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**Research
Gaps in Coastal
and Marine
Conservation in
India**

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Summary

India has a long coastline of about 7517 km length spanning 13 maritime mainland states and union territories. There are diverse coastal and marine ecosystems along this coastline, supporting nationally and globally significant biodiversity. The coastline also supports almost 30% of the country's human population that is dependent on the rich, exploitable coastal and marine resources. The coasts of the Bay of Bengal and Arabian Sea continue to be rich fishing grounds of the South Asian region, making India one of the world's largest marine product-generating nations. Marine ecosystems such as estuaries, coral reefs, marshes, lagoons, sandy and rocky beaches, mangrove forests and sea grass beds are all known for their high biological productivity. They provide a wide range of habitats for the aquatic flora and fauna. They also provide important food resources and innumerable ecological services to human beings. Therefore, sustainability of these fragile ecosystems needs to be our primary concern. So far, we have largely looked at marine biodiversity as a source of commercial products instead of appreciating its ecological values and services, which has resulted in overexploitation of several coastal and marine species. Many species are now on the verge of extinction. Moreover, human activities such as destructive fishing, shipping, indiscriminate coastal development and discharge of untreated effluent from industries have caused considerable damage and pose a severe threat to the coastal and marine biodiversity. In addition to these, global warming due to climate change also poses a major challenge to our marine biodiversity. In this context, we have identified the research gaps in coastal and marine biodiversity conservation in India through a consultative process and present a comprehensive review of the results.

Keywords : *Landscape; habitat; species*

Introduction

Coastal and marine ecosystems are among the most biologically and economically productive ecosystems in the world. In India, these ecosystems are a source of livelihood and provide a range of ecological services that are critical for the day-to-day well-being of millions of people, particularly coastal communities. India's coastline extends over a length of 2094 km in its islands and 5423 km in the mainland, which forms a major physical feature located between the Arabian Sea and the Bay of Bengal in the Indian Ocean. This coastline is characterized by the presence of long rocky and sandy shores, sand spits, barrier beaches, embayments and offshore islands that serve as habitats for a diverse marine fauna and flora, including 15,000 species or more, in India. Several taxonomic groups such as diatoms, dinoflagellates, marine algae, tintinnids, foraminiferans, hydrozoans, siphonophorans, sponges, octocorals, ctenophores, polychaetes and tunicates continue to be inadequately known from India. Among the coastal and marine habitats, coral reefs are the most diverse and vulnerable ecosystems in India. A high diversity of corals has been recorded in the Andaman and Nicobar Islands, which provide shelter to 180 species of benthic alga, 14 species of sea weed, 12 species of sea grass, 108 species of sponge, 4 species of lobster, 103 species of echinoderm, 600 species of fin fish and a significant number of species of crab, bivalve, gastropods and cephalopod (Devaraj 1997). There are also more than 500 species of hard coral belonging to 60 genera (Venkataraman 2003), and many more species are yet to be described by the Zoological Survey of India (pers. comm Zoological Survey of India, Port Blair).

India is one among the 17 mega-biodiverse countries in the world and is also ranked 14th among the 22 countries that hold the world's major mangrove areas. About 4000 floral and faunal species have been described from Indian mangroves (Wafar et al 2011). The Sundarbans regions make up the single largest contiguous block of mangrove forest in the world, with 40% of the area within India and the rest in Bangladesh. A total of 125 species of mangrove are known (Venkataraman et al 2012) from the 4662 km² of mangrove cover in India, as estimated by Forest Survey of India from 2009 data (FSI 2011). These mangroves are also inhabited by 11 species of seagrass and 12 species of salt marsh vegetation (Kathiresan & Rajendran 2005). Seagrass beds are extensively found in the subtidal zones of the Andaman and Nicobar Islands, Lakshadweep Islands and Gulf of Mannar. Fifteen species of sea grass belonging to 6 genera have been reported

from India (MoEF 2014). Similarly, seaweeds are abundant in the infralittoral regions of the Indian coastline, especially in shallow rocky coasts, intertidal lagoons, intertidal pools, etc. Close to 120 species of seaweed have been described from the coastal zones of India, which are also exploited for their commercial products (Venkataraman et al 2012). Apart from over 9000 species of invertebrate, about 2500 species of fish and 35 reptiles are known from India (Wafar et al 2011). Twenty-six species of marine mammal have been recorded in Indian waters (Kumaran 2002). Most of these groups are poorly studied in India and often the information comes from stranding records and fisheries interactions. The distribution of the only sirenian, the Dugong *Dugong dugon*, extends over the Gulf of Mannar, Palk Bay, Gulf of Kachchh and Andaman and Nicobar Islands. However, in most of these sites, appreciable numbers of Dugong are no longer found.

