4 Coastal and Marine Ecosystems

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1. Overview of the extent and status of coastal and marine ecosystems in India

Coastal and marine ecosystems are among the most productive ecosystems in the world and provide many services to human society and are of great economic value (UNEP 2006). The services include provisioning of food and water resources, and supporting functions such as climate regulation, water balance, flood control, waste management etc. Wetlands recharge freshwater aquifers, prevent erosion and buffer land from storms. The best available data suggest that substantial positive economic values can be attached to many of the marketed and non-marketed services provided by coastal and marine systems (UNEP 2011a). According to some estimates, the oceans and coastal biomes may provide as much as two-thirds of the ecosystem services that make up the planet's natural capital (TEEB 2010).

People have been using marine and coastal ecosystems for centuries. In recent years, the oceans have become the dumping grounds for unwanted materials including toxic wastes. Because of the multiple benefits provided by the coastal environment for human health, wealth and well-being, demographic pressures on coastal resources started increasing during the last century. Recent anthropogenic interventions on coastal and marine ecosystems are many. Dredging of water ways, filling or draining of waterways, large quantities of nutrients reaching the coastal waters, industrialization of coastal areas, and fisheries are a few important interventions. Today, the degraded condition of many seas and the overall decline in their diversity and productivity threaten our coastal communities and human well-being. Resources have been depleted and have collapsed due to human pressures and climate change (IPCC 2007), with economic and social consequences for humans. However, the coastal and marine systems suffer from both inadequate knowledge and governance in comparison with our knowledge on terrestrial ecosystems and their services.

Though posing challenges in conservation, marine and coastal ecosystems provide immense opportunities for conservation. Marine and coastal natural resources are, for the most part, renewable. If properly managed, they should provide continuing returns into the future without diminishing their productivity.

The main objectives of this report, therefore, are to prepare a toolkit for valuation of coastal and marine ecosystem services. The report will also seek to achieve the following sub-objectives:

- Provide an overview of the techniques used in valuation of coastal and marine ecosystem services; and values based on desktop study.
- Identify gaps in the valuation of coastal and marine ecosystems and services values and techniques.
- Identify potential applications for valuation studies on coastal and marine ecosystem services.

1.1 Extent of ecosystems in India

The most comprehensive scientific assessment of ecosystem services called the Millennium Ecosystem Assessment (MA) was initiated in 2002. In the context of MA, coastal and marine ecosystems include terrestrial ecosystems (e.g., sand dune systems), areas where freshwater and saltwater mix, nearshore coastal areas, and open ocean marine areas. For MA, the coastal and marine realm has been divided into two major sets of systems: (i) marine fisheries systems and inshore coastal systems; and (ii) coastal communities. Marine systems are defined as waters from the low water mark (50m depth) to the high seas; and coastal systems are <50m depth to the coastline and inland from the coastline to a maximum of 100 km or 50-metre elevation (whichever is closer to the sea). The MA defines the coastal zone as a narrower band of terrestrial area dominated by ocean influences of tides and marine aerosols, and defines a marine area where light penetrates throughout (MA Condition and Trends volume, section 19.1; www.MAweb.org).

Surrounded by the Indian Ocean, Arabian Sea and Bay of Bengal, the peninsular India has a coastline of about 8,100 km spanning nine maritime states and two union territories in the mainland, and two island union territories. The Exclusive Economic Zone (EEZ) extends to 2.02 million km^2 and the continental shelf area to 0.18 million km^2. The Indian coasts support about 30% of the total 1.2 billion human population. Considering the climatic, oceanographic and biological settings, the Indian coast and the adjoining Exclusive Economic Zone (EEZ) may be categorized into six major ecosystems, namely, northwest, southwest and Lakshadweep Island ecosystems in the Arabian Sea; and northeast, southeast and Andaman & Nicobar Island ecosystems in the Bay of Bengal (Fig. 4.1).

Figure 4.1. Six major coastal and marine ecological regions of India

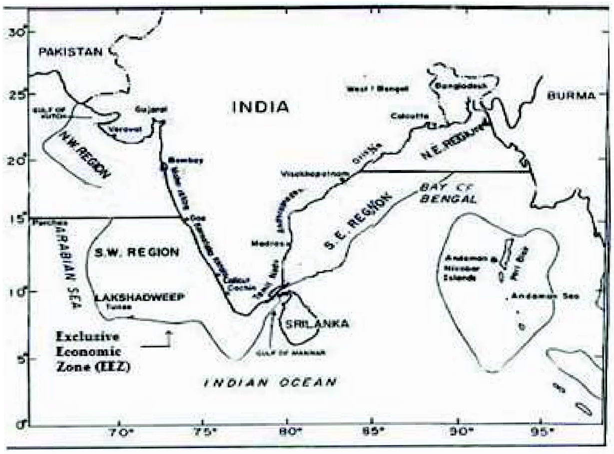


Table 4.1. Extent of coastal ecosystems of India (MoEF 2005)

Coastal ecosystem	Area (km^2)
Tidal/ Mud flats	23,621
Sandy beaches/ bars/ spits	4,210
Mangroves	4,445
Coral reefs	2,375
Estuaries & backwaters	1,711
Salt marshes	1,698
Lagoons	1,564
Other vegetation (including seagrass beds)	1,391
Aquaculture ponds	769
Salt pans	655
Creeks	192
Rocky coasts	177
Total	**42,808**

Indian coastal ecosystems comprising of mudflats, sandy beaches, estuaries, creeks, mangroves, coral reefs, marshes, lagoon, seagrass beds, and sandy and rocky beaches extend to 42,808 km^2 (Table 4.1). They are known for their high biological productivity, which provide a wide range of habitat for many aquatic flora and fauna. The number of species in the coastal and marine ecosystems is suggested to be more than 13,000 (Venkataraman and Wafar 2005; MoEF 2009). However, this is an underestimate considering the fact that the inventory is extensive in the case of commercially important resources, but incomplete for minor phyla and microbes. The species richness of well-surveyed groups include: marine algae - 844 species; sponges - 451 species; hard corals - 218 species; polychaetes - 250 species; crustaceans - 2,934(+) species (Copepoda - 1,925; Cirripeds - 104; Amphipoda - 139; Brachyura - 705; Prawns - 243; Stomatopoda - 121; Cladocera - 3; Ostracoda - 120; Anomura - 162; Lobsters - 26; Mysids - 3); molluscs - 3370; echinoderms - 765; fishes - 1546; reptiles - 35; mammals - 26.

1.2 Status of ecosystems

People are dependent on the coastal and marine ecosystems and their resources for their survival and livelihood. In spite of their ecological and economic importance and existence of a policy and regulatory framework, India's coastal and marine ecosystems are under increasing threat. The major drivers of change and degradation are mainly anthropogenic. 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. Major anthropogenic direct drivers of ecosystem degradation and destruction include habitat conversion to other forms of land use, overexploitation of species and associated destructive harvesting practices, spread of invasive alien species, and the impacts of pollution from agricultural, domestic and industrial effluents. Examples of few anthropogenic pressures are given below:

(i) The coastline of Bay of Bengal and Arabian Sea continues to be rich fishing grounds and India is one of the world's largest marine production nations. Marine fish landings in India has increased consistently in the last 60 years due to expansion of fishing fleet and increase in fishing efficiency. Expansion of fleet and new fishing grounds has helped increase the catches, but overexploitation of few stocks are evident (Srinath *et al.* 2004). Vivekanandan *et al* (2005) detected fishing down marine food web at the rate of 0.04 trophic level per decade in the Indian seas and cautioned fishery-driven changes in the structure and function of ecosystems in the Bay of Bengal and Arabian Sea.

(ii) Increased nutrient loading from agricultural runoff, sewage and fossil fuel burning is causing widespread eutrophication of coastal and marine ecosystems. UNEP (2006) report has indicated that the estimated total reactive nitrogen entering the coastal and marine ecosystems of India increased from 100-250 mg N/km^2/year in the year 1860 to 500-750 mg N/km^2/year in the early 1990s; and this is projected to increase further to about 1000 mg N/km^2/year by the year 2050.

(iii) Evidences are accumulating that climate change is having a growing impact on coastal and marine ecosystems due to increase in extreme weather events, sea level rise, warming of sea surface temperatures and ocean acidification. An extract from the publication of Vivekanandan (2011) shows that (a) the sea surface temperature has increased by 0.2 to 0.3^o C along the Indian coast in the last 45 years, and is projected to increase by 2.0 to 3.5^o C by 2099. (b) The projected sea level rise is 30 cm in 50 years. (c) During the southwest monsoon, the wind speed and coastal upwelling have strengthened, resulting in higher concentration of chlorophyll a along the Kerala coast. These changes are likely to influence the structure and function of marine ecosystems, on which evidences are accumulating. (d) The phytoplankton grow faster at elevated temperature, but the decay sets-in earlier. (e) Species response to elevated temperature is different, showing changes in composition and abundance at the base of the food web. (f) Coral bleaching is likely to be an annual event in the future and model shows that reefs would soon start to decline and become remnant between 2050 and 2060. (g) Mangroves in tropical regions are extremely sensitive to global warming and the extent and composition of mangroves may undergo major changes. Elevated temperature and changes in precipitation and aridity are likely to change the flowering of mangroves. (h) Occurrence of harmful algal blooms seems to have become more frequent, intense and widespread and cause considerable mortality of fish. (i) Among marine fish, the more mobile species should be able to adjust their ranges over time, but less mobile and sedentary species may not. Depending on the species, the area it occupies may expand, shrink or be relocated. This will induce increases, decreases and shifts in the distribution of marine fish, with some areas benefiting while others lose. The distributional and phenological changes may have impact on nature and value of fisheries. If small-sized, low value fish species with rapid turnover of generations are able to cope up with changing climate, they may replace large-sized high value species, which are already showing declining trends due to fishing and other non-climatic factors. Such distributional changes would lead to novel mixes of organisms in a region, leaving species to adjust to new prey, predators, parasites, diseases and competitors, and result in considerable changes in ecosystem structure and function.

(iv) Coastal habitats are also subject to powerful natural weather phenomena, such as tsunami, cyclones, hurricanes and storms.

(v) Indirect drivers of ecosystem change include demographic, socio-political, cultural, economic and technological factors.

1.3 Consolidation of available knowledge and bridging knowledge gaps in India

In a recent report of the Working Group on Ecosystem Resilience, Biodiversity and Sustainable Livelihoods for the XII Five Year Plan, the Planning Commission has consolidated the available knowledge on coastal and marine ecosystems in India and the ways for bridging the knowledge gaps. Salient findings of the Working Group are given below:

1.3.1 Identification of ecosystems of significant marine biodiversity (Planning Commission 2011)

The first step to value marine and coastal ecosystems would be to identify areas of significant marine biodiversity in India, classify them on the basis of research and conservation/ management requirements, record the threats they face, and undertake long-term surveys to document species diversity and trends in populations. The first requirement of such an exercise would be a systematic and exhaustive literature survey followed by a GIS-based mapping of available marine habitats and species in India. This large scale exercise should aim to identify gaps with respect to species, taxonomic groups and sites. The study would facilitate identification of sites in mainland India and help in prioritising sites in the two island systems as well.

1.3.2 Research requirements (Planning Commission 2011)

India has generated extensive checklists of marine species and some amount of information on their distribution and status. Coastal and marine biodiversity and ecosystem research in India has also moved into bar-coding of species and is collaborating in large global projects such as the Census of Marine Life that aims at documenting marine biodiversity. Though these are important baselines, these documents and bar-codes are of little value in undertaking conservation/ management actions. To address the issue of marine biodiversity and ecosystem valuation and conservation, we require a thorough understanding of not only the species richness in a given area, but also of the ecological and ecosystem processes that lead to the observed patterns in diversity. However, such an integrated approach to research on marine biodiversity and ecosystems is generally lacking in India. Research under this theme should focus on the biogeography of marine organisms, ecosystem linkages, and resilience and resistance of species in ecosystems. Conservation and sustainable use of biodiversity requires accurate data in space and time on species occurrence, population trends of species, annual harvest and trade of commercial species, habitat details water pollution etc. For coastal and marine areas, databases and systems developed by the Central Marine Fisheries Research Institute, Indian National Centre for Ocean Information Services, Indian Ocean Census of Marine Life, National Institute of Oceanography, Centre for Marine Living Resources and Ecology and National Institute of Ocean Technology may be used.

1.4 Management of resources

Coastal and marine ecosystems are inseparably linked to the activities on land. Hence, conservation strategies should consider a holistic approach, examining agricultural, industrial and other activities on land whose impacts flow to the rivers and coastal waters and oceans (MARES 2009). For conserving and managing coastal and marine resources and ecosystems, various legislations and acts exist in India (Table 4.2).

Table 4.2. Legislations and acts related to coastal and marine ecosystems

Name	Salient features
Indian Ports Act, 1908	Enactment relating to ports and port charges. Provides for rules for the safety of shipping and conservation of ports
Coast Guard Act, 1950	Provides levying of heavy penalties for the pollution of port waters In 1993, Coast Guard under Ministry of Defence, made directly responsible for combating marine pollution. National Oil Spill Disaster Contingency Plan, formulated in 1996, under Coast Guard Act lays down action to be taken in the event of oil spills
Merchant Shipping Act, 1958	Control of pollution from ships and off-shore platforms
Wildlife Protection Act, 1972	Offers protection to marine biota. Amended in 1991 to prohibit fishing within the sanctuary area in Gahirmatha, the annual mass nesting place for olive ridley turtle, an endangered species; accorded the status of marine sanctuary in 1997. Amended in 2001 to include several species of fish, marine mammals, corals, sea cucumbers and sea shells in Schedule I and III whale shark placed in Schedule I
Water (Prevention and Control of Pollution) Act	Control pollution from land-based sources and has jurisdiction upto 5 km in the sea
Maritime Zones Act, 1976	Describes various zones such as territorial waters, EEZ, Continental shelf etc
Forest Conservation Act, 1980	Includes protection to marine biodiversity
Marine Fishing Regulation Acts, 1981	Aims at sustainable fisheries; implementation initiated by all maritime states and UTs from different years since 1981

Coastal Pollution Control Series, 1982	Aims at assessing the pollution status of coastal waters
Environment Protection Act, 1986	Under this, the Coastal Regulation Zone 1991 has been notified. Standards for discharging effluents are listed
	Regulations on various activities in coastal zone.Classifies coastal zone into four categories specifying activities permitted and prohibited in each category. Offers protection to backwaters and estuaries. Aquaculture was allowed as foreshore activity. In 1996, the Supreme Court banned all aquaculture activities, except traditional and modified traditional, in the coastal zone upto 500m in most places. Aquaculture Authority formed
National Environmental Tribunal Act, 1995	Created to award compensation for damages to persons, property and environment arising from any activity involving hazardous substances
Coastal Zone Management Plans, 1996	Provision for all coastal states to prepare CZMPs
The Biological Diversity Act, 2002	Protect and conserve biodiversity and sustainable use of its components

In addition, India is a signatory to a number of international conventions on biodiversity and ecology such as the UNCLoS and CBD, which include management of marine and coastal ecosystems. India is also a signatory to several international fisheries management instruments such as Ecosystem approach to Fisheries (FAO) and the Indian Ocean Tuna Commission. These commitments have impact on India's management of its natural resources.

