobar islands (from 686 km^2 in 1987 to 617 km^2 by 2011). Updated in present report: 39+ species.

Protista: National reports of India to CBD 2001 & 2009 give the protistan species number in Indian waters as 730. However, the OBIS species abundance data for Indian Ocean have records of only 689 protozoan species. Wafar et al. (2011) have reported 532 species of protozoans, 500+ species of foramniferans and 32 species of tintinnids from Indian waters. The MLRP has records of 42 species of tintinnids from Indian waters. Updated in present report: 1074+ species.

Porifera: The World Porifera Data Base enlists 8132 valid species of deep sea marine sponges. Thomas (1983) described the distribution of 481 species of sponges in the Indian region. Pattnayak (1999) described 451 species of marine sponges from Indian waters. Number of species reported by Saxena (2012), National reports 2001 & 2009 to CBD & Wafar et. al. (2011) vary between 451 and 486+. Further, several new records of deep sea sponges have been recently reported under the MLRP. Available reports indicates high species abundance of sponges in the MPAs of Gulf of Mannar and Palk Bay (319 species), Andaman Nicobar Islands (95 species), Lakshadweep (82 species) and Gulf of Kachchh (25 Species). The MPAs are home to 408 species of Desmospongians, 3 species of Calcareans and 28 Hexactinellidan sponges. Updated in present report: 486+ species.

Cnidaria: There are 10,105 valid Cnidarian species recorded from world oceans consisting 6142 species of Anthozoans (true corals, sea anemones, sea fans, sea pens etc) 42 species of cubozoans (box jellies), 3643 species of Hydrozoans (hydroidae, siphonophores, fire corals and many medusa), 228 species of Scyphozoa (big jelly fishes) and 50 species of Staurozoa (stalked jelly fish). Total number of cnidarians species in Indian waters is 790 as per the 2001 & 2009 National reports to CBD. Wafar et. al. (2011) estimated the cnidarians species in Indian waters to be 842+, consisting of 212 species of Hydrozoans, 25 species of scyphozoans and 600 species of anthozoans. Among the anthozoans, corals species records are 252 comprising of 208 shallow water species (Venketaraman, 2006) and 44 deep sea or shallow water ahermatype species (Pillai, 2010). At the regional level hard coral species in Bangladesh (66), Maldives (209) and Sri Lanka (183) have been reported by Arjan Rajasuriya et. al. (2000) and for Iran (27) and UAE (34) by Wilson et. al. (2002).

India has 2383.87 km^2 coral reef area, most of which fall under MPAs. All the 3 types of reefs occur in India. Fringing reefs are found in Gulf of Kuchchh, Gulf of Mannar, Palk Bay and along the east coast of Andamans, whereas the west coast of Andaman has barrier reefs (329 km long). Lakshadweep has atolls. Bhatt et al. (2012) have categorised the coral reefs of Gulf of Mannar in Tamil Nadu and in A&N islands as vulnerable. Only the coral reefs of Lakshadweep are stated to be in pristine condition. Updated in present report: Total number of Cnidarian species in Indian waters is 942+ consisting of 693+ species of anthozoans (includes 301 species of hermatypic and 44 species of ahermatypic corals), 32 species of scyphozoans (ZSI has collections of 24 species and 8 more species are reported from Madras coast), 212 species of Hydrozoans (including 89 species of siphonophores) and 5 cubozoan species.

Ctenophora: The OBIS has records for 12 species of Comb jellies from the world oceans. From Indian waters 12 species are reported so far. However, the WoRMS has only 2 records from the Indian Ocean, the cosmopolitan species *Pleurobranchia piles* and B*erve cucumis.* Other common species in Indian waters are *Ctenoplana indica, C.bengalensis, Coeloplana tattersalli, C. krusadiensis* etc. Updated in present report: 12+ species.

Platyhelminthes: Reported species vary between 350 and 550. Updated in present report 350+. However, taking into consideration the existence of 20,000 valid species of flatworms in the world oceans, the species status from Indian EEZ seems to be an underestimate and reflect the lack of studies on this important group.