The Wildlife (Protection) Act 1972 provides for the establishment of protected areas by state governments. Apart from this act, the Environment (Protection) Act, 1986, Coastal Regulation Zone Notification, 1991 and National Biodiversity Act, 2002 have been enacted by India for conservation of coastal and marine environment in the country. So far, about 24 marine protected areas (MPAs) have been established in the country. The Gulf of Kachchh Marine National Park, Gujarat, the Gulf of Mannar National Park, Tamil Nadu and Wandoor Marine National Park, Andaman and Nicobar Islands are some of the important MPAs of India.

Threats to Coastal and Marine Biodiversity

Despite their tremendous ecological and economic importance and the existence of a substantial policy and regulatory framework, India's coastal and marine ecosystems are under increasing threat. Numerous direct and indirect pressures arising from different types of economic development and associated activities are having adverse impacts on coastal and marine biodiversity across the country. Indiscriminate industrial development along the shoreline of India over the last few decades has fuelled a spurt in activities near the coastal ecosystems in terms of human settlement along the coast, port development, increased pollution, sewage discharge, fishing, diving, etc.

The major anthropogenic direct drivers of ecosystem degradation and destruction include habitat conversion to other forms of land use, overexploitation of species, destructive harvesting practices, spread of invasive alien species, impacts of agricultural, domestic and industrial sewage and waste. Additionally, climate change is likely to have a growing impact on coastal and marine ecosystems, including a likely increase in extreme weather events, a sea level rise, warming of sea surface temperatures and ocean acidification. Coastal habitats are also subject to powerful natural weather phenomena, such as tsunamis, cyclones, hurricanes and storms. Indirect drivers of ecosystem change include demographic, socio-political, cultural, economic and technological factors.

Extensive urbanization and shore development along the eastern and western coasts have damaged vast habitats of naturally occurring mangrove stands (Nayak & Bahuguna 2001). Similarly, along much of the coast of western India, dense sea grass beds are uncommon or are not extensive, probably because of the degree of exposure to shore development and turbidity of these waters. Due to poor awareness regarding these ecosystems among most of the coastal stakeholders, these ecosystems have been left out of conservation plans (Jagtap et al 2003). It is estimated that perhaps 5% of the sea grass beds of the Indian Ocean have been destroyed by dredging or in-filling. Similarly, coral reefs in the Gulf of Mannar have been under severe stress from destructive fishing, pollution and coral mining. Extensive extraction of seaweeds, seashells, sea horses and sea cucumbers and extensive use of bamboo fish traps have seriously depleted fish stocks in this region (Rajasuriya et al 2002). These harmful practices have also destroyed much of the critical habitat for marine turtles and the Dugong. Sand mining, invasive species such as the Crown-of-Thorns Starfish and sedimentation due to coastal development have also degraded corals on the Indian coast. Coral bleaching due to climate change, deforestation and marine pollutants such as POPs (persistent organic pollutants) are also causing severe damage to the coral reefs (Jha et al 2011). Climate change may aggravate these stressors, leading to shoreline erosion, soil salination and flooding, thus impacting the biodiversity as well as livelihoods of the coastal people (MoEF 2014).

Current Focus of Research Activities: Coastal and Marine Biodiversity

The major scientific areas of current research on the coastal and marine biodiversity of India include fisheries, aquaculture and studies on seaweeds and mangroves (Kathiresan & Rajendran 2005; Venkataraman & Wafar 2005). Fishery research in India has concentrated on capture and culture fishery of perches, carangids, barracudas, mackerels, milkfish, mullets, tunas, sardines, scombroids, silverbellies, pomfrets, letherinids, groupers, sharks and rays. Similarly, the finfish fishery includes oysters, mussels, clams, prawns, shrimps, lobsters and crabs. Aquaculture research has been concentrated on pearl oysters, edible oysters, crabs, prawns, milkfish, ornamental fishes, etc. (Joseph 2003). Localized research has also been carried out on the distribution, nutrient analysis and commercial production of seaweeds (Manikandan et al 2011; Venkataraman et al 2012). Research into culture of organisms of export value such as sea cucumbers, sea horses and ornamental fishes has also been carried out by institutions including the state and central fisheries departments and academic institutions (Gopakumar 2005; Asha & Muthiah 2007). Research into corals,