Wildlife (Protection) Act, 1972 has listed few coastal and marine species for protection (Table 4.3). The act reviews the status periodically by taking into consideration management measures that are appropriate for marine areas.

Table 4.3. Marine species/groups protected under Wildlife (Protection) Act, 1972

Species/groups	Number
Molluscs (mainly gastropods)	24 species
Whale shark	1 species
Other elasmobranchs	9 species
Grouper fish	1 species
Sea horse	All species
Sea cucumber	All species
Sponges and sea fans	All species
Corals	All species
Turtles	All 5 species
Whales, dolphins & dugong	All 26 species

India has established 31 marine and coastal Protected Areas. The Gulf of Kutch Marine National Park, the Gulf of Mannar National Park and Wandoor Marine National Park are some of the Marine Protected Areas (MPA).

1.5 Understanding economic challenges of changing ecosystems

The four main economic activities in the coastal and marine ecosystems are fisheries and aquaculture, tourism, ports and marine transport, and energy. It is now recognized that future economic development is inextricably linked with environmental and social considerations. This concept is more important in coastal and ocean areas than on land, as linkages among economic sectors, human impacts and all aspects of environmental health are very strong and challenging to manage (IOC 2011). One of the concepts that has emerged in recent years is to develop Green Economy. In its report, IOC (2011) has listed the following key dimensions as the contribution of coastal and marine sectors to the green economy:

(i) protection and restoration of coastal and marine ecosystems and biodiversity, including beyond national jurisdiction; (ii) development of blue carbon markets; (iii) active sea-floor management (including oil, gas and mining); (iv) change in fisheries and aquaculture management regimes toward equitable, non-subsidised and sustainable practices; (v) adaptation to sea level rise and climate change; (vi) integrated coastal zone management; (vii) increasing sustainable use of bio-resources, including biotechnology and bioprospecting; (viii) recognition and adoption of ocean/coastal carbon sinks and create a market for blue carbon trading; (ix) enhanced recycling of major ocean pollutants such as nutrients through market mechanisms; and (x) greater adoption of renewable energy from the ocean.

There are three broad conclusions of the recent UNEP Green Economy study that are relevant to ocean (UNEP 2011b):

a. Greening not only increases wealth over the long term, but also produces a higher rate of GDP growth.
b. There is a clear link between poverty eradication and better protection and restoration of habitat, marine fishery resources and biodiversity.
c. In a transition to a Green Economy, new jobs are created, which over time exceed the losses in jobs in conventional economies.

Moving towards a green economy requires a better understanding of the economic value of coastal and marine ecosystems and biodiversity, as well as contributions of these ecosystem services to societal, cultural and ecological well-being.

2. Prominent examples of the ecosystem types in India

The open seas, coral reefs, mangroves, turtle nesting sites, seagrass beds, salt marshes, mudflats, wetlands, beaches, rocky shores, intertidal habitats, estuaries, deltas and lagoons provide food, water, fuel, recreation, fibre, firewood, habitat, shoreline protection and transportation. They are also important components of nutrients, carbon, water and oxygen cycles.

2.1 Coral Reefs

Coral reefs are shallow water, tropical marine ecosystems, which are characterized by a remarkably high biomass production and a rich fauna and flora. Coral reefs are one of the most productive and complex coastal ecosystems with high biological diversity. The species diversity of coral reefs is perhaps unequaled by any other habitat (www.fao.org/docrep/x5627e/ x5627e06. htm).

2.1.1 Services

The services provided by coral reefs are many. The salient ones are:

- Coral reefs are natural protective barriers against erosion and storm surge.
- The coral animals are highly adapted for capturing plankton from water, thereby capturing nutrients.
- Corals are the largest biogenic calcium carbonate producers.
- They provide substrate for mangroves.
- They provide habitat for a large variety of animals and plants including avifauna.
- They contribute goods and service through tourism.

Reef resources have traditionally been a major source of food for local inhabitants and of major economic value in terms of commercial exploitation. Reefs provide economic security to the communities who live alongside them. In the villages around the Gulf of Mannar, the traditional fishermen have been catching reef fish, diving for pearls, sacred chanks, sea cucumber and sea weeds for centuries. In Lakshadweep, the reefs provide live bait that forms the basis for pole & line fishing for skipjack tuna.

To have an understanding of the human ecology of the coral reef islands, it is important to gain an insight into the relationship between local populations and reef resources. Traditional fishers and people whose livelihood is dependent on the reef perceive reefs as a source of food and revenue. They also perceive the reef as a defense against erosion caused by ocean waves. Mainland communities see reefs as a storehouse of limestone to be extracted for cement and lime industries.

2.1.2 Distribution

In India, major coral reef ecosystems are Gulf of Mannar and Palk Bay (southeast coast), Gulf of Kachchh (northwest coast; which is one of the most northerly reefs in the world; Kelleher *et al.* 1995), Andaman & Nicobar Islands (fringing reefs and a 320 km long barrier reef on the west coast between latitude 10° 26´ N and 13° 40´ N) and Lakshadweep Islands (atolls). The coral reefs in the Indian seas consist of all the three major reef types (atoll, fringing and barrier) and include diverse and extensive reef areas of the Indian Ocean. There are also patches of reef in the inter-tidal areas of the central west coast in Ratnagiri, Malvan and Redi, south of Bombay, Gaveshani Bank and 100 km off Mangalore. Hermatypic corals along the shore are reported from Quilon in Kerala coast to Enayem in Tamilnadu. Corals also occur on the southeast coast between Parangipettai, south of Cuddalore (10°50'N, 79°80'E) and Pondicherry.

The total area of coral reefs in India has been estimated as 2,375 km^2 (Table 4.4). These estimates were calculated from maps developed from IRS LISS II, Landsat TM (bands 2, 3 & 4) and SPOT bands 1, 2 and 3) FCC (DOD & SAC 1997). Recently, the Space Application Centre (SAC), Ahmedabad (SAC 2010) estimated the overall reef area as 3,062.97 km^2, including 521.5 km^2 as lagoons and 157.6 km^2 as coralline shelf interspersed within the system.

Table 4.4. Extent of coral reef area (km^2) in the Indian seas

Category	Gujarat	Tamil Nadu	A & N Islands	Lakshadweep	Total
Reef flat	148.4	64.9	795.7	136.5	1,145.5
Sand over reef	11.8	12.0	73.3	7.3	104.4
Mud over reef	117.1		8.4		125.5
Coralline shelf			45.0	230.9	275.9
Coral heads			17.5	6.8	24.3
Live coral platform				43.3	43.3
Algae	53.8	0.4		0.4	54.6
Seaweeds				0.7	0.7
Seagrass				10.9	10.9
Reef vegetation	112.1	13.3	8.9		134.3
Vegetation over sand	17.0	3.6	10.5	0.4	31.5
Lagoon		0.1		322.8	322.9
Others				101.2	101.2
Total	460.2	94.3	959.3	816.1	2,375.0

The corals in India are from 15 families, 60 genera and >235 species of scleractinian corals from four major reefs of India namely Gulf of Kachchh (45 species, 20 genera; GEC 2010), Lakshadweep (124 species, 34 genera; Jeyabaskaran 2009), Gulf of Mannar and Palk Bay (117 species, 40 genera; Patterson *et al.* 2007). Underwater field mission revealed that the coral reefs of the Andaman Islands are globally significant in terms of diversity. The GOI and UNDP GEF Field Mission reported a total of 235 species of scleractinian (reef building and hermatypic) corals from Andaman group of islands. The Andaman Islands have around 80% of the global coral diversity, suggesting that a final count could reach up to 400 species.

2.1.3 Threats

MoEF (2009) has stated that diverse human activities such as runoff and sedimentation from developmental activities, eutrophication from sewage and agriculture, physical impact of maritime activities, dredging, destructive fishing practices, pollution from industrial sources and oil refineries of anthropogenic disturbances have emerged as threats to the coral reefs. Among natural threats, storms, waves and particularly cyclones are major stresses on corals. The tsunami of 2004 had devastating effect, especially on the corals of Andaman & Nicobar Islands.

Another major challenge for sustainability of coral reefs is warming and acidification of seawater. By establishing relationship between past temperatures and bleaching events, and predicted SST for another 100 years, Vivekanandan *et al* (2009) projected that Indian reefs would soon start to decline in terms of coral cover and appearance. Given the implication that reefs will not be able to sustain catastrophic bleaching events more than three times a decade, reef building corals are likely to disappear as dominant organisms on coral reefs between 2020 and 2040 and the reefs are likely to become remnant between 2030 and 2040 in the Lakshadweep Sea and between 2050 and 2060 in other regions in the Indian seas.

2.1.4 Management

As the reefs were common property, often conflicts in resource use were witnessed. Later, protection of all species of corals under Wildlife (Protection) Act 1972 and declaration of Marine Protected Areas and National Parks (Table 4.5) effectively reduced exploitation of corals. After the implementation of protection measures, the corals reefs are stated to be recovering from their status in the 1960s (MoEF 2009).

Table 4.5. Protection status of coral reef areas

Locality	Status
Gulf of Kachchh	Marine National Park (110 km^2 in 1982)
Gulf of Mannar	Gulf of Mannar Bioreserve
Palk Bay	Collection of coral banned
Andaman Islands	Mahatma Gandhi Marine National Park at Wandoor (234 km^2) and Rani Jhansi Marine National Park at Ritchies Archipelago
Lakshadweep Islands	Collection of corals banned

Coral reef protection and restoration programmes may be initiated in the Indian seas by undertaking the following initiatives (see also Wilkinson 2008):

- There is a continued need to strengthen coral reef monitoring and research in India to reinforce positive recovery trends and rectify particular gaps. Capacity needs strengthening for improving coverage of the vast reef areas in Indian seas. There is also a need for sound data management, analysis and reporting. Broader application of more comprehensive coral reef monitoring approaches, such as the Resilience Assessment methodology developed by the IUCN Climate Change and Coral Reefs Working Group, may be encouraged.
- For protection of coral reefs, Marine Protected Areas (MPAs) have become increasingly prominent. Management of MPAs should be strengthened; management effectiveness has to be reviewed in order to improve management decision making and strategies. The objectives of MPAs are both social and biological, including reef restoration, aesthetics, increased and protected biodiversity, and economic benefits. Conflicts surrounding MPAs involve lack of participation, clashing views and perceptions of effectiveness, and funding.
- Protecting the coral reef resources such as groupers, ornamental fish and crustaceans is essential. Careful management could prevent these from collapsing like many other reef resources elsewhere.
- More genuine and inclusive collaborative approaches in resource management are required. Increased collaboration between government, NGOs, and in particular, the empowerment of communities to participate meaningfully is necessary.

2.2 Mangroves

Mangroves consist of a number of species of trees and shrubs that are adapted to survival in the inter –tidal zone. They are basically land plants growing on sheltered shores, typically on tidal flats, deltas, estuaries, bays, creeks and barrier islands. The best locations are where abundant silt is brought down by rivers or on the backshore of accreting sandy beaches. Their adaptation to salinity stress and to water logged anaerobic mud is high. In size, mangroves range from bushy stands of dwarf mangroves found in Gulf of Kachchh, to 30 m or taller stands found in the Sunderbans.

2.2.1 Services

The mangrove swamps are one of the most productive ecosystems, harbouring a complicated community of animals (Kathiresan 2010). The roots provide a rich substratum for a variety of attached animals, especially barnacles, bivalves and worms. Fish, molluscs and crustaceans find shelter inbetween roots. The branches of trees are evidently habitats of insects, lizards, snakes and birds, including the migratory ones. All the animals depend on the leaves and detritus which when carried by the estuary contribute to the production of organic matter, which is the basic food available to other animals and plants. Plankton and other micro-organisms, which proliferate in the mangroves and the surroundings, are eaten by fishes, prawns, crabs and molluscan larvae. Many of them are commercially important finfish and shellfish. The fertility generated by the mangroves extends to the marine areas. The mangrove forest is also a nursery ground for the juveniles of many important species of finfish and crustaceans. Mangroves for the Future (MFF) has reported that the Indian mangroves support 3985 species that include 919 flora and 3066 fauna. Mangroves play an important role in sediment repository, stabilize shoreline and act as a buffer against storm surges. During cyclones and Asian tsunami 2004, the devastation of coastal areas is reported to be lesser where sufficient mangrove buffers were present.

2.2.2 Distribution

In India, significant mangrove covers are available in Sunderbans (West Bengal), the deltaic regions of Mahanadi of the Bhitarkanika (Orissa), the Krishna and Godavari delta in the Andhra Pradesh, fringing the coast in Andaman and Nicobar islands, on the coral reefs and fringing the mainland in the Gulf of Kachchh, the deltaic regions of Kori creek in Gujarat coast and Pichavarm-Vedaranyam of the Tamil Nadu coast. The mangroves of Sundarbans are the largest single block of tidal holophytic mangroves of the world. The major species of this dense mangrove forest include *Herritiera fames*, *Rhizophora* spp., *Bruguiera* spp., *Ceriops decandra*, *Sonneratia* spp., *Avicennia* spp. and *Nypa fruticans*. The mangroves of Bhitarkanika (Orissa), which is the second largest spread in India, are dense concentration with high genetic diversity. On the west coast of India, mangroves, mostly scrubby and degraded, occur along the intertidal region of estuaries and creeks in Maharashtra, Goa and Karnataka. In Andaman & Nicobar Islands, the small tidal estuaries, neritic inlets and lagoons support a dense, diverse and undisturbed mangrove flora. Compared to the estimate of mangrove spread of the late 1980s (6,740 km^2), the estimate of 4,445 km^2 in the year 2005 shows that the mangroves are fast degrading in the country (MoEF 2005).

2.2.3 Threats

Mangroves provide a life support system and income for people who use them as timber. They are exploited for use as fuel and fodder and the area is converted for coastal development. In general the mangroves are resistant to environmental perturbations and stresses. However, mangrove species are sensitive to excessive siltation or sedimentation, stagnation, surface water impoundment and major oil spills. Salinities high enough to kill mangroves result from reductions in freshwater inflow and alterations in flushing patterns from dams, dredging and bulk heading. Seawalls, bunds and other coastal structures often restrict tidal flow, which is detrimental to the mangroves. It is important to recognize that many of the forces, which detrimentally alter mangroves, have their origin outside the mangrove ecosystem.