Gnathostomulida: About 80 species of small (<1mm) worm like marine interstitial organisms, that can live even anaerobic. Records not available from India.

Nemertinea [Nemertia or Nemertini or Rhinocoela]: Group of acoelomate, unsegmented mostly marine worms. Though 1561 species are recorded from world oceans, there is record of only one species from Indian EEZ. Poor records from Indian EEZ is probably due to lack of expertise in India on this Group. Need to initiate specific R&D on marine Nemertinea.

Acanthocephalae: Endoparasite worms. Around 1000 species are reported from world oceans. Indian EEZ has more than 157 species. Updated in present report: 157+ species.

Aschelminthes [Nemathelminthes]: Class Rotifera, Gastrotricha, Kynohyncha, Priapulida, Nematomorpha and Nematoda are discussed.

Rotifera: Approximately 2220 species are known from world oceans. However, information from Indian EEZ is limited and doubtful.

Gastrotricha: From the world oceans 400 valid species are recorded. Information on 75 species is available from the Indian EEZ. *Pseudostomella andamanica, Acanthodasys aculeatus, Paradasys turbanelloides, Macrodasys caudatus, Urodasys viviparous, Thaumastoderma beideri, Tetranchyroderma megastoma, T.cirrophora, Xenotricha velox, X.subterranea, X.beauchampi, Chaetonotus atrox, Aspidophorous marina* etc are few common gastrotrichs in Indian waters.

Kinorhyncha [Echinodera]: Though there are inconsistencies in the number of species reported under Kinorhyncha, it is to be noted that Kinorhyncha is represented by 150 species globally and that perhaps not much work on this Group has been conducted in Indian waters after Higgins (1969) who reported few species from Indian waters. Species reported from Indian EEZ include *Echinoderes bengaliensis, E. sonadiae & E. ehersi* (West Bengal), *Cateria gerlachi & C. Stys* (Waltair), *Condyloderes paradoxus* (Vishakhapatnam) and *Sphenoderes indicus* (Visakhapatnam and Jamnagar). Updated in present report: 10+ species.

Priapulida: Though 16 marine species are recorded globally, Information from Indian EEZ is not available.

Nematomorpha: 250 marine species recorded globally. No information from Indian EEZ.

Nematoda: Species abundance of nematodes in the marine ecosystems within Indian EEZ [South East Arabian Sea (SEAS), North East Arabian Sea (NEAS), South East coast (SBOB), North East coast (NBOB) and Andaman Nicobar Island (ANI) was assessed by MLRP. Maximum number of nematode species recorded in these studies was 225. Reports other than MLRP indicates 154 species of nematodes in the west coast, 89 species in the North East coast, 192 species in the South East Coast, 37 species from Lakshadweep, 44 species from Pichavaram Mangroves and 40 species from Cochin backwaters. Updated in present report: 225+ species.

Entoprocta (Calyssozoa): Small sessile animals epizoic on sponges, ascidians etc. Records from Indian EEZ not available.

Annelida: Around 8000 species of annelids are reported from world oceans of which more than 4000 are polychates. From the Indian EEZ the ZSI report 450 species of polychates, whereas the CMFRI report 200 species. Under the MLRP number of benthic polychates recorded so far is 311. In addition there are 35 species of valid planktonic polychates. Thus as per MLRP, the number of polychate species in Indian EEZ is 346+. There are 20 species of valid archiannelids reported from Indian EEZ. Further, Group Echiura (33 species from Indian EEZ) which is considered separately by Wafer et al., is now included under Annelida (McHugh, 1997) as also the Group Pogonophora. Updated in present report: 493+ species.

Chaetognatha: Chaetognaths or Arrow worms are exclusively marine and represented by both pelagic (About 100 species) and benthic (about 30 species) forms. World Register of Marine Species (WoRMS) has more than 100 species of chaetognaths represented by Adinosagitta (26 spp), Heterokrohnia (18 spp), Eukrohnia (14 spp), Ferosagitta (9 spp), Krohnitella (6 spp), Caecosagitta (6 spp), Flaccisagitta (4 spp), Decipisagitta (2 spp), Bathyspadella (2 spp), Leptosagitta (2 spp), and one species each in Hemispadella, Calispadella, Bathysagitta and Bathybelos. Kusum (2012) reported on 22 species of pelagic chaetognaths from Indian EEZ which include 16 species under genus Sagitta, 3 species under the genus Eukrohnitta, 2 species under genus Krohinitta and one species under Pterosagitta. Details of the 30 chaetognath species reported from Indian waters is given in Annex. IV. Updated in present report: 30 + species.