mangroves, sea grasses and certain threatened fauna have also been carried out, but in sporadic manner and in selected sites. So far, most of the research carried out in India has considered marine biodiversity as commercial products and largely failed to appreciate its ecological role. Moreover, recent threats such as climate change, invasive species and unregulated coastal development are posing major challenges for conservation of marine biodiversity. These challenges need to be addressed immediately through scientific research.

Major requirements for marine biodiversity conservation research in India

Most importantly, cross-sectoral coordination among organizations/institutions working for conservation of coastal and marine biodiversity and welfare of coastal communities is required. Moreover, documentation and creation of databases on marine biodiversity are also urgently required. It is also important to develop a specialized field-based programme in marine ecosystem ecology with an emphasis on rigorous scientific research, hypothesis testing, taxonomy and conservation, based on models established by the M.Sc. course in Wildlife Science at the Wildlife Institute of India or at the National Centre for Biological Sciences. Development of human resources to manage the MPAs of India is also immediately required. In this connection, it is prudent to establish a new national research institution to take up and coordinate coastal marine biodiversity-related work.

Research gaps in coastal and marine biodiversity conservation in India *(Summary provided in Table1)

a) Landscape-/seascape-/ecosystem-level research areas

- **Long-term monitoring studies on dynamics of coastal geomorphology** covering the entire coastline of the country. The focus should be on ecologically sensitive coastal areas such as coral reefs, mangroves, turtle nesting beaches, sand dunes, mudflats and estuaries. Studies should also focus on the impacts of climate change, special economic zones (SEZs), infrastructure development, etc. on the coastal geomorphology and use advanced techniques such as remote sensing, satellite imagery and GIS.
- **Assessment/estimation of coastal marine habitat lost or being lost, especially in coral reefs, mangroves, sand dunes, mudflats, etc.** Considerable areas of critical habitats have been lost due to developmental activities and natural calamities (e.g. sea erosion, landmass uplift as in the case of the coral reefs of the Andaman & Nicobar Islands after the earthquake that caused the tsunami in December 2004). An estimation of the area lost over the years and analyses of the reasons will enable future loss and continuation of such losses to be stemmed and may provide solutions for restoration.
- **Linkages/connectivity among habitats/ecosystems.** It is important to find out the linkages and connectivity between various coastal and marine habitats/ecosystems to understand their ecological functioning better. This kind of study is crucial for planning for landscape-/seascape-level conservation. These studies should also analyse the impact of human activities on the linkages/connectivity between habitats/ecosystems.
- **Study the structurally important elements of ecosystems.** Studies on corals, mangroves, sea grasses, etc. should focus on population dynamics, meta-population processes, connectivity and other drivers of these structural elements. Studies of interactions of these elements and processes with human use will provide the necessary understanding to safeguard the linkages.
- **Reduction in freshwater flow and sediment influx.** Long-term monitoring of impacts of a reduction in freshwater and sediment influx on the coastal and marine environment is required. Due to various developmental projects and changes in the land-use pattern along coastal areas, the influx of sediments is being increased and the inflow of freshwater is being reduced, which needs to be studied immediately to prevent their adverse impacts on sensitive coastal and marine habitats such as estuaries, lagoons, mangroves, sea grass beds, coral reefs and mudflats.
- **Studies on functionally vital processes in various marine ecosystems.** Studies on trophic linkages and processes such as predation, herbivory, detrital pathways, productivity, community linkages, trophic redundancies, resilience, etc. must be conducted.
- **Bio-shield-Enhancing species diversity.** Studies to develop bio-shields along selected parts of the coastline to enhance the native coastal and marine biodiversity.
- **Climate change and impacts on the coastal and marine landscape and biodiversity.** Global climate change is predicted to adversely affect marine biodiversity through temperature rises and ocean acidification. Therefore, it is important to monitor the coastal and marine environment with respect to its biodiversity.
- **Need for research and creation of a gene bank for coastal and marine flora.** National Biodiversity Action Plan (2008) emphasizes the importance of having a gene bank for the entire Indian flora and fauna. In this connection, a gene bank must be created exclusively for coastal and marine flora and fauna. This gene

bank is expected to contribute to ex situ conservation of our natural treasures as well as to protect species from illegal trade.