Climate change components that affect mangroves include changes in sea-level, high water events, storminess, precipitation, atmospheric CO_2 concentration, ocean circulation patterns, health of functionally linked neighboring ecosystems, as well as human responses to climate change (Ellison and

Stoddard 1991; Clough 1994). Of all the components, relative sea-level rise may be the greatest threat. Sea-level rise submerges the areal roots of the plants, and reduces mangrove sediment surface elevation. Rise in temperature and the direct effects of increased CO_2 levels are likely to increase mangrove productivity, change the timing of flowering and fruiting, and expand the ranges of mangrove species to higher latitudes (Gilman *et al.* 2007). Changes in precipitation and subsequent changes in aridity may affect the distribution of mangroves.

Mangroves in tropical regions are extremely sensitive to global warming because strong temperature dependence of physiological mechanism to temperature places many tropical species near their optimum temperature. The extent and composition of mangroves in India may undergo major changes, depending on the rate of climate change and anthropogenic activities.

2.2.4 Management

To reduce the vulnerability of mangroves and increase resilience, non-climatic stresses such as filling, conversion for other human activities and pollution should be eliminated (Field 1993). To augment mangrove resistance to sea-level rise, activities within the mangrove catchment can be managed to minimize long-term reductions in mangrove sediment elevation, or enhance sediment elevation. Mangrove enhancement (removing stresses that cause their decline) can augment resistance and resilience to climate change, while mangrove restoration (ecological restoration, restoring areas where mangrove habitat previously existed, development of inter-tidal mudflats) can offset anticipated losses from climate change (Field 1993; McLeod and Salm 2006). In India, the large expanse of inter-tidal mudflats (23,621 km^2) may provide a scope of adjustment and adaptation in some areas, mostly in the semi-arid region.

Given uncertainties about future climate change and responses of mangroves and other coastal ecosystems, there is a need to monitor the changes systematically. Outreach and education activities can augment community support for adaptation actions.

The value of mangrove resource in terms of its marketed products can be expressed in economic terms. The “free” services provided by the mangroves are difficult to measure and consequently are often ignored. Since these values are seldom taken into account in the government process, the total value of the mangrove resource is often quite significantly understated. With the purpose of conserving the mangroves, the Coastal Regulation Zone notification (1991) declared total prohibition of developmental activities in the mangrove areas. Afforestation programmes have been initiated in few locations.

2.3 Seagrass beds

Seagrasses are specialised angiosperms that resemble grass in appearance and form dense underwater meadows. They are the only group of higher flowering plants adapted to life in salt water. They occur in shallow nearshore coastal waters upto 8 m depth that are sheltered from high wave energy and in estuaries and lagoons. Seagrasses have key ecological roles in coastal ecosystem and can form extensive meadows supporting high biodiversity. The global species biodiversity is low (< 60 species), but species can have ranges that extend for thousands of kilometers of coastline (Short *et al.* 2007). Major seagrass meadows occur along the southeast coast of Tamil Nadu, in the lagoons of a few Lakshadweep Islands and around Andaman and Nicobar islands. The rich growth of seagrasses along the Gulf of Mannar and Palk Bay coasts and Lakshadweep Islands is mainly due to high salinity, clarity of water and sandy substratum. Seagrasses in India comprise 14 species, dominated by *Cymodocea serrulata, Thalassia hemprichii, Halodule uninervis* and *Halophila* spp.

2.3.1 Services

Seagrass ecosystem provides a sheltered, nutrient rich habitat for diverse flora and fauna. Seagrass beds physically help to reduce wave and current energy, help to filter suspended sediments from water and stabilise bottom sediments to control erosion. They function as stabilizers and sediment accumulators of intertidal and subtidal areas of the coast. They trap nutrients and supply them to the ecosystems. An important phenomenon in seagrass meadows is that they change their own environment, by sediment fixation, or by their capacity to enhance sediment and organic matter trapping (Moriarty and Boon 1989). The habitat complexity within seagrass beds enhances the diversity and abundance of animals. In lagoons wherever seagrass beds are widespread, population of fish and migratory birds is high. Seagrasses on reef flats and near estuaries are nutrient sinks, buffering or filtering nutrient and chemical inputs to the marine environment. They provide a direct source of food for herbivorous animals such as some urchins and fish, green turtles and dugong. The endangered dugong feed exclusively on seagrasses and damage to seagrass beds has direct impact on dugong population. Seagrasses provide nursery and feeding areas for fish, crustaceans, molluscs and other invertebrates, many of which are economically important (e.g., penaeid shrimp, pearl oysters).

2.3.2 Threats

There are several reports of reduction in the spread of seagrass meadows along the Indian coasts. Sridhar *et al* (2010) reported that the seagrass spread in the Palk Bay has reduced (for example, reduction of 785.6 ha area of seagrass meadows in Devipattnam area of Palk Bay) during 1996-2004. Several causes have been attributed for deterioration of seagrass beds. Eutrophication, siltation, trawling, coastal engineering constructions and removal for commercial purposes are the major threats for seagrass beds. Seagrass occurs in shallow water bodies below the low tide line and since water bodies are not brought under regulations, the CRZ notification is ineffective to protect sea grass beds.

2.3.3 Management

In general, seagrass coverage has been observed to remain steady or increase in habitats with relatively pristine environmental conditions, and has declined in areas heavily impacted by overdevelopment of shoreline areas and wetlands. It is important that concerned institutions should actively pursue the goal of managing the seagrass habitats to preserve and restore seagrass coverage to historic levels. Two main focus for improving water quality in the habitats may be addressed to: (i) assist governments in controlling and managing stormwater runoff; and (ii) purchase, and to the extent possible, restore, fringing wetland areas. Water quality for seagrass health has to be improved in the habitats. Improved water quality, over the long-term, is expected to increase the cover and biodiversity within seagrass meadows. Enriching biodiversity within the seagrass meadows will contribute to the economy of the area by enhancing fish stocks, increasing tourism, increasing property values, and potentially creating additional jobs. Outreach and education efforts may be undertaken to improve public awareness and support of seagrass restoration as an effective management strategy.

2.4 Seaweeds

Seaweeds, the larger and visible marine plants, are one of the important sea plants along the Indian coast. They are thalloid plants called algae, which means they have no differentiation of true tissues found in land plants such as roots, stems and leaves. They only have leaf-like appendages. Based on the colour of their pigmentation, seaweeds are broadly classified into different classes and families such as *Cyanophyceae* (bluegreen), *Chlorophyceae* (green), *Phaeophyceae* (brown), *Rhodophyceae* (red) etc. In Indian coast about 770 species of seaweeds are distributed, of this 184 species are green, 166 are brown and 420 are red algae. The maximum of 302 species occur in Gulf of Mannar and Palk Bay (Tamil Nadu), followed by 202 species in Gujarat, 152 in Maharashtra, 89 in Lakshadweep Islands, and 75 in Goa. It is estimated that the total standing stock of seaweeds in India is about 541,340 tonnes (wet weight; Table 4.6) consisting of 6,000 tonnes of agar yielding seaweeds (*Gracilaria* and *Gelidiella*), and 16,000 tonnes of algin yielding seaweeds (*Sargassum* and *Turbinaria*). Extracts of selected seaweed species show antibacterial activity. Iodine yielding seaweed (*Asparagopsis taxiformis*) resources are available in the sub-tidal reefs of Saurashtra coast.

Over-utilization coupled with short supply of seaweeds on one hand, and their loss due to natural calamities like cyclones on the other hand, have prompted cultivation of seaweeds along the Indian coasts. Cultivation conserves the natural resources and improves the elite germplasm. Cultivation technologies for important agarophytes like Gracilaria acerosa and G. edulis, and important carrageenophytes like Hypnea valentiae and Kappaphycus alvarezii have been developed. For the last five years, large-scale cultivation of K. alvarezii has been practiced along Palk Bay in Tamil Nadu coast.

Table 4.6. Standing stock (wet weight in tonnes) of seaweeds in India (modified from Rao and Mantri 2006)

State	Main locality	Standing stock (t)
Gujarat	Gulf of Kachchh	105,720
Maharashtra		20,000
Goa		2,000
Kerala		1,000
Tamil Nadu	Gulf of Mannar	98,120
Andhra Pradesh		7,500
Odisha	Chilika Lake	269,700
Andaman Islands	South Andaman	27,300
Lakshadweep		10,000
Total		541,340

2.4.1 Services

Seaweeds are important as food for humans, feed for animals and fertilizer for plants. Seaweeds are used as drug for goiter treatment, intestinal and stomach disorders. Products like agar-agar and alginates, which are of commercial value, are extracted from seaweeds. By the biodegradation of seaweeds, methane-like economically important gases can be produced in large quantities. Seaweeds are also used as potential indicators of pollution in coastal ecosystem, particularly heavy metal pollution due to their ability to bind and accumulate metals. The seaweed ecosystem provides excellent breeding grounds for marine organisms. Coralline seaweeds provide habitat, refuge and grazing areas for numerous invertebrates and fishes. They form food of herbivorous molluscs and fish. Seaweeds provde three dimensional space in the habitat and provide surfaces for invertebrates to settle and grow, and provide shelters. They modify light penetration, water motion and nutrient recycling, and thereby enhance productivity of the area. Against waves, they provide a dampening effect and thereby shape the environment. They are reported to release chemicals that trigger settlement of invertebrates. They are also effective carbon sequestering agents.

2.4.2 Threats

The major threats to seaweeds are bad water quality, invasive species, overharvest and coastal zone developments. Accumulation of sediments, turbidity, reduction in water clarity; water pollution in the form of chemicals, sewage, fertilizers and nutrient enrichment are threats. Excess removal by herbivores and coastal human populations; reclamation of coastal habitats and shoreline erosion are other threats.

Sea level rise could significantly alter the shape of the coastline and depth distributions near the shore, changing the hydrography of the intertidal and subtidal zones. This in turn would impact seaweed distribution and abundance. In addition, predicted increases in the frequency of storm surges and larger waves could also significantly impact on seaweeds through increased offshore erosion.

2.4.3 Management

Management of seaweeds has received little attention in India. Government actions have been restricted to controlling trade through licensing. Seaweed harvesting is not currently regulated through a specific licensing or permit system. Code of Conduct for environmentally sustainable harvesting of seaweeds needs to be developed and implemented. Sustainable utilization includes conservation efforts to develop seaweed farming and conservation efforts. Associated fauna inadvertently collected with the target species should be returned to the harvested area. Damage and disturbance to the surrounding environment should be minimized. Timetables for commercial harvest of economically important seaweeds based on maturity of the plants should be followed, which may improve sustainability. Several countries have enacted legislation to regulate the harvest.

2.5 Geomorphological coastal ecosystems

The geology of coastal environments provides the underpinning framework on which biological ecosystems exist and interact. Strategic valuation and planning of coastal and marine ecosystems must accommodate a diverse shoreline consisting of a wide variety of marine, coastal landforms and associated geomorphological types (Robbins 1998). Within each of these environments, ecological processes differ, as do the services and anthropogenic impairments. The complex coastal landscapes can be divided into several broad geomorphic systems such as river deltas (fluvial), estuaries, backwaters and lagoons (tidal), beaches (waves), mudflats (tidal and waves), rocky (limited sediment). Each of these systems can be subdivided into distinct coastal landforms that reflect local patterns of sediment accumulation and erosion. The landforms are sand dunes, earth cliffs, sand bars, salt marshes etc (Table 4.7).

Table 4.7. Geomorphological ecosystems of importance (see also MoEF 2005)

Ecosystem	Characteristics	Services	Threats	Management approach
Beaches	Dynamic landforms subjected to erosion/ accretion	Buffer against land erosion; habitats for fauna & flora; turtle nesting; energy base for invertebrates, fish and birds; tourism	Urbanization; industrialization, construction of ports, wharfs, sand mining, dredging	Setback line for coastal constructions; restrictions on dredging & sand mining
Sand dunes	Derived from marine sand delivered to the beach by waves	Sand reserve for coastal protection & stability; helps recharge of freshwater aquifer in coastal areas; habitat for plants and animals	Sand mining; leveling for constructions; unplanned tourism	Setback line for coastal constructions; restrictions on dredging & sand mining
Earth cliffs	Instability and rapid changes due to sea erosion, groundwater, soil binding	Barrier against strong winds and cyclones; establishment of resorts, agriculture	Urban use	Regulations on usage
Rocky cliffs	Composed of hard materials such as sandstone, limestone, granite	Natural barrier against storms; support distinct vegetation; tourism	Mining for minerals	Regulations on usage
Estuaries	Two way flow and mixing of water; tidal range determines the estuarine processes; high productivity	Fisheries value; nutrient transport; spawning, nursery and feeding ground; bivalve beds, site for mangroves; controls salinity and coastal stability by absorbing waves and floods, cleans pollutants by flushing, aquafarming, transportation, saltpans, tourism	Reclamation, pollution, reduction of freshwater discharge from dams, formation of sandbars and siltation restrict entry of tidal water; barriers like dams obstruct migration of fish; overfishing	Control reclamation and release of untreated wastewater discharge; ensure tidal exchange; zonation of users to avoid conflicts
Lagoons	Shallow water body, separated by barriers of sand, but with openings to the sea	Highly productive; migration of species to feed and breed; nursery ground; rich faunal and floral diversity; high detrital composition; ensures coastal stability by absorbing waves and floods, aquaculture site	Reclamation, pollution, reduction in freshwater discharge from dams, dredging	Control reclamation and release of untreated wastewater discharge; ensure tidal exchange; zonation of users to avoid conflicts

Ecosystem	Characteristics	Services	Threats	Management approach
Deltaic areas	Piling up of carried sediments from rivers at the river mouth	Fertile soil, highly productive, large agricultural settlements, barriers to tide & wave actions, sites for mangroves, human settlements	Reclamation, flooding	Zonation of multiple users, ensure sufficient drainage and tidal flow
Salt marshes	Natural or semi-natural halophytic grassland on the alluvial sediment bordering saline waterbodies	Very productive; source of minerals and plant materials, detritus contribute to fertility	Pollution; reclamation	Control reclamation and release of untreated wastewater discharge
Islands	Two major island chains, Lakshadweep (coral atolls; 36 islands, 10 inhabited) and Andaman & Nicobar (mostly forests & hills; 325 islands, 38 inhabited)	Rich and unique biodiversity, tourism and fisheries are of importance	Pollution, reclamation, human settlements	Integrated Coastal Zone Management approach

2.5.1 Mudflats

Mudflats, also known as tidal flats, are coastal wetlands that form when mud is deposited by tides or rivers. They are found in sheltered areas such as bays, lagoons and estuaries. Mudflats may be viewed geologically as exposed layers of bay mud, resulting from deposition of estuarine silts, clays and marine animal detritus. The tidal flats have typical tripartition, namely, supratidal, intertidal and subtidal zones. Most of the sediments in a mudflat is within the intertidal zone, and thus the flat is submerged and exposed approximately twice daily. Great Rann of Kutch (18,000 km^2) and Little Rann (5,100 km^2) in Gujarat are large and typical tidal flats in India. In the past tidal flats were considered unhealthy, economically unimportant areas and were often dredged and developed into agricultural land. Even now, most mudflats in India are listed as wastelands in revenue records. According to the Indian Naval Hydrographic Department's data, the mainland coast consists of 46% mudflats, 43% sandy beaches and 11% rocky coast including cliffs.