Sipuncula: About 350 species are reported globally. Indian EEZ has 35 species.

Pycnogonidia [Pantopoda]: From world oceans 900 species are reported. No reports available from the Indian EEZ.

Tardigrada: About 600 species recorded from world oceans. Indian EEZ has more than 10 species.

Crustacea: Globally, 60,000 species of marine crustaceans are reported. Whereas, the National reports to CBD put the number of crustacean species from Indian waters as 2440, Saxena (2012) has reported the occurrence of 2900 species and Wafar et. al. (2011) give a figure of 3498 species. From the available records, there are 767 species of copepods, 120 species of Ostracods, 104 species of Cirripedes, 348 species of Stomatopod [Isopods (7Sp), Amphipods (164 sp), Euphasids (25 sp), Mysids (102 sp] , 1098 species of decapoda [lobsters(26 sp), prawns (179 sp), sergestids (8sp), anomuran crabs (162 sp), Brachyuran crabs (705 sp), Solenoceridae (8 sp), Lucifer (7 sp),cladocera (3 sp)] and 5 species of Merostomata (Horse-shoe crabs). Updated in present report: 2442+ species.

Echinodermata: There is consistency in the reports and therefore Echinoderm species in Indian waters can be safely put as 765.

Protochordata: Wafar et. al. (2012) have reported 119+ species. This can be accepted as published reports give occurrence of 6 species of Cephalochordates, 47 species of Ascidians, 48 species of Thaliacea and 18 species of Larvaceae in Indian waters.

Pisces: There are considerable differences in the number of species reported by various authors/ reports. As per the report of the Working Group on Fisheries for the 12th Plan period, the number of fin fishes in Indian EEZ is given as 1707. In view of this, the number of fin fish species can be taken as 1800 as given in the National Reports to CBD.

Marine Reptiles: Number of species reported vary from 26 to 35. Information on 22 species of sea snakes from Indian EEZ is currently available. Out of the 6 species of sea turtles found in the NIO, 5 species are represented in Indian waters. These include the Olive Ridley (*Lepidochelysis olivacea*), Green turtle (*Chelonia mydas*), Leatherback turtle (*Dermachelys oriacea*), Hawks bill turtle (*Eretmochelys imbricata*) and the Logger head turtle (*Caretta caretta*). In addition 4 species of marine crocodiles are found in Indian EEZ. Updated in present report: 31 species.

Marine Birds: National Reports (2001 & 2009) to CBD report 145 species of Marine birds. This seems to be an overestimate, as the IOTC have reported on the occurrence of only 17 species of true sea birds for the entire Indian Ocean that include 19 species of albatrosses, 5 species of petrels and 2 species belonging to other genus. Species status uncertain. Need reconfirmation.

Marine Mammals: National reports 2001 & 2009 lists 29 species of marine mammals whereas Saxena (2012) reported 30 species and Wafar et al. (2011) reported 25 species. Kumaran (2002) stated that the number of known marine mammals in the Indian EEZ is 25 consisting of 14 species of whales, 9 dolphins, one porpoise and one dugong. In addition, detailed survey under MLRP located the occurrence of the Pygmy whale (*Kogia sima*) and the Indo-Pacific beaked whale (*Indopacetus pacificus*) in the Indian EEZ. In addition the Irrawady dolphin and the Ganges dolphin which are not covered by the MLRP need to be included. Updated in present report The number of Marine Mammal species in Indian EEZ is 29, consisting of 16 whales, 9 dolphins, 1 porpoise and 1 dugong.