- **Invasive species.** Invasive species have been identified as the second most important threat to marine biodiversity, next to habitat loss. Landscape-/seascape-level studies are required to study the impact of invasive species to manage them at the seascape level/ecosystem level.
- **Biodiversity of estuaries.** Of the approximately 200 estuaries present in India, only around 60 are listed in the literature, and the biodiversity of very few estuaries has been investigated. As these estuaries are facing increased anthropogenic disturbances, assessment of their ecological health needs to be conducted on priority basis.
- **Identification and conservation of important coastal and marine biodiversity areas of India.** The Wildlife Institute of India is finalizing the Atlas for Important Coastal and Marine Biodiversity Areas of India. This project needs to be further reviewed with wider participation of various stakeholders, research institutions, NGOs, etc. This will serve to guide us in taking decisions about economic zones and other developmental projects along the coast.
- **Ecological services of coastal and marine habitats/ecosystems.** It is necessary to understand and monitor the ecological services of all coastal and marine habitats/ecosystems for better management and sustainable use of resources and understanding the impact of human use on these ecological services.
- **Understand resilience.** Studies need to be undertaken to understand ecosystem processes with reference to disturbances-thresholds, discontinuities and recovery potentials.
- **National-level assessment and specific site-level studies for high-salinity mudflats.** The diversity and values (traditional and commercial) of halophytes need to be assessed to safeguard them as well as to utilize them in a sustainable manner.
- **Experimental studies in estuaries and mangroves.** Bio-resource enhancement needs to be undertaken in major estuaries and mangrove habitats of India.
- **Economic valuation** of ecological services of various coastal and marine habitats needs to be initiated.
- **Review and carry out management effectiveness of MPAs.** It is important to review the existing marine protected areas network in India and carry out management effectiveness evaluation for all MPAs in the country.

b) Habitat-level research on coastal and marine biodiversity

- **Intertidal mudflats.** Studies to assess their ecological significance, restoration and dynamics
- **Corals.** Studies to understand and analyse the connectivity within and between associated habitats. Detailed ecological studies on coral-associated micro-organisms and their responses to climate change and various anthropogenic activities. Information about the taxonomy of zooxanthellae, their role in the coral habitat and biology is scarce. This gap has to be filled.
- **Mangroves are considered to be repositories of biodiversity.** Therefore, an integrated study to record the diversity associated with mangroves has to be undertaken (to cite few groups, the diversity of fungi, nematodes, amphipods, brachyuran crabs, etc. is not known fully). Further research is needed on the lesser known mangrove species.
- **Sea grass species inventory.** Sea grass beds provide feeding and breeding habitats for many species including marine turtles and the Dugong. Long-term monitoring of these fragile ecosystems needs to be done to understand changes in the habitat.
- **Documentation of biodiversity along intertidal rocky shorelines.** The important research gap area with regard to intertidal rocky shorelines is the poor documentation of the biodiversity of the symbiotic and associated microbial community.
- **Coastal lagoon ecology and biodiversity.** Lagoons have been ignored for a long period. This needs to be addressed. Details of their biodiversity, ecological services and livelihood interactions of local communities and other stakeholders need to be studied.
- **Habitats of threatened animals.** Special habitats of certain threatened animals such as the Dugong, Whale Shark, sea horses and horseshoe crabs need to be assessed and monitored.
- **Impact of coral bleaching on the biodiversity of corals and other associated organisms in coral reef ecosystems.** The frequency of bleaching events has increased in the recent past in reefs around the world. While large-scale coral mortality is the immediate result, species-wise mortality and the effects on the actual coral cover are often not clearly understood. The process of recovery of coral species needs to be monitored also.