Tidal flats, along with intertidal salt marshes and mangrove forests act as flood plains, controlling floods. In areas where the mudflats are deep and stable, salt marshes and mangrove swamps are formed, which are important biologically. They usually support a large population of wildlife, although levels of biodiversity are not particularly high. They are of vital importance to migratory birds, as well as certain species of crabs, molluscs and fish. The soft sediments are a vital part of the coastal ecosystem and provide a number of ecosystem services, namely, primary and secondary production, nursery and habitat for finfish and shellfish, and interception and uptake of nutrients and contaminants from watershed drainage. The maintenance of mudflats is important in preventing coastal erosion.

Intertidal biodiversity is a measure of environmental quality, as sentinel species like bivalves provide a warning of environmental pollution. Seaweeds and several bivalves and crabs in the intertidal areas contribute to the income of dependent human population. The value of intertidal aquaculture is well known. However, mudflats worldwide are under threat from sea level rise, land claims for development, dredging due to shipping purposes, and chemical pollution.

2.5.2 Estuaries

Estuaries, the transitional zones between river and sea, have specific ecological properties and biological composition. They have extremely variable salinity, ranging from 0.5 ppt to 35 ppt. In general, they are very productive and the reasons for high productivity are (ICAR 2011): (i) abundance of autotrophs (phytoplankton, benthic algae and mangroves), which ensures maximum utilization of sunlight for organic production. This organic matter is used as a source of energy by all heterotrophs. (ii) As tidal currents cause turbulence, oxygen content is higher than other natural waterbodies. (iii) Due to rich biological activity of primary consumers (zoo-benthos and zooplankton), the nutrients are rapidly regenerated and conserved. (iv) Large quantities of organic detritus are deposited from surrounding intertidal wetlands. Estuaries are called "nutrient traps" as they conserve large quantities of nutrients from freshwater discharge and land drainage. (v) Several estuaries are bordered by mangroves. It is reported that the mangrove swamps of Sunderbans produce organic detritus of 8 tonnes/ha/year.

The total estuarine and brackishwater area of India is 3.9 million ha and 3.5 million ha, respectively. All the maritime states in the country have major estuarine and backwater systems (Table 4.8).

Table 4.8. Profile of major estuarine systems in India

Estuarine system	Area	Annual flow	Tide	Remarks
Hooghly-Matla (West Bengal)	8,029 km^2	142.6 billion m^3	Highwater elevation: 5.7 m; tidal regime: 200 km	Gangetic delta, the Sunderbans, the world's largest delta and mangrove vegetation; river Ganges deposits 616x10^6 suspended solids
Chilika lake (Odisha)	906-1165 km^2			Mahanadi deposits 10 million tonnes of silt/year
Mahanadi (Odisha)	300 km^2	66,640 million m^3	Tidal regime: 42 km	Rich mangrove canopy
Godavari (Andhra Pradesh)	180 km^2		Tidal regime: 45 km	Coringa mangrove swamp
Krishna (Andhra Pradesh)	320 km^2		Tidal regime: 22 km	
Pulicat lake (Tamil Nadu)	350km^2		Tidal regime: 6 to 10 km	Average depth reduced in last 40 years
Muthupet (Tamil Nadu)	200 km^2			One of the tributaries of river Cauvery
Vembanad lake (Kerala)	250 km^2	10,348 million m^3 during monsoon	Wetland extent: 96 km	Ramsar site
Nethravathi (Karnataka)	11 km^2		Tidal regime: 19 km	
Mandove-Zuari (Goa)	120 km^2			
Narmada (Gujarat)	142 km^2			

2.5.3 Marine Protected Areas

According to the third national report of the MoEF to the CBD in 2006, there are 31 Marine & Coastal Protected Areas, 18 of which are fully under marine environment, and the other 13 are partly also on land (MoEF 2009). These PAs have been notified either as national parks or wildlife sanctuaries, mainly under the Wildlife Protection Act. They cover an area of 6,271km^2, or 4% of the total area under protection. The list of marine protected areas is available in the publications of Singh (2002), Rajagopalan (2008) and Wildlife Institute of India (2008). However, the list is conflicting between these publications. The number of MPAs identified depends on how MPAs are defined.

The Wildlife Protection Act restricts entry into a sanctuary and national park, except certain specified categories, such as those permitted by the Chief Wildlife Warden, or those who have immovable property within the limits of the sanctuary. In the case of a national park, there is no provision to allow the continuance of any right of any person in, or over, any land within its limits. The Act also states that "no person shall destroy, exploit or remove any wildlife from a sanctuary or destroy or damage the habitat of any wild animal or deprive any wild animal or its habitat within such a sanctuary…". On the other hand, biosphere reserves are not legally a PA category, but are an important entity since they are formed by a Central government notification under the UNESCO-MAB programme.

Sanctuaries and national parks are thus primarily no-commercial extractive-use zones, though there are differences between them (Rajagopalan 2008); the highest degree of protection is accorded to national parks where no human interference is permitted, except those beneficial to conservation. In the case of sanctuaries, certain rights may be permitted by the District Collector in consultation with the Chief Wildlife Warden. Thus, while grazing and fishing are completely banned in national parks, in wildlife sanctuaries, grazing and fishing may be regulated, controlled or prohibited. In the case of national parks, the focus is on conserving the habitat of a species, allowing no human activity except tourism, and providing the highest degree of protection. In sanctuaries, the focus is on conservation of a species, with provisions for allowing traditional activities practiced for non-commercial purposes.

In India, the benefits and values of MPAs have not been assessed. There is a need to value and assess the benefits accrued to validate the gains, if any, and to make suitable amendments to the existing and potential MPAs.

3. Ecosystem Services

As mentioned in earlier Sections, coastal and marine ecosystems provide many services to human society, including food and other goods, shoreline protection, water quality maintenance, waste treatment, support of tourism and other cultural benefits, and maintenance of the basic life support systems. Millennium Ecosystem Analysis has conceptualized the ecosystem services framework as (Table 4.9): (i) provisioning services such as supply of food, fuel wood, energy resources, natural products, and bioprospecting; (ii) regulating services, such as shoreline stabilization, flood prevention, storm protection, climate regulation, hydrological services, nutrient regulation, carbon sequestration, detoxification of polluted waters, and waste disposal; (iii) cultural and recreational services such as culture, tourism, and recreation; and (iv) supporting services such as habitat provision, nutrient cycling, primary productivity, and soil formation (UNEP, 2006). These services are of high value not only to local communities living in the coastal zone but also to national economy and trade.

Considering the framework suggested by the MA, the marine and coastal habitats provide at least 16 services to human society (Table 4.10).

Table 4.9. Ecosystem services framework conceptualized by Millennium Ecosystem Analysis

Type of service	Description	Examples
Provisioning	Direct services and consumption goods	Production of food, timber and water
Regulating	Modulates environment	Control of climate, floods, waste, water quality and disease
Cultural and Recreational	Recreational, aesthetic, and spiritual benefits	Religious or tourism services
Supporting	Services that enable the maintenance and delivery of other services, habitat provision	Soil formation, photo-synthesis, nutrient cycles and crop pollination
Other services: “carrying” or “preserving” services, which includes insurance against uncertainty by maintenance of diversity		

Table 4.10. Ecosystem services provided by different coastal and marine habitats (see also UNEP 2006)

Services	Estuaries	Mangroves	Lagoons	Intertidal	Seagrass & Seaweeds	Mudflats	Rocky reefs	Coral reefs	Inshore region	Oceanic
Provisioning services										
Food	√	√	√	√	√	√	√	√	√	√
Fibre, timber, fuel	√	√	√						√	√
Bioprospecting	√	√	√		√				√	
Biological regulations	√	√	√	√	√	√		√		
Regulating services										
Freshwater storage & balance	√									
Climate regulation	√	√							√	√
Human disease control										
Waste processing	√	√	√		√	√		√	√	
Flood & storm protection	√	√	√	√		√	√	√	√	
Erosion control	√	√	√				√	√		
Cultural and Recreational services										
Cultural	√	√	√	√	√	√	√	√	√	
Recreational	√	√	√	√			√	√		
Aesthetics	√	√						√		
Supporting services										
Education & Research	√	√	√	√	√	√	√	√	√	√
Biochemical	√	√						√		
Nutrient recycling	√	√	√	√	√	√	√	√	√	√

3.1 Provisioning Services

Provisioning services are the products people obtain from ecosystems, such as food, fuel, timber, fibre, building materials, medicines, genetic and ornamental resources.

3.1.1 Fisheries

Food provisioning in the form of fisheries catch is one of the most important services derived from all coastal and marine ecosystems. For example, mangroves are important in supporting fisheries due to their function as fish nurseries. Fisheries yields in waters adjacent to mangroves tend to be high. Coral reef-based fisheries are also valuable, as they are an important source of fisheries products for domestic and export markets. Other ecosystems such as rocky intertidal, nearshore mudflats, deltas, seagrass and seaweed beds also provide habitat to fish populations.

In India, marine fisheries contribute to nutritional security, livelihood and income generation to a large population. Marine fish landings in India consistently increased from 0.6 million tonnes (Mt) in 1961 to 3.6 Mt in 2011 (Fig. 4.2). This is different from the global trend, which showed stagnation of marine fish landings at around 90 Mt since 1995 (FAO 2010). Increase in marine fish production in India was possible as fishing extended to new offshore grounds. India has established an extensive infrastructure in marine fisheries and a large population is employed in the marine fisheries sector (Table 4.11). Census 2010 shows that 1.67 million fishermen are employed in the subsistence and industrial fishing sectors of the country.

Figure. 4.2. Estimated marine fish catch along Indian coast during 1961-2011

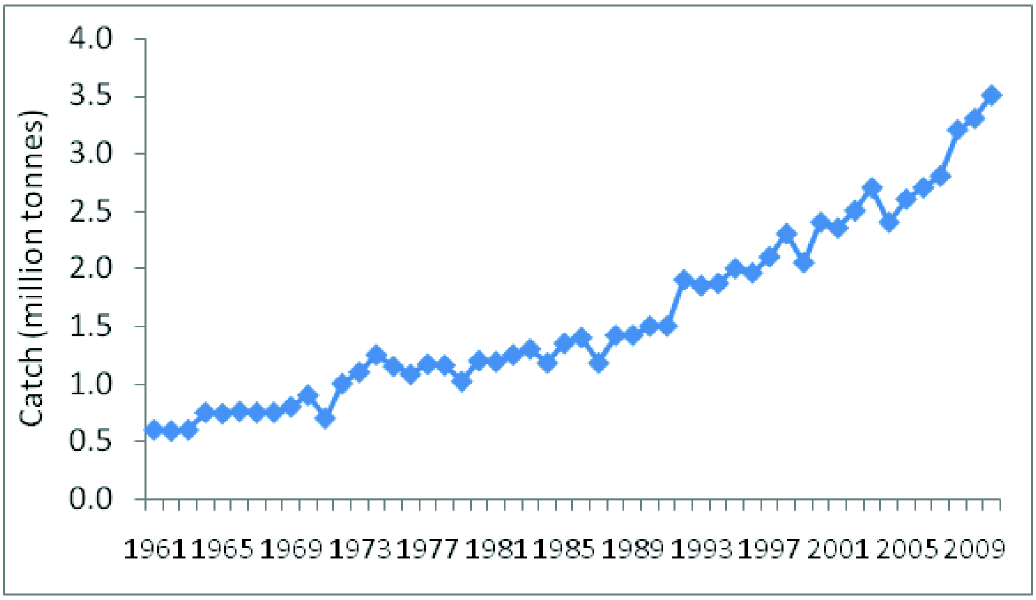


Table 4.11. Profile of Indian marine fisheries in the year 2010 (CMFRI 2012)

Attributes	Number
Marine fishing villages	3,288
Marine fish landing centres	1,511
Marine fishermen households	864,550
Families below poverty line	61%
Fishermen engaged in fishing	990,083
Fishermen engaged in allied activities	675,259
Mechanised boats (inboard engine)	72,559
Motorised boats (outboard engine)	71,313
Non-motorised boats	50,618

The marine fisheries sector witnessed rapid expansion of fishing fleet in the last 50 years. The number of mechanized boats (overall length: 10 to 17 m) with inboard engine increased from 6,708 in the year 1961 to 72,559 in the year 2010; in addition to this, the motorized boats (overall length: 5 to 7 m) with outboard engine, which were introduced in the mid-1980s, increased to 71,313 in the year 2010 (CMFRI 2012). Fishing has thus transformed from a subsistence level to the status of a multicrore industry. However, traditional subsistence fishing, by operating small non-motorised boats, still exists.

In India, the coastal biome (< 100 m depth) produces approximately 80% (in the year 2011) of the marine catches. The coastal biome is also the most impacted by human activities. Besides a source of food and nutrition, germplasm resources are important source of various products of pharamaceutical and commercial value and other trades like ornamental fish. It is recorded that 1,368 species of marine finfish occur in the Indian seas, of which, more than 250 species are food fishes and another 200 are of ornamental value. In addition, about 175 species of crustaceans and molluscs contribute to fisheries in one region or the other along the coast. A bottom trawl haul of one hour, on an average, consists of 40 species of finfish, shellfish and other non-edible biota.