4.2 *Microbial diversity*

A Marine Microbial Reference Facility (MMRF) has been established at the CSIR-National Institute of Oceanography, Regional Centre, Kochi under the COMAPS program. A total of 525 bacteria collected from the coastal and estuarine regions and identified using polyphasic taxonomic method are available in the reference collection of MMRF. Among these approximately 70% are health indicator species. *Vibrio* spp are the most common indicator bacteria present in coastal waters of Kerala, Tamil Nadu, Andhra Pradhesh, Pondichery and Andaman & Nicrobar islands having the maximum diversity along Kerala followed by Tamil Nadu and Andhra Pradesh. Major pathogenic species are, *V. parahaemolyticus, V. cholerae, V. harveyi* and *V. alginolyicus.* However, *V. furnissi* isolated from Andaman & Nicobar Islands is a non pathogen. *Enterobacter* spp reported from coastal areas are *E. aerogenes, E. agglomerans, E. cloacae, E. fergusonii* and *E. Hormaechei*, of which *Escherichia coli* is ubiquitous. Interestingly, many of them are resistant to multiple antibiotics. *Aeromonas hydrophila, A. salmonicida, Klebsiella pneumonia, Salmonella typhi, Staphylococcus aureus, Pseudomonas aeruginosa* and *Shigella sonnei* are the other health indicators recorded from coastal areas of Kerala, Tamil Nadu and Andhra Pradesh.

Reports on other bacterial species along Indian waters are highly scattered. Other microbial species recorded include *Pseudoalteromonas* sp., *Serratia marescens*., *Azotobacter sp., Planococcus sp, Bacillus subtilus* (Goa), and *Chlorobium spp, Chromatium spp Micrococcus sp., Bacillus sp., Moraxella sp., Acinetobacter sp., Flexibacter sp.* (Kerala). Culturable bacterial diversity in the sediments of the continental margin of the Arabian Sea showed the dominance of *Bacillus* sp, with representations from *Halobacillus* sp., *Virgibacillus* sp., *Paenibacillus* sp., *Marinilactibacillus* sp., *Kytococcus* sp., *Micrococcus* sp., *Halomonas* sp. and *Alteromonas* sp. Recent attempts using different media compositions facilitated the isolation of novel species of microorganisms. These includes *Oceanospirillum nioense* and *Photobacterium marinum* from Palk Bay, *Shivajiell indica* a new genus under family Cyclobacteriaceae from Kakinada, *Flavobacterium nitratireducens* and *Aliidiomoarina haloalkalitolerans* from coastal waters of Vishakapatnam, *Algoriphagus sivajiensis* and *Imtechella halotolerans* from Cochin estuary and *Echinocola shivajiensis* from brackish water pond in West Bengal. Culture independent approaches also have been initiated in the past decade to understand the microbial diversity of marine environments of India. These surveys recorded the dominance of Proteobacteria in continental shelf, particularly in the OMZs in the Arabian Sea. Further, the phylogenetic analysis of 16S rRNA gene library revealed the dominance of Proteobacteria (52.5%), followed by Planctomycetes (12.7%), Chloroflexi and un-classified bacterial group (8.8 %). Additionally, the DGGE based analysis of DNA from central west cost of India showed the presence of unclassified bacteria, Flavobacteria, Gammaproteobacteria and actinobacteria Divya et al., 2010). By complete sequencing of 16S rDNA from 2664 clones sequences from the coastal waters along the west coast of India revealed that Proteobacteria was the most dominant group (517 operational taxonomic units; 71%) with minor contributions from other groups such as Bacteroidetes, Cyanobacteria and plastids etc. (Singh, 2010). Since 2007, about 42 new marine bacterial species have been recorded from India.

Recognizing the importance of studies on microbial pathways governing the ecosystem processes, the Ministry of Earth Sciences (MoES) has initiated a new program namely "Microbial Oceanography" to be implemented by CMLRE with the participation of institutions such as CSIR-National Institute of Oceanography (NIO), Goa and University of Pune. The program will focus on the processes governing microbial carbon pump, modelling the bacterial production, isolation of single cell and analysis of its functional genome, development of bioinformatics tools for metagenomic analysis of environmental genome and elucidation of novel sequences involved in biochemical pathways occurring in OMZ region of the northern Arabian Sea.