Importantly, the impact of the disappearance or a dramatic reduction in percent cover of a coral species-which in turn will influence the associates-needs to be studied on a long-term basis.

c) Species-level research on coastal and marine biodiversity

- **Strengthening of taxonomic capacity.** The current knowledge about the taxonomy of marine fauna and flora is inadequate. This is mainly due to declining numbers of trained taxonomists and introduction of modern subjects at the college and university levels. The current curriculum of the education system (especially in the biology and marine sciences streams) does not amply expose young researchers to the fields of taxonomy and ecology. There is an urgent need to build capacity in taxonomy and ecology of marine organisms through a series of training programmes. In addition to traditional taxonomic training, training in the use of molecular tools including molecular markers and DNA barcoding to strengthen/confirm morphological identity is necessary.
- **Preparation and implementation of species recovery plans.** Recently, the Ministry of Environment and Forests, Government of India decided to conserve and manage highly threatened marine species through species recovery plans. More species need to be included in this programme, and all the species recovery plans must be prepared with scientifically validated data.
- **Periodic assessment of threatened and endemic species.** As a part of long-term monitoring of the populations and distribution ranges of all threatened and endemic coastal and marine species, periodic assessment at 5-year intervals needs to be carried out to review the scheduled species of the Wildlife (Protection) Act, 1972 and periodically revise the IUCN Red List, appendices of CITES, etc.
- **Ecological studies of endemic and threatened species of invertebrate and Pro-chordate groups.** A large number of invertebrate faunal species in coastal and marine ecosystems are being commercially exploited for food, medicine and ornamental goods. The status of many endemic and threatened invertebrate forms is unknown from the scientific and commercial perspectives. Detailed studies need to be undertaken for evaluating the status and distribution of the following groups: sea cucumbers; sea anemones; starfishes; sponges; Brachiopoda; Placozoa; Pogonophora; Gnathostomulida; Echiura; Phoronida; Ctenophora; Kinorhyncha; Priapula; Loricifera; Echinodermata; Cycliophora; and the endemic molluscan species. Studies on polymorphism among gastropods also need to be carried out. Studies are also necessary for poorly known meiofauna along the coast and intertidal mudflats. It is also important to study the ecology of horseshoe crabs, giant or coconut crabs, estuarine crabs, etc. The pro-chordates are a very poorly studied group in India. *Balanoglossus*, *Ptychodera flava*, ascidians such as *Herdmania* and *Eceinascidia*, and the *Amphioxus Branchiostoma lanceolatus* are some of the pro-chordates that need more studies.
- **Impact of global warming and climate change.** The effects of climate change and global warming bring about changes in the trophic dynamics, abundance and distribution of fauna at various trophic levels. They are among the causes of coral bleaching phenomena. Studies need to be carried out on the long-term impacts of climate change on the marine fauna, including microbes, and coral reefs for mitigation/prevention of coral bleaching.
- **Marine/coastal mammals.** A comprehensive survey dedicated to marine mammals is needed to assess the status of mammalian species in Indian waters. The Dugong-population studies need to be carried out, and threats to habitats need to be investigated properly, particularly in the Gulf of Mannar, Gulf of Kachchh and Andaman & Nicobar Islands. Surveys are required to assess the status of the Fishing Cat and Smooth-Coated Otter in coastal and mangrove habitats.
- **Coastal and oceanic birds.** The baseline data available on seabirds along the Indian coastline are inadequate. Ecological surveys and long-term monitoring of coastal birds and seabirds along the west and east coasts and identification and protection of nesting and feeding grounds of migratory birds in the coastal areas are essential. In addition, studies are required on the flamingo habitats in Gujarat. Ecological studies of the terns in Lakshadweep and identification of important habitats for shorebirds are needed.
- **Ecological studies on marine reptiles.** Very few species of marine reptile are found in the coastal and marine habitats of India along the west coast, east coast and islands. These include the Saltwater Crocodile, sea snakes and marine turtles. These species are facing severe threats due to the use of inappropriate fishing gear and various coastal developments. To conserve these species, it is essential to study their reproductive ecology, population dynamics and habitat characteristics.
- **Long-term monitoring and ecological studies on lesser-known fish species.** Though we have very good historical documentation of marine fisheries resources in the country, there are gaps regarding lesser known fish taxa. The important gap areas are the following: status and diversity of seahorse populations along the Indian coast; exploration of enzymic and non-enzymic anti-oxidants from bycatch; bait species management;

and status surveys of Whale Sharks and other threatened elasmobranchs (ecological studies conducted using state-of-the-art technologies). The life history and biology of threatened, endemic and commercially important fishes with special reference to their egg and larval stages need to be studied.