In spite of its importance and increasing catches, the sector faces the following sustainability issues (Vivekanandan 2011): (i) The annual harvestable potential yield from the Indian EEZ is 3.9 mt (DAHDF 2000). As the production (3.6 mt in 2011) is approaching the potential yield, the country has reached a stage in which further increase in production may have to be viewed with caution. It would be difficult to achieve goals related to sustainability if more fish are continuously removed. (ii) The population depending directly on fishing is very great in India and there may not be any quick solution to the problem of overcrowding. At present, only 12% of fishermen are educated at secondary level of school education (CMFRI 2012). Relocating a large number of fishermen with alternate employment is possible only by providing them higher education for highly skilled jobs and improve their societal status. This would be a long-term process. (iii) Fishing has extended to deeper waters as well into new geographical areas. At present, overcapacity is an issue in capital-intensive mechanised fishing sector as well as in the employment-oriented motorised sector. However, the effect of overcapacity of fleet and overfishing of coastal fish populations has been masked by increased landings of additional resources from distant water fishing grounds. (iv) Fishing remains, to a large extent, as regulated open access. In spite of promulgation of Marine Fishing Regulation Acts by maritime state governments, licensing of craft, mesh size regulation, catch declaration, ceiling on number and efficiency of fishing craft, monitoring, control and surveillance of fishing vessels remain as issues. Consequently, entry barriers and capacity controls are ineffective or are absent. The situation exerts fish resources under pressure. The major dilemma is that if access to fisheries resources is restricted, it would affect livelihoods of coastal communities, while if the access is open, the resources will sooner or later decline beyond recovery. (v) The demand for niche seafood products is increasing in international markets. Shark fins and tuna sashimi are some examples. These market-driven fishing activities are changing the face of India from a coastal fishing nation to that of ocean fishing nation. This would exert pressure on oceanic fish stocks, which are highly vulnerable to fishing. (vi) One of the often-ignored factors that causes degradation of environment and depletion of fish stocks is the anthropogenic interference other than fishing. The man-induced alteration of the physical, chemical, biological and radiological integrity of air, water, soil and other media is causing irreversible damage to several fish stocks. (vii) Evidences are accumulating in the Indian seas on the impact of climate change on marine fisheries. Long-term climate change will affect the ocean environment and its capacity to sustain fishery stocks and is likely to exacerbate the stress on marine fish stocks.

The different types of craft use a wide variety of gear types such as trawls, gillnets, seines, lines etc, thereby operating at least 25 major craft-gear combinations. The economics of fishing operation of these combinations differ between each other, which has been monitored from time-to-time for majority of operations (for example, Narayanakumar *et al.* 2009). Similarly, data on the market price of different fish types at landing centres, and at wholesale and retail markets has been collected regularly by Central Marine Fisheries Research Institute (for example, Sathiadhas *et al.* 2011). During 2010, the gross revenue from the catch of 3.2 million tonnes at the point of first sales (landing centre) was estimated as Rs. 19,753 crores (= $ 4.39 billion), and at the point of last sales (retail market) as Rs. 28,511 crores (= $ 6.33 billion) (CMFRI 2011). The estimated gross private investment on fishing equipment (boats) was Rs. 15,496 crores (= $ 3.44 billion). The export of marine products from India was 813,091 tonnes, valued at Rs. 12,901 crores (= $ 2.86 billion) during 2010-11. The sector contributes around 1% to the GDP of the country and 5.8% to the agricultural GDP.

However, the value of fishing and fish price are not the same as the value of fish. In other words, the economic value of a fishing day does not directly address the question of fish resource value. Availability and quality of fish, and the cost of fishing are related to the value of fishing. The value of a particular fish stock or of a prospective change in fish abundance can be estimated in terms of (i) willingness to pay for enhanced fishing opportunities, or (ii) willingness to accept compensation for diminished fishing opportunities.

3.1.2 Aquaculture

Growth in demand for fish as a food source is being met in part by aquaculture. Aquaculture is growing more rapidly than all other animal food-producing sectors. Demands for coastal and brackishwater aquaculture have been on the rise. Brackishwater shrimps *Penaeus monodon* and *Penaeus vannamei*, and the fish *Lates calcarifer* contribute to brackishwater aquaculture in India. The area under shrimp farming is about 100,000 ha (in 2009) and annual shrimp production is 80,000 tonnes. Export has major influence on aquaculture, especially for shrimps. India is one of the leading producers and exporters of shrimps from aquaculture. Farmed shrimps contribute about 42% to the total value of marine products export from the country. However, in the last ten years, shrimp production is stagnant due to issues concerned with viral diseases and environment.

Coastal waters provide the foundation for mariculture. Farming of marine mussels, namely, *Perna viridis* and *P. indica* has become popular among coastal communities of Kerala, Karnataka and Goa, from where about 17,000 tonnes are produced annually. India has the potential for farming of other bivalves such as clams, cockles and pearl oysters; gastropods such as abalone; crustaceans such as sandlobster and rocklobsters. In the last five years, farming of the seaweed *Kappaphycus alvarezii* has become popular among the coastal communities in the Palk Bay and Gulf of Mannar in the southeast coast.

Open sea cage culture has been initiated in the country in the last four years. The high-value Asian seabass *Lates calcarifer*, the cobia *Rachycentron canadum* and silver pompano *Trachinotus blochii* are used as candidates for cage culture. It has the potential to expand in future in the coastal areas of India.

3.1.3 Bioprospecting

Bioprospecting (the exploration of biodiversity for new biological resources of social and economic value) has yielded numerous products derived from species in coastal and marine ecosystems (for example, antibiotics, antifreeze, fibre optics, and antifouling paints). Coral reefs are exceptional reservoirs of natural bioactive products, many of which exhibit structural features not found in terrestrial natural products. Mangrove forests are good reservoirs for medicinal plants. The pharmaceutical industry has discovered several potentially useful substances, such as cytotoxicity (useful for anti-cancer drugs) among sponges, jellyfish and starfish. Cone shells of the molluscan family and sea snake venom are highly prized for their highly variable toxins. This exciting opportunity of bioprospecting is in its infancy in India. CMFRI has recently developed extracts from green mussel and seaweeds, which are reported to relieve pains from arthritis.

3.1.4 Provisioning building materials

Many marine and coastal ecosystems provide coastal communities with construction materials (such as lime for use in mortar and cement) and other building materials from the mining of coral reefs. Mangroves provide coastal and island communities with building materials for boat construction. To discourage exploiting the corals and mangroves for these purposes, the existence of alternative materials should be informed to the communities.

3.2 Regulating services

Regulating services are the benefits people obtain from regulation of ecosystem processes, including air quality maintenance, climate regulation, erosion control, regulation of human diseases, and water purification, among others (UNEP 2006). Ecosystems such as mangroves, seagrass, rocky intertidal, nearshore mudflats, and deltas play a key role in shoreline stabilization, protection from floods and soil erosion, processing pollutants, stabilizing land in the face of changing sea level by trapping sediments, and buffering land from storms (Table 4.10). Mangroves and coral reefs buffer land from waves and storms and prevent beach erosion. Estuaries and marshes prevent beach erosion and filter water of pollutants. Seagrasses play a notable role in trapping sediments (acting as sediment reserves) and stabilizing shorelines.

Marine ecosystems play significant roles in climate regulation. CO_2 is continuously exchanged between the atmosphere and ocean and is then transported to the deep ocean. Mixing of surface and deeper waters is a slow process, allowing increased uptake of CO_2 from the atmosphere over decades to centuries. Phytoplankton fix CO_2 by photosynthesis and return it via respiration. A case study of the Paracas National Reserve, Peru valued carbon sequestration by phytoplankton as $181,124 per year (UNDP 2009).

3.3 Cultural and Recreational services

Cultural services encompass tourism and recreation; aesthetic and spiritual services; traditional knowledge; and educational and research services. Among the most important services provided by the coastal and marine ecosystems are tourism and recreation. Beautiful landscaping, scenic beauty and biodiversity play key roles in promoting tourism along the Indian coasts, especially in the islands. Beaches and estuaries provide numerous recreational opportunities and represent significant economic value. Rapid and uncontrolled tourism growth can be a major cause of ecosystem degradation and destruction, and can lead to loss of cultural diversity. In addition, there are numerous religious and spiritual values that are associated with coastal and marine ecosystems. These relate to both fishing communities as well others who may be not directly involved for their livelihood on these systems such as rituals of birth and death to idol immersion.

3.4 Supporting services

Supporting services include provision of habitats, primary productivity, nutrient cycling, and soil formation.

3.4.1 Provision of habitats

A large number of marine species use coastal areas, especially estuaries, mangroves, coral reefs seaweeds and seagrasses as habitats and nurseries.

Estuaries provide habitat, feeding and breeding grounds for shellfishes and finfishes of commercial and ecological value. They are particularly known for rich bivalve beds and mangrove forests. They are sites of nutrient transport. They control salinity and provide coastal stability by absorbing waves and floods, and clean pollutants by flushing. They support transportation, saltpans, tourism and aquafarms.

The support services provided by mudflats, mangroves, coral reefs, seagrasses and seaweeds are mentioned elsewhere in this chapter.

3.4.2 Primary productivity

Primary productivity is the amount of production of living organic material through photosynthesis by plants, including algae, measured over a period of time. Marine and coastal ecosystems play an important role in photosynthesis and productivity of the systems. Marine plants (phytoplankton) fix CO_2 in the ocean (photosynthesis) and return it via respiration. The primary productivity is the driver that determines the energy flow and biomass of the ecosystems.

3.4.2 Nutrient cycling

One of the most important processes occurring within estuarine environment is the mixing of nutrients from upstream as well as from tidal sources, making estuaries one of the most fertile coastal environments. Mangroves and saltmarshes play a key role together in cycling nutrients. Beaches and sandy shores are important in the delivery of land-based nutrients to the nearshore coastal ecosystem.

3.4.3 Education and research

Marine and coastal ecosystems are areas that have received attention through education and research. Education and research on these ecosystems in India has improved our knowledge on ecosystem dynamics, prey-predator interactions, biological regulations, bioprospecting and fisheries and aquaculture potential. Applied multidisciplinary research on ecosystem function, sustainable yields, and economic valuation of coastal ecosystems is needed. Adequate funding needs to be allocated for education and research on coastal and marine ecosystems.

4. Key issues for conservation of ecosystem services and biodiversity

A number of emerging issues continue to threaten or does not allow rapid progress towards sustainable development of coastal and marine ecosystems. Some of them are:

- Direct dependence of a large poor population on coastal and marine ecosystem services and biodiversity;
- Lack of integration of concerns about ecosystem services and poverty, and the lack of attention on poverty reduction through sound management of ecosystem services;
- Increased nutrient over-enrichment and eutrophication, contributing to pollution, hypoxia and habitat degradation;

- Non-utilisation of ocean-based renewable energy despite proven technological advancements;
- Continuing threats to coral reefs and other major ecosystems from ocean acidification, warming, pollution, habitat loss, and invasive species;
- Barriers to implementation due to other political and administrative priorities, insufficient institutional and scientific understanding of the mechanism and capacity, market issues, lack of financing and unwillingness of stakeholder communities.

5. Current state of art on valuation of ecosystem services and biodiversity

5.1 Global eco-system research: A select summary

The Millennium Ecosystem Analysis provided a framework for classification of ecosystem services, and their relation to human well being. The MA recorded the deterioration of the ecosystem services despite their importance to human wellbeing. It noted that one of the contributing factors for this deterioration was the inadequate use of ecosystem service values in policy decision-making. The TEEB assessment which followed in 2008 was a natural successor of the MA. TEEB made a significant extension of the MA framework by focusing on biodiversity and relating it with ecosystems services (Kumar, 2010).

The literature on ecological philosophy has classified environmental values as (NRC 2004):

(1) instrumental and intrinsic values,

(2) anthropocentric and biocentric (or ecocentric) values, and

(3) utilitarian and deontological values

5.2 Resource valuation methods

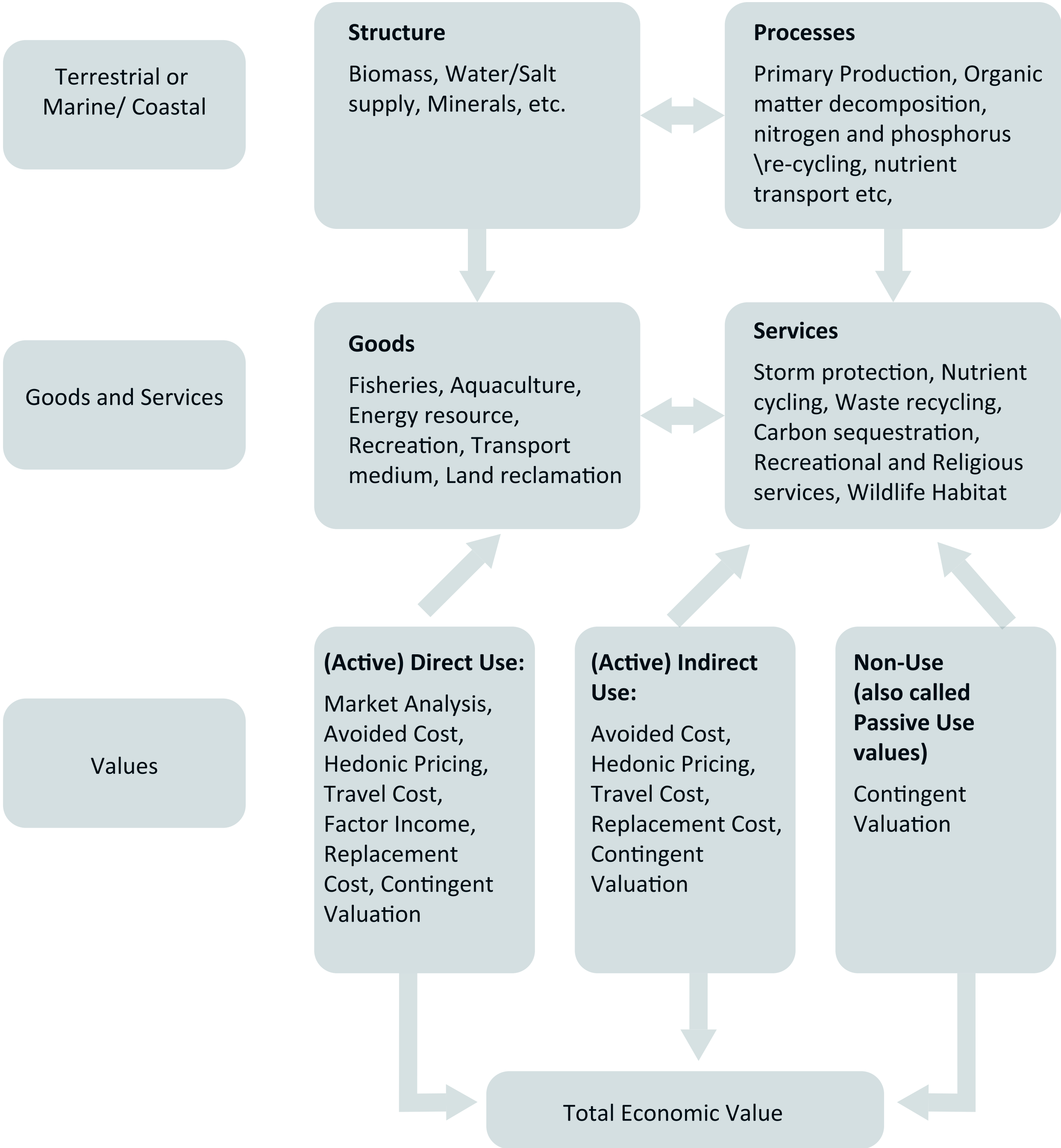
5.2.1 Revealed Preference Method (actual measurements)

Resource valuation is the process of assigning a numeric value, usually monetary, to a natural resource. . There is ongoing debate among economists on how to achieve this but there are two broad schools of thought on the valuation methods in natural resource accounting. One school proposes an 'energy theory of value' while the other proposes the standard neoclassical theory of value (Farber *et al.* 2002). The energy theory of value is based on the principles of thermodynamics and considers solar energy as the only "primary" input to the global ecosystem (Georgescu-Roegen, 1971). The intellectual roots of such a proposition in economics can be found in the Smith-Ricardo-Marx-Sraffa tradition which sought to explain true price or value in terms of labour input into a commodity. They considered labour as the "primary" input in production and proposed values that were production-based rather than exchange-based. In addition to the other long standing debated issues with their neo-classical counter-parts, ecological economists have argued that labour cannot be treated as a primary input. It is only energy that is the truly "basic" commodity and scarce factor of production and therefore their argument is that the theory of valuation must be based on the laws of thermodynamics. The problem that arises with this framework is the difficulty in empirical implementation. This is probably one reason why there are fewer empirical studies using the entropy method (Gowdy and Erickson, 2005).