5. Socio-economic aspects in marine fisheries sector

The marine fisheries sector contributes to Indian economy through employment generation, development of subsidiary industries dependent on fish catch, processing and marketing, contributing to food and nutrition security besides being a foreign exchange earner. The CMFRI as per its 2010 census report identified 3288 marine fishing villages and 8.65 lakh marine fishers' households in India of which around 7.90 lakh households were "Below Poverty Line" (BPL). The 12th Five Year Plan approach paper had opined that a one per cent growth in overall GDP from the agriculture & allied sectors is twice as effective in elimination of poverty as a one per cent growth in overall GDP from non-agricultural sector. Given this background, the socio-economic aspects in sustainable development of marine fisheries sector becomes an important aspect of assessment

Assessment of demographic profile of fishers: A national level survey is conducted in every five years and assessment are made on the education, level of participation in fisheries, types of subsidiary occupation, religion, membership in cooperatives, assets owned and other socioeconomic aspects. The data are in digitized form and can be accessed.

Assessment of role of microfinance in reducing indebtedness among marine fishers: The Microfinance Institutions (MFIs) and Self Help Groups (SHGs) play a pivotal role in Indian marine fisheries sector in reducing indebtedness among marine fishers. Assessments were made on the extent of indebtedness among marine fishes in mechanized, motorized and traditional fisheries sectors and the impact assessment of MFIs on coastal indebtedness.

Labour Migration in Marine Fisheries: Employment status and opportunities in marine fisheries sector has increased over the years and the manpower employed in active fishing as well as in secondary and tertiary sectors both from coastal villages and other regions was assessed.

Nutritional status and health of women employed in fisheries sector: Assessments were made in different sectors on intake levels of micronutrients and health status.

Assessment of Fishers' Social Status in India -Rural Livelihood Security: The levels of literacy, health, income and livelihood security of the fishers in India in six fisheries sectors -

marine capture, inland capture, mariculture, fresh water and brackish water aquaculture and marketing and processing in 19 states of India were assessed.

Socio-economic impact assessment of monsoon trawl ban on marine fisheries sector: Trawl ban is an important regulatory measure for resource conservation in the country. Compound growth rate were calculated for comparing the growth in landings of major pelagic and demersal fishes during pre and post ban periods. Net operating income, net profit, capital and labour productivity ratios were used for comparing the economic performance of different fishing units.

Assessment of impacts of remote sensing on fisheries: Remote sensing has improved livelihood of fishers. A field survey in maritime states revealed that identification of Potential Fishing Zones increases productivity, significantly improves catch size and reduces fuel consumption, and avoiding extreme weather-related emergency situations. The net economic benefits computed due to the scientific identification of PFZs based on satellite information can be estimated to lie in the range of Rs 34,000 to Rs 50,000 crore.

Assessment of socio-economic impacts of coastal aquaculture: Impacts of shrimp farming, oyster and mussel farming and frontline demonstrations of sea cage farming have been assessed periodically at sub national level. Impacts integrated mangrove fishing and aquaculture and potential of Marine Ornamental fishes as livelihood in Lakshadweep Islands have also been assessed. At the national level the number of fishers involved in aquaculture is assessed regularly.

Assessment of threats and challenges to marine fishers: Several targeted assessments have been made on Impact of unsustainable development practices on coastal ecosystem, scaling up of coastal aquaculture, sea water desalination technologies and Marine Protected Areas and loss of livelihoods

Indigenous Technical Knowledge in Marine Fisheries Sector – ITK are important in fisheries and targeted surveys were conducted to identify the ITKs and their scientific background. These have been listed and documented.