- **Tridacnidae.** Habitat specialists and long-lived species among these giant clams need to be studied intensively and require continuous monitoring. In 2010, they underwent massive bleaching, as a result of which the entire population, especially in Lakshadweep, was threatened. The factors responsible for bleaching need to be studied immediately.
- **Diseases.** Research into marine wildlife diseases, especially those of mammals, corals and molluscs.

d) Socio-economic and policy-level research

- Economic evaluation—a working model for ecological benefits versus economic benefits in a dynamic marine ecosystem needs to be established on priority basis.
- Impacts of climate change and other economic developments on the demography of coastal communities.
- Determination of socio-economic dependence of user communities on coastal and marine resources. Documentation, promotion and extension of eco-compatible alternate livelihood options. Identification of various stakeholders and assessment of impacts of their activities on ecological resources.
- Gender issues involving resource use and management. Development of empowerment mechanisms and models of community-based institutions involved in resource management.
- Data collection on fishing communities based on fishing villages and Panchayat Raj Institutions (PRIs)
- Baseline data collection on import of banned gear and craft use
- Document and analyse the impacts of infrastructure projects (ports, power plants, etc.) on communities and their livelihoods.

e) Policy-level research

- It is important to have a 'National Policy on Coastal and Marine Environment and Biodiversity'.
- The efficacy of international, national and state policies and legal instruments in managing the resources of coastal and marine environments needs to be assessed.
- Develop a national-level policy for collecting baseline information on communities depending on the resources (including the unorganized sector and allied sectors).
- Mechanism of networking various governmental, non-governmental and communities-based institutions in participatory management of coastal and marine resources.
- Identify various components that need to be part of a national-level policy for restoration and rehabilitation of communities affected by conservation initiatives and recommend such a national-level policy.
- Documentation of successful community-led conservation initiatives and developing indicators to identify the reasons for success
- Identify conflicts between policies at union and state levels for conservation and development and impacts on communities and ecosystems.
- Analyse, evaluate and recommend changes in policies for conservation, considering the impacts on livelihoods in communities (e.g. seven-month ban on trawl-fishing in Odisha)
- Periodic review and analysis of existing policies (based on research and supportive data)
- Undertake a study on the present institutional structure and function (for implementation of policies for marine and coastal biodiversity) and recommend measures for effective institutional re-structuring and functioning.
- Study and identify institutional models (government, non-government and community-led organizations) that can be given responsibility for managing and conserving resources.
- Study the socio-economic impact on communities (especially livelihoods) due to bans on collection of certain species (seaweeds, sea cucumbers).
- Study the livelihood skills of fishing communities (in specific locations) and recommend measures to enhance skills.
- National-level documentation of existing livelihood options for coastal communities, specifically looking at the causes of successes and failures.

f) Development of technology for coastal and marine biodiversity research

- **Development of silviculture technology for endemic and threatened mangrove species:** So far, selected mangroves that are most adaptive have been chosen for mangrove plantation along the coastal areas.

Due to this selection and monoculture of mangroves, the overall biodiversity of their habitat will diminish. Therefore, it is important to develop and practice silviculture to propagate endemic and threatened mangrove species of India and restore more diverse mangrove areas.

- As less than 1% of the microbes are cultivable, their biodiversity is not fully known. Investigators depend upon culture-based techniques to identify them. In the backdrop of advancements in methodology, techniques such as pyro-sequencing are being used to study the diversity at the global level. In India, such studies have to be undertaken to study the biodiversity of microbes.
- **Development of restoration technology for endangered habitats.** Technologies are available for restoring endangered coastal and marine habitats such as sea grass beds, coral reefs, mud flats and sand dunes. However, these technologies need to be reviewed to suit Indian coastal environmental conditions, considering the hydrological and coastal settings of Indian marine ecosystems.
- **Impact of advances in fishing technology on biodiversity.** Fishing is one of the oldest professions, and fishing technology has a long history of evolution. Newer technologies are always aimed at getting more catch with the least regard for biodiversity conservation or sustenance. Therefore, it is important to develop techniques with these concerns and to assess the impact of presently used tools on the overall marine biodiversity.
- **Development of technology to minimize the by-catch:.** Indian fisheries has been witnessing a growing trend in bycatches that may not be desirable for the well-being of the entire marine ecosystem as well as fisheries. Therefore, it is important to develop a suitable fishing technology to minimize the bycatch.
- **Ecological modelling studies include**
 - (1) Determining and predicting the effects on sea turtles and marine mammals of boating activity.
 - (2) Predicting the flow of an inadvertent discharge (such as a fuel spill) into the coastal environment.
 - (3) Modelling the transport of sediment in coastal and marine environments.
 - (4) Estimating the impact of the loss of sea grass beds/kelp habitats/coral reefs on higher trophic levels. Such models are useful for determining effective management strategies.
- **Development of better technology to monitor the benthic and pelagic biodiversity.** Cost-effective technology is required to monitor the benthic and pelagic biodiversity of marine ecosystems, including the deep water benthos, to understand the cascade effect of climate change.
- **Development of technology for facilitating in situ conservation of threatened species** by developing better captive breeding technologies for sea ranching of threatened species such as pipe fishes, holothurians, molluscs, corals, etc. Technology developed by the CMFRI and CASMB for ranching sea horses needs to be adopted in the field at appropriate sites on a larger scale.
- Development of cost-effective technology to monitor the coastal and marine biodiversity of India for a longer period using the latest sensor technologies
- Development of advanced technology to assess the populations of marine organisms such as mammals for long-term conservation
- Technology to monitor sea level changes and topography
- Sensor technology for rising sea level and climate change