The neoclassical school on the other hand relies on a marginalist framework which is more amenable for empirical enquiry (Pearce 2002). It attempts to value changes in welfare (or some indicator of it) with respect to small changes in environmental resources/ attributes (Turner *et al.* 1993). However, the valuation of a resource in the presence of (i) limited information, (ii) thresholds and (iii) irreversibility, needs careful consideration (Dasgupta, 2008).

We will present the major techniques used in ecosystem service valuation and present the Total Economic Value (TEV) framework which has emerged as an over-arching framework for resource valuation (Krutilla and Fisher 1975; Pearce and Turner 1990). The logic of TEV is that resources have multiple "use" (direct and indirect) and "non-use" benefits.

Figure 4.3. Schematic of Valuation Techniques and Ecosystem Services (adapted from Farber et al. 2002)



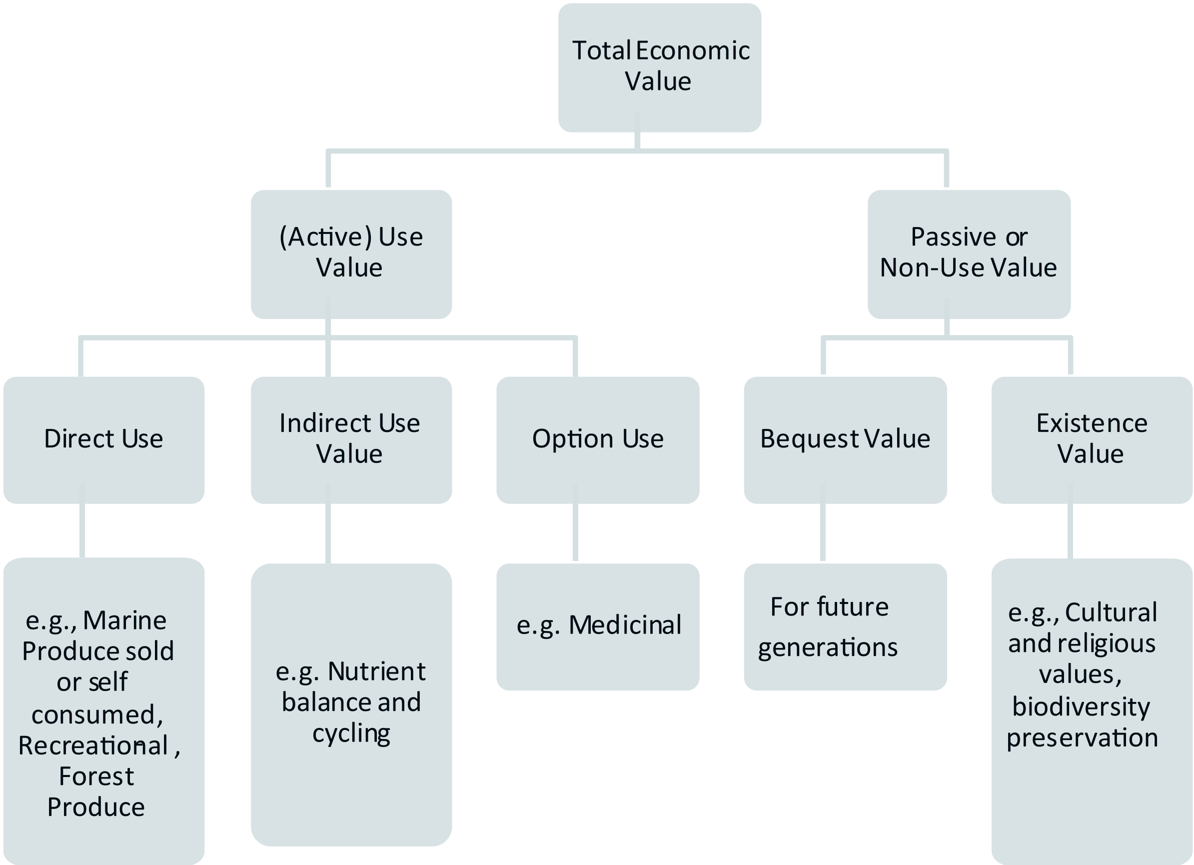
If all these items could be added up then we would arrive at a composite value for one or more natural resources (Fig. 4.3).

Fig. 4.4 provides a schematic for the mechanism to start with the ecosystem and the processes embodied in the system and generate the services.

5.2.2 Market-based valuation methods

Market-based valuation methods rely on market prices to evaluate the flow of resources and also existing stocks. These methods use actual market prices as an indicator of the true value of a resource. Here, willingness-to-pay (WTP) is taken to be equal

Figure 4.4. TEV Schematic diagram (adapted from Beaumont et al. 2006)



to market price. In Gross National Product (GNP) accounting for environmental services, we would include the value obtained from the product of the market price and quantity (Costanza *et al.*, 1997). Since this requires the ecosystem services to have a market price, it implies that this is a service that is traded in the market and refers to a directly used product. Unfortunately, market based approaches do not take us very far as we have pointed out above. Many ecosystem services provide benefits to society but have no direct market and therefore a money value attached to it.

5.2.3 Non-market based methods

A number of methods however allow us to infer values for goods and services that are not directly traded in the market. These non-market methods are classified into two broad categories, namely the revealed preference and the stated preference methods.

The revealed preference methods of valuation are normally considered more reliable than stated preference since it is based on actual observed behavior whereas stated preference methods rely on responses to hypothetical situations. In the earlier applications of stated preference methods there were large differences in estimates. The National Oceanic and Atmospheric Administration (NOAA) deliberated on these methods and provided guidelines of "good practice"(Arrow and Solow 1993). Techniques in both categories have steadily improved and recent studies show that revealed preference estimates could be in the near vicinity of values of stated preference estimates.

Revealed preference methods attempt to value a resource using one or more of the following techniques (Table 4.12):

Table 4.12: Typology of non-market valuation (adapted from Freeman 2003)

	Revealed Preference	Stated Preference
Direct	• Competitive market prices	• Contingent valuation
Indirect	• Production function • Travel cost method • Hedonic models • Avoided cost • Replacement cost • Factor incomes	• Contingent valuation • Contingent choice • Conjoint analysis

Production function approaches use ecosystem services as an input and relate changes in the output to a change in the quality or quantity of ecosystem goods and services of a marketed good or service. This provides an indirect mechanism to value the input by examining its impact on a marketable output. In studies of pollution, this is also called a dose response function.

Surrogate market approaches typically take the form of travel costs and hedonic pricing.

Travel Cost (TC): This technique infers an individual's willingness to pay for a natural resource from the amount that the individual spends on visiting a location.

Hedonic Pricing (HP): This technique examines the willingness to pay for an ecosystem service by examining the differences in prices in a simulated market for natural resources. The housing market with differential location features provides for an oft used application of the Hedonic Pricing method.

Apart from these, we have the cost-based approaches which include replacement costs, mitigative or avertive expenditures and avoided damage costs.

Avoided Cost (AC): The presence of various natural assets allow society to avoid the incurring of various costs – like storm protection and reduced flooding (life and property damage reduction), climate control (reduced energy consumption), health, etc. So, it can be inferred that households would be willing to pay this amount for services rendered.

Replacement Cost (RC): Some natural ecosystem services can be provided by man-made capital or by regeneration the natural capital in case it is degraded. The cost thereby incurred is called Replacement Cost.

Factor Income (FI): This largely belongs to the domain of provisional and recreational services which provide for the enhancement of incomes; for example, improvement in forest quality improves incomes from NTFPs, fishers gain from water quality improvements.

The stated preference methods provide respondents with hypothetical scenarios of environmental quality and seek their responses on them. Contingent valuation is the most popular of these techniques. Respondents are asked their willingness to pay for hypothesized improvement in environmental quality. The Contingent choice models are similar to Contingent valuation except that they do not ask the respondent to place a monetary value to the resource directly. They rely on responses to choices between different states of nature which may or may not have a monetary value associated with them. Sometimes, these models can be used to rank choices. The Conjoint analysis method is more popular among psychologists and marketing research but has also been applied to ecosystem valuation (Farber and Griner 2000). It presents people a set of hypothetical scenarios with multiple levels of attributes. Respondents are asked to choose, rate, or rank among them. Based on the choices they make, analysts derive the structure of their preferences.

5.2.4 Value (or Benefit) Transfer Approach

Apart from the methods discussed above which are used for onsite valuation, the value transfer method is also widely used. This is a technique used to generate estimates for ecosystem services when it is difficult (either due to financial or time constraints) to undertake a specific local area study. It is the second best strategy in the absence of a first best primary valuation study.

As the term implies, value transfer adapts existing value estimates from other contexts dispensing with the need for new data generation. The existing estimates may be taken from a single study but it is often recommended that a sensitivity analysis be done after a meta-analysis of existing studies. The greater the number of similarly located studies available to the researcher, the better would be the accuracy of the estimates from a Value transfer study. The increasing use of GIS information allows better adaptation of values from one context to the other (Beaumont *et al.*, 2006).

Before we discuss some other strengths and weakness of the different techniques we have mentioned above, we would like to highlight the role of discounting in valuation since benefits and costs occur at different periods in time.

5.2.5 Social Discount Rate (SDR)

The debate on SDR has been revived with the discussion on climate change and taken us back a full circle to (Ramsey, 1928). A critical point in this debate has been the choice of a discount rate for comparing temporally separated costs and benefits. Discounting allows us to convert future streams of costs and benefits into present values. However the size of the present value is critically dependent on the size of the discount rate and a small change in it can lead to large differences in NPVs. There are two kinds of discounting that are common – utility discounting and consumption discounting (Heal, 2004).

The Utility discount rate is called by many different names – the discount rate, the pure rate of time preference, the social rate of discount, and the social rate of time preference .

If there is a compelling reason to value the future generations utility less than the present generations, then a positive utility discount rate should be chosen, otherwise this rate should be zero (when society weighs future generations equally as the present).

The consumption discount rate on the other hand measures the value of increasing consumption (as opposed to utility) of one generation with respect to the future. It is not unethical to argue that if in future (due to growth and rising incomes) consumption will be higher, then we should give greater weight to consumption at present (favour the inter-temporally poor vis-à-vis the rich), then the consumption discount rate should be positive. It is also possible that this rate can be negative if there is going to be a fall in the consumption goods (like ecosystem services) in the future – implying the need for sustainable use, by reducing consumption now to save for the future.

The question that remains is whether the utility discount rate should be used or the consumption discount rate. In the partial framework analysis, where the overall social utility is unaffected by the perturbation caused by a project, the consumption discount rate is recommended whereas if the perturbation is of a scale where the future utility would be affected (general equilibrium framework) then the utility discount rate should be used (NRC, 2004).

The literature tells us that the value of the discount rate is ultimately an ethical choice combined with some facts (Dasgupta, 2008). It turns out that the social discount rate is dependent on two ethical parameters – the pure rate of time preference and the value of consumption elasticity of marginal utility and one factual parameter – the growth rate in consumption.

The Ramsey (1928) equation is stated as:

$r = \rho + \theta g$

where r = Discount Rate, ρ = Rate of time preference, θ = elasticity of marginal utility (also called felicity); and g = growth rate of consumption.

If we assume that there is only one kind of commodity – consumption goods, then "r" becomes the consumption discount rate. Therefore, for society to give up one unit of consumption today it would demand (1+r) units of consumptions goods in the next period. There are two ways of approaching the value of "r". The descriptive one "r" and "g" are inferred either from market information or from experiments and then a set of combinations of "ρ" and "θ" would be compatible.

The prescriptive method on the other hand proceeds by assuming a value for "ρ" and "θ". Then "r" becomes dependent on "g". Here the choice of "ρ" and "θ" are ethical choices (for a detailed discussion, see Dasgupta 2008). There is a fair bit of variation in discount rates used in empirical analysis around the world (see for example, H M Treasury 2011; Mukhopadhyay and Kadekodi 2011).

5.3 Global status of valuation

5.3.1 Global Valuation Estimates

One of the most discussed attempts to value the world's ecosystem services placed the value at about \$ 33 trillion annually (range: \$ 16–54 trillion), estimated to be nearly twice the global GNP of around \$ 18 trillion at that time (Costanza *et al.*, 1997). Seventeen types of ecosystem services were valued and the authors distinguished between marine and terrestrial systems. The marine systems had sub-categories of open ocean and coastal, which included estuaries, seagrass/algae beds, coral reefs, and shelf systems (Costanza *et al.* 1997). They found that the bulk of the world's ecosystem services (about 63%) came from marine systems amounting to \$ 20.9 trillion per year of which the coastal systems contributed about \$ 10.6 trillion per year. Though there were numerous questions raised about these estimates, the paper generated a large amount of academic as well as policy interest (see for example Nature 1998). Another attempt by Pimentel *et al.* (1997) placed the global value of ecosystem services much lower at \$2.9 trillion (which was 11% of the world GNP).

These two are representative of the wide range of values that seem to emerge not only from global but also local valuation exercises.