6. Capacity Building

The Global Ocean Observing System (GOOS) monitoring initiatives along with other international programmes have improved the capability to assess oceanographic conditions making it possible to detect changes on high temporal and spatial resolution and assess the effectiveness of policies adopted. However, due to variety of reasons, the assessment capacity (personnel and infrastructure) varies widely across countries in the Indian Ocean region. Ample opportunities and arrangements do exist in India, though, for capacity building in education, training, research and assessment pertaining to various aspects of marine resources and environment. Master's program in Oceanography is offered by over half a dozen Indian universities. Research facilities pertaining to various disciplines exist in many more academic and research institutions, including seven major institutes where hundreds of students are currently pursuing research leading to Ph.D. degrees. Many of them are involved in the ongoing national programmes such as COMAPS, Sustained Indian Ocean Biogeochemical and Ecological Research (SIBER) and GEOTRACES - an International Study of Marine Biogeochemical Cycles of Trace Elements and their Isotopes.

The CSIR-NIO has expertise for training and research in all aspects of marine sciences.

The ICMAM Project Directorate (MoES), Chennai, has been extensively involved in carrying out capacity building programmes since 2001. So far more than 45 courses have been conducted in (i) Integrated Coastal Zone Management; (ii) Applications of remote sensing and GIS in coastal areas; (iii) Satellite oceanography; (iv) Sediment transport in near-shore areas; (v) Coastal vulnerability; (vi) Ecotoxicology; (vii) Shoreline management; (viii) Marine pollution; (ix) Coastal ecosystem modelling; (x) Oil spill modelling; and (xi) Application of remote sensing in fisheries management. Additional programmes are exclusively conducted on the request from government departments such as the Coast Guard and the Public Works Department (PWD).

The CMFRI has resources to conduct capacity building programmes specific to the theme of Marine Food Security. These include training in catch assessment /monitoring, census methodology, litter assessment and grading, taxonomy to corals and fishes, biomass dynamic models, trophic modeling of marine ecosystems, impact of fisheries management plans from fish stocks /destructive fishing practices, and socio-economic analysis related to fisheries.

In addition to the development of human resources within the country, several institutions in India are also involved in organizing training programmes for researchers from other Indian Ocean Rim (IOR) countries. For example, CSIR-NIO has been conducting on a regular basis training programmes on ‘Multi-disciplinary oceanographic observations for Coastal Zone Management’ for participants from the South Asian Association for Regional Cooperation (SAARC) and IOR countries. The Indian National Centre for Ocean Information Services (INCOIS), Hyderabad, is engaged in scientific and institutional capacity building for creating a pool of scientists/engineers/researchers, which is open to IOR countries, to carry out research in the field of Operational Oceanography. An International Training Centre for Operational Oceanography (ITCOcean) has been established at INCOIS, Hyderabad, with support by the Intergovernmental Oceanographic Commission (IOC)/UNESCO. The primary objective of the Centre is to enhance regional capacity and capability in operational oceanography that include ocean observations, ocean modelling, acquisition and processing of satellite data, telemetry of data in real time, generation of PFZ advisories, ocean colour applications, generation of tsunami warnings, etc. through short and long term courses to students/researchers/government officials from the IOR countries. Two short courses have already been conducted by ITCOcean in 2013, and a training course on ‘Remote sensing of Potential Fishing Zones and Ocean State Forecasts’ is scheduled for March 2014. INCOIS has also been coordinating Indian Ocean-Global Ocean Observation System (IOGOOS) activities in India which include (i) Enhancement of Ocean Observing System; (ii) Data Management, Data Exchange and Communication; (iii) Ocean Services; (iv) Capacity building; (v) Research; and (vi) Co-operation with other programmes and bodies.

Several international hands-on-training programs have been organised on board research vessel O.R.V. Sagar Kanya to researchers of the Members States of the Indian Ocean region under the SACEP and IOGOOS forums. India has a fleet of 6 major oceanographic research vessels (*Sagar Kanya, Sagar Sampada, Sagar Nidhi*, *Sagar Manjusha*, *Sindhu Sunkalp,* and *Sindhu Sadhana*) and two coastal research vessels (*Sagar Purvi and Sagar Paschimi*)

In conclusion, India possesses the necessary resources and expertise to spearhead a major regional initiative involving networking of researchers/institutions in the IOR region such that an effective system can be put in place for regular reporting and assessment of the state of marine environment including the socio-economic aspects from the Indian Ocean.

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