g) Monitoring and restoration ecology

Effective monitoring requires an understanding of long-term changes in the status of the resources and their environment. Long-term monitoring is a way of detecting and documenting these changes in environmental quality, ecology and effects of human activity and determining if changes in management strategies are needed. The primary purpose of a monitoring programme will be to detect change, determine its causes, whether natural or anthropogenic, and develop and evaluate management strategies. Overall, the monitoring programme will assist us in our understanding of the general health of coastal and marine ecosystems. A monitoring programme should include pollution monitoring studies and monitoring the population dynamics of species in all marine and coastal habitats. Changes in the relative distribution of these species could indicate natural or anthropogenic pressures on marine biodiversity. Results of the monitoring programme will be useful in basic scientific research as well as in setting academic, educational and applied management goals.

- **Examples of environmental factors to be monitored include:**
 - (1) Status and trends of contaminants in coastal waters.
 - (2) Environmental factors, such as wind, sea level and temperature, collected by coastal stations, offshore data buoys and satellites.

- (3) Changes in the abundance (over various life stages) of invertebrates and fishes.
 - (4) Fluctuations in the abundance of marine mammals, holothurians, turtles and seabird species in coastal and marine ecosystems.
 - (5) Biological impacts of organics and faecal coliforms on these taxa.
- **Certain activities and their effects, both individually and cumulatively, should be monitored. These include**
 - (1) Commercial vessel traffic.
 - (2) Recreational activities.
 - (3) Commercial fishing.
 - (4) Natural and anthropogenic (e.g., sand mining) erosion and sedimentation.
 - (5) Fishery-mammal/turtle interactions, such as incidental catches of dolphins, whales, turtles, etc. in fishing nets.
 - (6) Pesticide/fertilizer runoff.
 - (7) Industrial effluent/domestic sewage discharge.
 - (8) Dredge spoil disposal.
 - (9) Recurring road repair debris side-casting along the coast.
 - Another important component of a monitoring programme is assessment of the effectiveness of management strategies. Once new management strategies have been put in place, usually in response to a detected change in the environment or use of MPAs, monitoring must continue to determine whether the management strategy is having the desired effect or not. In fact, in most cases, each new management strategy will require the design and implementation of specific monitoring activities to augment the long-term monitoring programme envisioned by this plan. Some of the major research gaps which need to be taken up immediately are listed in the following:
 - **Long term monitoring:** Creation of baseline data on physico-chemical, geological and meteorological parameters and primary productivity in ecologically sensitive areas, especially MPAs, sea turtle nesting grounds, estuaries, mangroves, etc. for long-term monitoring. Long-term monitoring of flora and fauna of coastal and marine ecosystems of India with special reference to climate changes, developmental projects in the coastal and marine environment, fishing, pollution, etc.
 - Identification of indicator species for evaluation of efficacy of management intervention in marine ecosystems
 - Identification and establishment of inviolate vegetation preservation plots and coral reef transects for long-term monitoring of biodiversity in different parts of the country, especially MPAs
 - Temporal and spatial distribution patterns of migratory fauna in the coastal and marine environment
 - Identification of foraging and breeding grounds of migratory fauna including determination of migratory paths through the use of advanced technology
 - Monitoring the impact of ballast water release in the seascape
 - Documentation of kinds of fisheries practices and their impacts on habitats and species
 - Long-term monitoring of status and distribution of various threatened and endemic species of marine fauna in Indian territorial waters
 - Long-term monitoring and study of ecology of birds, mammals and other fauna of the southern Indian Ocean and Antarctica as India is one of the signatories of the Antarctic Treaty
 - Studies on restoration of coral reefs in different parts of the country including the coastal areas of Gujarat, Maharashtra, Karnataka, Lakshadweep Islands, Tamil Nadu, Orissa and Andaman & Nicobar Islands
 - Research on restoration of sea grass beds to prevent extinction of several threatened species including the Dugong
 - Studies on restoration of degraded horseshoe crab habitats along the east coast of India
 - Studies on restoration of degraded habitats or lost habitats due to tourism-related activities, especially along the coastal areas of Goa, Maharashtra and Gujarat