5.3.2 Marine and coastal valuation

Coastal and marine resource valuation studies use methods developed for the broad spectrum of natural resource valuation which accounts for use and non-use values. Natural resource valuation is different from other normal goods and services since many of these resources do not have readily available market prices – either due to distortions or the absence of markets. Some goods that emerge from nature do have market prices – for example fishery output, non-timber forest produce like fuel wood or honey but their market value only reveals a partial value of the resource (Costanza *et al.* 1997) and therefore results in uninformed policy making and inadequate conservation of the resource. This has implications for sustainability and loss of natural capital stock and could result in lowering human well-being. Valuation of coastal and marine resources pose difficulties not dissimilar to terrestrial systems – most ecosystem services are public or semi-public in nature and the problem of uncertainty and irreversibility requiring estimation with thresholds.

One of the early studies attempting to capture the value of coastal systems using the marginal productivity method was by Farber and Costanza (1987). The annual economic value of five different native species (shrimp, blue crab, oyster, menhaden and muskrat) was estimated by totaling the market value of commercial catch. At 1983 prices, the total value of marginal productivity of wetlands in Terrebonne Parish, Louisiana was \$ 37.46 per acre.
A global estimate of coastal and marine ecosystems by Martinez *et al.* (2007) found that the total value of ecosystem services and products provided by the world's coastal ecosystems, including natural (terrestrial and aquatic) and human-transformed ecosystems, added up to \$25,783 billion per year.

A recent evaluation of five ecosystem services in the Mediterranean (fisheries production, recreation, climate regulation, erosion control and waste treatment) found the aggregate value of services to be above 26 billion Euros annually. Fisheries services were valued at 3 billion Euros, recreational services were about 17 billion Euros, carbon sequestration at 2.2 billion Euros, protection against coastal erosion at 530 million Euros, and waste assimilation estimated at 2.7 billion Euros, annually (UNEP-WCMC 2011).

Cisneros-Montemayor *et al.* (2010) estimated the global demand for eco-tourism in marine ecosystems from a meta-analysis and found that three activities (whale watching, diving and recreational fishing) generated as much as \$ 47 billion in 2003, bulk of this coming from the USA (about \$ 30 billion). Similarly, a worldwide review of fisheries in 2006 by FAO estimated the value of high sea fisheries to be €447 million (Armstrong *et al.*, 2010).

The total profit (or loss) from fisheries is measured by total revenues minus total costs. Total subsidies are subtracted from this, as they represent an additional cost to society of the fishing industry. The FAO's estimate of the value of annual global catch in

2004 was around $79 billion. According to the World Bank, the operating costs, including fuel costs, labour costs and other operating costs, totalled around $73 billion, with the total capital costs of the industry estimated at $11 billion. This implies that the industry as a whole made a loss of $5 billion. Taking into account all other subsidies except fuel subsidies, the full economic value of the fishing sector is equal to a cost or loss of US$26 billion (Sumaila and Pauly 2006). A complete understanding of the economics of fisheries must take into account not only the direct revenues and costs of the fishing industry, but also the broader environmental and social costs and benefits that the industry provides. This is necessary in order to provide an estimate of the aggregate 'value to society' that fisheries provide. These represent a cost to society, which is generally not accounted for by the industry's direct revenues and costs. Many of them are also very difficult to assign a monetary value to. This valuation of externalities at the global level is therefore limited to the cost of carbon dioxide emissions from global fisheries, although it is evident that there are other externalities that would represent a negative cost even if they cannot be quantified. Other major externalities are: destruction of coral reefs; unwanted bycatch and discards; and destruction of benthic habitats. The total carbon emissions from global fisheries have a social cost of $5 billion. To account for this, the cost of $5 billion is added to the full economic cost of fisheries of US$26 billion, to get a total cost of US$31 billion (Sumaila 2010).

In spite of these estimates, the number of valuation studies in this domain is comparatively limited. A recent review of ecosystem provisioning services pointed out that even though many studies are now available for terrestrial natural resources, there is a large gap in marine resource valuation (NRC 2006). These include valuation of on-site consumptive and non-consumptive use, as well as off-site non-consumptive services. Even the recent TEEB review points out that "the ecological aspects of marine conservation have been studied, but research into its social and economic dimensions is rare" (TEEB 2012). In recognition of this knowledge gap, there have been a number of initiatives. One such initiative funded by the European Union is a network called MarBEF (www.MarBEF.org). The objective of this network is to bring together knowledge and expertise on marine biodiversity and provide monetary estimates of marine biodiversity.

Within the marine ecosystems, few ecosystem specific studies are also available. The coral reefs form an important ecosystem providing both use and non-use values. Conservation International (2008) compiled the estimates available from different researchers on the ecosystem services available from coral reefs. Total net benefit per year from the world's coral reefs was estimated at $ 29.8 billion of which recreation benefits were $9.6 billion, coastal protection $9.0 billion, fisheries $5.7 billion, and biodiversity $ 5.5 billion (Cesar *et al.* 2003).

Wetlands form a very proximate and important ecosystem that provides multiple services – provisioning, regulatory, supporting as well as recreational and cultural. It is also probably the most studied ecosystem in terms of valuation estimates in the coastal and marine segment. A 2006 meta-analysis of wetlands valuation from around the world found that the average annual value of services is about $2,800 per hectare (Brander *et al.* 2006).

The mangrove systems, like coral reefs, are known as nurseries for fish and shrimp as supporting services. Damage to such mangroves could affect aquatic production. Barbier and Strand (1998) who studied mangrove reduction in Mexico found a reduction in annual shrimp output by more than $150,000 per square kilometer reduction of mangroves during 1980-81.

5.3.3 National estimates

At the country level for the USA, Pimentel *et al.* (1997) estimated ecosystem services to be $ 319 billion. Patterson and Cole (1999) estimated New Zealand's terrestrial ecosystem services from biodiversity and placed the value at NZ $ 44 billion per year (1994) and found it to be about half the size of the GNP. However, they did not include marine ecosystem services and suggested that it might be higher than the terrestrial ecosystem services. A country level estimate of ecosystem services of Scotland placed the value at $ 24 billion (Williams *et al.*, 2003).

5.4 Indian status and potential adaptation of global valuation information and methods to Indian conditions

There have been attempts in India to estimate the value of natural resources. Some of these are macro estimates, for example to calculate the green NNP both by official and non-official agencies. The official estimates are not yet available in the public domain but one non-official initiative from the Green Indian States Trust (GIST) provides a set of estimates of national and sub-national income. They call this the environment-adjusted state domestic product, ESDP. The traditional NNP estimates are adjusted for values of forest resources, agriculture and grazing land values, cattle, known mineral deposits, and surface freshwater at the state level and national level. Unfortunately, GIST did not bring within its ambit marine and coastal ecosystem services. Therefore, this remains a gap in the literature.

However, there is now a growing literature of micro studies that look at either specific sites or services using a multiplicity of techniques discussed above. We list a few studies in India that are linked to coastal and marine ecosystems (Table 4.13).

Table 4.13. Studies on coastal and marine ecosystem services in India

Type of Ecosystem	State	Area	Type of services	Method	Type of goods	Authors
Coral reef	Gujarat	Gulf of Kacchh	Multiple	Mixed	Multiple	Dixit *et al.* (2010); Dixit *et al.* (2012)
Mangroves	Orissa	Bhitarkanika	Provisioning	Market Value	Fisheries and Forestry	Hussain and Badola (2010)
Mangroves	Orissa	Kendrapada	Regulating	Damage reduction function	Reduction in loss of life and property	Das and Vincent (2009); Saudamini Das (2009)
Mangroves	West Bengal	Sunderbans	Provisioning	Travel Cost	Recreational Aspect	Guha and Ghosh(2010)
Mangroves	West Bengal	Sunderbans	Provisioning	Translog Cost Function	Valuation of biodiversity loss	Chopra *et al.* (2010)
Mangroves	West Bengal	Sunderbans	Provisioning	Market value	Contribution of tourism in livelihood	Guha and Ghosh(2007)
Mangroves	Gujarat		TEV	Multiple	Mangrove contribution to livelihood	Hirway and Goswami (2007)
Soil productivity	Gujarat	Olpad Taluk, Surat Dist	Regulating	Damage Cost	Salinity Ingress	Sathyapalan and Iyengar (2007)

5.4.1. Provisioning services

Direct Market Method

Direct market valuation of provisioning services is the least complicated to compute as they have direct market values available.

At a micro-level using the direct market values, Hussain and Badola (2010) provided estimates of livelihood support from mangroves in the Bhitarkanika conservation area in the Odisha coast. They considered only two items of provisioning support from mangroves–fishery and forest products. In order to examine the contribution of mangroves to fishery, they separately valued flows from inshore fishery, offshore fishery, and as nursery ground for fish and shellfish. The price at first sale (local market prices) was used for market valuation. They also considered timber and non-timber extraction from mangroves. An average household derived about

US$ 107 per annum worth of livelihood support per year. In comparison to the average family income in this area of US$ 603 per annum, the dependence on ecosystem services as a livelihood support was found to be significant.

In recreational provision studies it is not common to find estimates of gains in livelihoods (factor incomes) due to tourism in India. Guha and Ghosh (2007) provided a case study of the Indian Sunderbans where they examined the gains in livelihood (from factor incomes) generated by tourism and find that households that engage in tourism are less dependent on forest products.

Chopra *et al* (2010) examined the ecological loss due to biodiversity decline in the Sunderbans driven by over-extraction of shrimp larvae. The biodiversity decline is perpetuated by aquaculture farms which acquire seedlings from the wild and thereby deny the natural ecosystem of the wild shrimp larvae. This decline in shrimp larvae disrupts the ecological balance of higher trophic fishes which feed on shrimps.

5.4.2 Regulatory Services

Even though direct market methods are often used to estimate provisioning services, Sathyapalan and Iyengar (2007) considered the regulating service provided by the coastal zones by way soil salinity prevention to agricultural farms in Gujarat. They examined the differences in agricultural productivity in two areas – one where there is salinity ingress and another where there is no ingress and found that the per acre cost of salinity ingress ranges between Rs. 72,221 to Rs. 98,145 (depending on the discount rate). Their study did not undertake valuation of ecosystem services, but their estimates are an indicator of the value of the regulatory services that nature provides by preventing salinity ingress.

Apart from the application of direct market techniques, there have been some studies that use non-market valuation techniques. A study based in Kendrapada, Orissa on the storm-protection services of mangroves during the Super Cyclone 1999 suggests that mangroves reduced loss of human life, house damage, livestock damage, etc. Their cost-benefit calculations show that it is economically beneficial to reconvert land surface which earlier had been under mangrove cover (Das and Vincent, 2009). If house damage alone is considered, the protection benefit was US $ 1218 per hectare of forests (Das 2009).

5.4.3 Recreational Services

The travel cost method has been applied in India to coastal and marine areas, for example to estimate the recreation value of the Indian Sunderbans which is a UNESCO World Heritage and also a Ramsar site. Guha and Ghosh (2009) used a zonal travel cost method to estimate the annual recreational value to Indian citizens of the Indian segment of the Sundarbans and found that it amounts approximately to $ 377,000 (in the year 2006). Their study suggested that by hiking the entry fees to Sunderbans park, the authorities could raise revenues amounting to US$ 0.12 million per year. This would be useful for improving park maintenance.

5.4.4 Contingent Valuation Method

The CVM has been used in India to capture non-use values despite concerns raised on the reliability of the method. Anoop and Suryaprakash (2008) attempted to calculate the Option Value of Ashtamudi Estuary, a Ramsar site located in Kerala. The ecology of this estuary is under threat from anthropogenic activity. The preservation of the wetland prompted the authors to ask how much people (three categories: fishers, tourists and coir producers) are willing to make a "one time payment …. towards the conservation of the Ashtamudi estuary". They used a contingent choice technique and found that the option value of the estuary was Rs.3.88 million. They also estimated the present value of the estuary by using a discount rate of 4% and found it to be Rs. 87.1 million.

5.4.5 Multiple Method Valuation studies

Coral Reef Ecosystem

There have been very few attempts to study ecosystem services values of coral reefs in India. Dixit *et al.* (2010, 2012) valued five different kinds of services that emanate from corals - fisheries, recreation, protection of coastal aquifers (against salinity ingression), protection of coastal lands (against erosion) and biodiversity. They used different methods to assess the value of each service. In order to estimate the biodiversity value and protection from coastal erosion, they used the value transfer method. Fishing benefits were calculated by direct market method. Recreation values were estimated indirectly by extrapolating tourist arrivals instead of the more common Travel Cost estimates or stated preference method. The protective role of corals for aquifers and soil erosion was estimated partly using a Benefit transfer method and partly using the preventive expenditure information and crop damage information. They found the value of ecosystem services emanating from coral reefs of Gulf of Kachchh was Rs. 2200.24 million (2007 prices) and Rs. 7.95 million per km^2.

Wetland System

Anoop *et al.* (2008) attempted to value the direct and indirect use benefits from Ashtamudi estuary. Four types of direct use benefits are estimated: fishery, husk retting, inland navigation and recreation. For valuation of recreational benefits, the travel cost method was used while the rest were valued by the direct market value technique. Two indirect benefits were also examined – carbon sequestration and shrimp larvae protection. The value transfer method was used to estimate the indirect benefits. They found the net approximate value of use benefits as Rs. 1924 million.

Mangrove system

In a study based in Gujarat, Hirway and Goswami (2007) attempted to calculate the TEV of mangroves. They found that the direct use value (2003 prices) of mangroves was Rs. 1603 million, and the indirect use value was Rs. 2858 million per year. The total use value (direct and indirect) of mangroves was estimated at 7731.3 million per year (2003 prices).

Marine Protected Area

In recognition of the critical role that coastal and marine ecosystems play in human well-being, Marine Protected Areas (MPAs) have been designated in the world oceans. In a remarkable exercise in the UK, as a part of identifying areas and preparing the bill for MPA notification and enactment, a marine valuation exercise was undertaken and discussed with the public prior to enactment of the MPA Act.

In India, while a lot of conservation efforts have been made to terrestrial protected areas (especially forests), marine protection is yet to see similar efforts. The Coastal Zone Regulation Act provides a degree of protection, but its implementation is not uniform across different states. There is an urgent need to address coastal and marine ecosystem management issues that are beyond the Coastal Zone Management bill, which received a mixed response from the public and different stakeholders. The discussion with stakeholders needs to be based on independent evaluation of the ecosystem services. In India, among the MPAs, valuation work has been done in the Gulf of Kucchh (as we have mentioned earlier).

It is important to note that valuation needs an interdisciplinary approach and the need for bio-economic modeling cannot be over stated when we are dealing with issues of valuation. Empirical examples in India are rare. One such attempt was by Bhat and Bhatta (2006) who estimated sustainability in fisheries but not with the objective of explicit valuation. They argue that increase in mechanisation and access to technology has made it possible for large scale fishing activity but increased fishing effort has made the fish stock in many species unsustainable without substantially improving profitability of the fishers. An extension of such an exercise may allow an estimation of shadow values of fishery services and better management of resources.