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Table 1 : Summary of research gaps in coastal and marine biodiversity conservation in India

Sl. No.	Landscape-/seascape-/ecosystem-level research areas	Habitat-level research on coastal and marine biodiversity	Species-level research on coastal and marine biodiversity	Socio-economic and policy-level research	Development of technology for coastal and marine biodiversity research	Monitoring and restoration of ecology
1	Long term monitoring studies on dynamics of coastal geomorphology	Intertidal mudflats- their ecological significance	Strengthening of taxonomic capacity	Economic evaluation	Development of silviculture technology for endemic and threatened mangrove species	Status and trends of contaminants in coastal waters
2	Assessment/estimation of coastal marine habitat lost in coral reefs, mangroves, sand dunes, mudflats, etc.	Corals	Preparation and implementation of species recovery Plans	Policy-level research	Development of restoration technology for endangered habitats	Environmental factors, such as wind, sea level and temperature
3	Linkages/connectivity among habitats/ ecosystems	Mangroves	Periodic assessment of threatened and endemic species	Documentation of successful community-led conservation initiatives	Impacts of advances in fishing technology on biodiversity	Changes in the abundance (over various life stages) of invertebrates and fishes
4	Study the structurally important elements of ecosystems	Inventory of sea grasses and lesser known mangrove species	Ecological studies of endemic and threatened species of invertebrate and protochordate groups		Development of technologies for minimizing bycatch	Fluctuations in the abundance of the Dugong, holothurians, whales, turtles and seabird species
5	Reduction in freshwater flow and sediment influx	Documentation of biodiversity of intertidal rocky shorelines	Impacts of global warming and climate change		Ecological modelling	Biological input of organics and faecal coliforms
6	Study functionally vital processes in various marine ecosystems	Coastal lagoon ecology and biodiversity	Marine mammals		Development of better technologies for monitoring benthic and pelagic biodiversity	Effects of commercial vessel traffic and recreational activities
7	Bio-shield-enhance species diversity	Habitats of threatened animals	Coastal and oceanic birds		Development of technologies for facilitating in-situ conservation of threatened species	Natural and anthropogenic impacts
8	Climate change and impacts on coastal and marine landscapes	Impacts of coral bleaching on the biodiversity of corals	Ecological studies on marine reptiles			Fishery-mammal/turtle interactions



Sl. No.	Landscape-/seascape-/ecosystem-level research areas	Habitat-level research on coastal and marine biodiversity	Species-level research on coastal and marine biodiversity	Socio-economic and policy-level research	Development of technology for coastal and marine biodiversity research	Monitoring and restoration of ecology
9	Need for research and creation of a gene bank for coastal and marine flora		Long-term monitoring and ecological studies on lesser known fish species			Pesticide usage, sewage discharge, dredge spoil disposal
10	Invasive species		Tridacnidae (giant clams)			Recurring side-casting of road repair debris along the coast
11	Biodiversity of estuaries		Diseases			
12	Identification and conservation of important coastal and marine biodiversity areas of India					
13	Ecological services of coastal and marine habitats/ecosystems					
14	Understand resilience					
15	National-level assessment and specific site-level studies for high-salinity mudflats and halophytes					
16	Experimental studies in estuaries and mangroves					
17	Economic valuation of ecological services					
18	Review and assessment of management effectiveness of MPAs					