Managing the marine and coastal ecosystems requires an understanding of the socio-ecological systems and their inter-connections. We need a way to incorporate our knowledge on thresholds and regime shifts into our policies. Management strategies must complement scientific knowledge of marine and coastal ecosystems with social concerns of distribution, equity and justice.

6. The way TEEB assessment can contribute to the conservation challenges

6.1 Policy implications for capturing the value

Economic valuation becomes necessary when there is scarcity of a resource and there are alternative competing uses of these resources. When society must choose one of many options available, Cost-benefit analysis is the preferred tool but we need values in order to undertake this exercise. In situations where monetary values are difficult to obtain, multi-criteria analysis has emerged as a substitute technique. Natural resource damage assessments in the light of demand for compensation and the need for adjudication by the Courts have also spurred the need for valuation (Nunes *et al.* 2009). On a macro-level too the issues of sustainability have compelled economists to engage with the traditional measures of well-being.

In received development theory, the gross national (or domestic) product (GNP) has been used widely as a measure of well-being as it measures the amount of gross economic activity (and thus employment). However, since growth in GNP could occur by depleting assets it has been argued that GNP could be a misleading indicator as a part of GNP does not represent income but just revenue. Thus, a rise in GNP may be a short-run phenomenon if it is being achieved by depleting the asset base of the economy (Hamilton and Ruta 2006).

This problem is partly overcome when we compute the Net National Product (NNP) which accounts for depletion of fixed capital. But traditional measures of NNP do not incorporate changes in the "natural" capital stock. Receipts from extractive industries like oil and minerals constitute increases in revenue and not income as they are achieved by depleting natural capital. Revenues cannot be treated as income as it gives a false sense of high current well-being. So we need to find a way to adjust the traditional NNP for any depletion of the natural resource base.

To overcome this gap, a System of Integrated Environmental and Economic Accounting (UN *et al.*, 2003) has been developed which extends traditional measures of national income to record changes in the natural resource base and accounts for environmental pollution. This environment-corrected measure is often referred to as the green NNP. The SEEA is known as satellite accounts since it is an addendum to the traditional NNP computation methods. A specialized manual on fisheries, the System of Environmental and Economic Accounting for Fisheries (SEEAF) is already available. Interestingly, the manual takes a system wide approach for fisheries accounting, as fisheries production cannot be examined in isolation from the rest of the marine and coastal ecosystems. It is possible that there already exists adequate sector-wise information for fisheries, tourism, and coastal land use planners. The advantage of putting this information in a national income framework is that these sectors can then perceive inter-sectoral links, and better align their policies to develop their resources.

The debate on sustainability, however, suggests that Green NNP is not a sufficiently reliable measure. The reliable indicator of sustainability is comprehensive "wealth," which is the sum of all forms of capital – physical, human and natural - valued at their shadow prices (Dasgupta and Maler, 2000; Arrow *et al.*, 2004; Dasgupta, 2009). Social preferences in terms of both contemporaneous as well as inter-generational equity would be reflected by the nature of the inter-temporal social welfare function. This would in turn help establish the shadow prices. If the present value of aggregate capital is non-decreasing then one can anticipate that the economy is on a sustainable path.

6.2 Role of policy-based instruments for optimizing the value

State responses to halting environmental degradation can take two possible paths. One set of instruments fall under the category of command and control policies and the other are market based instruments which take the form of taxes and fees. The command and control policies directly mandate the extent of resource use and do not rely on any market mechanism. Taxes and fees on the other hand rely on the existing marketed goods and a levy that at the efficient level should compensate for the resource use or damage.

Theoretically, it is possible to show that both these instruments can lead to similar outcomes. However, when there is risk of great damage from degradation or overuse, command and control policies are preferred to market-based instruments. In the context of ecosystem services, if the ecosystem has reached a state of criticality or if a tax/fee is difficult to implement and monitor, command and control instruments would provide more satisfying outcomes. There are numerous examples of such policies both in India and abroad. For example, a ban on fishing during breeding season, land use zoning, are common command and control measures. Entry fees to wildlife sanctuaries and protected areas, pollution taxes, water cess, garbage tax and royalty fees on mineral extraction form part of a set of market instruments deployed for ecosystem management.

Private responses may also emerge in the absence of state policies. These responses could lead to evolution of social norms and conventions or market creation which may take the form of Payment for Ecosystem Services.

There are numerous examples of social norms being used for ecosystem management. A self- regulated ban on fishing during breeding season have sustained the livelihood of fishing communities; restrictions on non-timber forest product extraction, and efforts to protect biodiversity by creating inviolate spaces like sacred groves, have provided forest communities sustenance.

Bargaining is usually the mechanism for interaction between competing users in the absence of a market. Bargaining could be as local as between two villages sharing a common lagoon for fishing, or in the case of trans-boundary resources as complicated as the International Convention for the Regulation of Whaling or the ongoing climate change negotiation between multiple governments and non-governmental organizations.

6.3 Role of market-based instruments for optimizing the value

Market-based instruments are used quite frequently, and in addition to offering the option of efficient management of ecosystems, also provide much needed revenue for management. Payment for Ecosystem Services (PES) has emerged as a possible mechanism for optimal use of natural resources creating the opportunity for re-generating or conserving a natural resource. PES is an umbrella term which includes schemes that rely on one-off deal between two communities, and more complex 'market' mechanisms involving multiple nations and intricate futures instruments.

PES scheme could involve at least four types of participants:

(i) Public sector agencies who secure ecosystem services for public at large

One of the best known examples of this is the Catskill Mountain scheme for New York's water supply. This watershed delivers about 1.2 billion gallons of drinking water daily to 9 million New Yorkers. It spans nearly 2000 square-miles, 19 reservoirs and aqueducts cutting across nine counties. The water supply of New York is delivered through aqueducts from these mountains for the last two centuries. However, in order to meet the water quality regulations, the city had the option of protecting its watershed and allowing the ecosystem to provide high quality water or to use a modern water filtration plant. The relative cost of the two options was estimated; whereas the modern filtration plant was estimated to cost about $6 billion (with an annual maintenance cost of $ 250 million), the ecosystem option was estimated to cost about $1.5 billion. The city selected the second option wherein they bought over 70,000 acres of land from upstream communities and worked with them to reduce pollution from farm waste run-off. This has not only reduced the cost that the citizens of New York have to bear but also helped upstream communities to improve their well-being substantially due to ecosystem related payments from the city.

(ii) Philanthropists who pay to conserve a resource as an act of altruism

These are agents who are motivated by non-use values. Environmentally conscious citizens and organisations very often contribute money or resources either for specific programmes or to conservation-oriented organisations.

(iii) Private agents (including communities) who undertake private deals to conserve ecosystem

They are motivated by use-values derived from ecosystem services. There are many emerging examples of this.

(iv) Consumers of eco-certified products, which include both use and non-use values

This market has emerged due to increased consumer awareness. A market for eco-products that range from food to various non-food items (including household and construction material) has emerged across the globe. The market in developing countries is still small, but in Europe and the USA this is much larger.

6.4 Implications for corporate decision-making

With increasing public awareness, and environmental legislation, there has been concerted effort by the corporate sector to act more responsibly towards the environment. Some firms have encapsulated these efforts within the ambit of Corporate Social Responsibility. Valuation of natural resources and ecosystem services would help the corporate to plan their activities better. It will also enable them to assess the risks involved in their domain of operation. The World Business Council for Sustainable Development, for example, is actively engaging corporate to make better business decisions incorporating values for ecosystem in their business plans (WBCSD 2011).

These have acquired certain amount of importance following compensation awarded by Courts after a human caused environmental disaster (Carson *et al.*, 2003). The Exxon Valdez oil spill which occurred in Alaska in March, 1989, and the Deepwater Horizon oil spill in April, 2010, are regarded as some of the most devastating human- caused environmental disasters for the marine ecosystem (Martínez *et al.*, 2012). After the oil spill in the Arabian Gulf following the Gulf War 1991, compensation was paid to the affected countries bordering the Arabian Gulf by Iraq through United Nations Compensation Committee. The compensation was adjudicated by the Geneva Court. These developments had significant impact on the legal framework as well as corporate planning.

6.4.1 Marine & coastal spatial planning

Valuation would be of great help in marine and coastal planning in India. It would allow the citizens as well as the government to evaluate alternative proposals for development projects on shore and off shore by weighing their impact on sustainability. It would improve Integrated Coastal Zone Management plans in the country which are sensitive to local needs.

For example, in Goa there has been a long-standing tradition of following a decadal regional plan which attempts a state-wide planning exercise. In its current phase, this Plan involves both micro-planning at the village level which is expected to reflect in the aggregated state level plan. The draft plan 2012 has been prepared in conjunction with local bodies to demarcate zones that are ecologically sensitive (http://www.goa.gov.in/pdf/RPG21.pdf). Village level plans have been created in the spirit of the 73rd and 74th Constitutional amendment developed to accommodate local aspirations in a participatory process. Valuation of resources and ecosystem services would help future planning of this nature.

6.4.2 Bioprospecting - Access and benefit sharing arrangements

The marine and coastal ecosystem has great prospects for bioprospecting. The estimated value of the pharmaceutical industry globally was estimated to be $643 billion (in 2006), and for the cosmetic industry it was $ 231 billion (in 2005). These industries have important formulations based on marine extracts and therefore the bioprospecting values of marine ecosystems could be significant (Vierros *et al.*, 2007). The Convention on Bio-Diversity and the Bonn guidelines provide guidelines for international policy on access and benefit sharing arrangements (Naber *et al.* 2008).

7. Proposed methodology

7.1 Strength and weakness of methods

Each valuation method has strengths and weaknesses. As we have said earlier, due to the committed nature of behavioural response, revealed preference techniques are considered more robust and reliable than stated preference since these rely on expected behavior from hypothesised scenarios. However, revealed preference methods are unavailable for Non-Use valuation where we necessarily have to rely on Stated preference methods. So, if one were attempting a TEV of an ecosystem service, several techniques would need to be combined to arrive at reasonable values.

Some valuation techniques, depending on the circumstances could either yield an over-estimate or under-estimate of the value of the service. This problem is typical when using Replacement Cost (RC) methods. It is possible that an ecosystem may yield less value to society than the cost that society would have to incur if it had to be restored or replaced. There could be a situation where the cost of service provided by the ecosystem in terms of avoided damages is much lower than if the same service was provided for by alternate means.

There are some well-known biases with stated preference techniques (Cesar, 2000):

Hypothetical bias: The respondents know that the process is only dealing with a hypothetical situation they may not reveal true preferences.

Strategic bias: If people anticipate that their responses could influence forthcoming policy, they will answer strategically to shape policy – they may lower their bid if they feel that their statement may get converted into a tax or fee level.

Information bias: This is a critical error that may creep in due to design of the survey. The manner in which the hypothetical situation is described can influence bid responses. Design bias refers to the manner in which the queries are structured. Instrument bias occurs when the interviewee has a bias towards the payment vehicle. Starting-point bias is a well-known problem which refers to an outcome being disturbed because of the starting bid level.

8. Challenges

In the three ecosystem services that this scoping report engages with (namely, forests, wetlands and marine & coastal), the valuation literature in marine and coastal ecosystem services would be significantly thinner than the other two. The reason for this is the comparative lack of relevant natural science, social and economic data. This is true not only for India but also globally.

This report does not attempt to generate or aggregate the value for marine and coastal ecosystems as it is premature on many counts. The number of marine and coastal ecosystem services studies in India is limited. One could use the benefit transfer method to extrapolate values from other parts of the world but these need to be done with care as it could lead to inaccuracies (see Beaumont *et al.* 2006). Some of the values that have been generated for India need to be peer-verified for commonality of methodology. Scaling up from micro-studies to macro-region poses its own limitations. They do not account for regional variation (unless specifically incorporated). Further marine resources are mobile and move across several administrative jurisdiction in international borders and therefore present accounting problems.

Valuation of natural resources is expected to help better management of sustainable use and social allocation. Under-valuation can cause excessive extraction whereas over-valuation would result in under-utilisation. Given the state of knowledge about the scientific processes as well as methodological limitations, valuing restricts our ability to do this satisfactorily as many of the non-market valuation techniques are not proven. Having said that one must acknowledge that in the absence of any better estimates we have to work with what is currently available while constantly trying to improve upon them. Within the domain of valuation techniques, revealed preference methods are considered more reliable and robust and nearest to market valuation. Stated preference methods remain controversial despite the large body of literature that has now been accumulated. Improvement in contingent valuation techniques suggest that the difference in WTP values obtained from both these methods for quasi public goods can sometimes converge (Carson *et al.*, 1996).

Apart from the estimation of costs and benefits, the inter-temporal nature of the service flows causes additional problems. Simply stated, over-extraction of resource today may make the current generation well off but may reduce the future generation's well being. Therefore there is an ethical need for balancing off the need of the current generation against that of the future.

The benefits accrued from coastal and marine ecosystems are best discerned if they are compared with baseline conditions for the area under investigation. The initial and important step in valuation exercise is to consider that ecosystem service provision and benefits is a spatially explicit process. Hence there is a requirement to set the ecosystem under investigation in its spatial, socio-economic, political and cultural contexts (Turner *et al.* 2008). For valuation, it is "marginal" values that are required rather than aggregated values. As "marginal" values are surrounded by uncertainties of threshold effects, judging "marginal" effect is not straightforward.

A likely complication of collecting "marginal" values would be due to non-linearity between critical habitat variables and changes in ecosystem services. For instance, fringe mangroves may cause small losses, and not economic benefits of storm buffering. Data on such nonlinear functions of marginal losses are hard to collect.

Another challenge is to identify sources of double counting. Nutrient recycling, for example, will support a series of outcomes such as clean water, better support to life systems, higher productivity, etc. It should be kept in mind that economic values relate to end products, and not to nutrient recycling per se. It is important that the full range of complementary and competitive services should be distinguished before initiating valuation.

It may be possible to transfer data from other related studies as a guide to appropriate values. The procedure has problems and a strict protocol is required (Wilson and Hoehn 2006). Moreover, the benefits valuation methods and cost-based valuation cannot be aggregated in a simplistic way.

Given the urgent need for understanding the value of ecosystems and the wide differences in the available estimates, this is an area that will continue to engage researchers. Economic valuation will remain a challenging enterprise as it will have to negotiate with ecological non-linearity, uncertainties, existence of ecological thresholds, and conceptualization of resilience in the social context. Even if well executed micro-studies are available, there would still remain the issue of scaling up values of ecosystem services.

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Nature Protects if She is Protected

XI Conference of Parties

CONVENTION ON BIOLOGICAL DIVERSITY

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