2 Mangroves: A Unique Gift of Nature

Mother Earth has created several gifts in the ecosystem vaults, which need to be priced properly. A free gift invites destruction, degradation, spoilage and conflict.

The Author

2.1 Mangroves: An Overview

Mangroves are salt-tolerant forest ecosystems found mainly in the tropical and subtropical intertidal regions of the world. They encompass swamps, forestland within, and the surrounding water bodies. It is a matter of great surprise that mangrove floral species can thrive luxuriantly in saline habitat (which is basically physiologically dry in nature) through orientation of their morphological, anatomical and physiological systems. Thus, this vegetation is the most efficiently adapted biotic community in response to climate-change-induced sea-level rise.

The term 'mangrove' has originated from the Portuguese word *Mangue*, which means the community, and the English word *Grove*, which means trees or bushes. According to Mepham and Mepham (1984), the term has been inconsistent and confusing in the past. Mangroves are basically evergreen sclerophyllous, broad-leaved trees with aerial root like pneumatophore or stilt root and viviparously germinated seedlings (UNESCO 1973). They grow along protected sedimentary shores especially in tidal lagoons, embayment and estuaries (MacNae 1968). They also can grow far inland, but never isolated from the sea. These emergent, evergreen canopies are found along the sedimentary shores of both tropical and subtropical regions in association with intertidal flora and fauna commonly known as mangrove ecosystem, and the community of these mangroves was coined by MacNae (1968) as *Mangal*. Lear and Turner (1977) expressed the word 'mangrove' of coastal ecosystem in a holistic manner, including its common habitat or inhabiting fauna. The term 'mangrove' also denotes both the ecological group of flowering halophytic shrubs and trees of up to 30 m high belonging to several unrelated families and the complete community or association of plants which fringe sheltered tropical shores. About 60–75 % of tropical coastline is fringed with mangroves (Reimold and Queen 1974). Duke (1992) defined mangroves as '… A tree, shrub, palm and ground fern, generally exceeding one half meter in height and which normally grows above mean sea level in the intertidal zone of marine coastal environments or estuarine margins …'. This definition is acceptable except that ground ferns should be considered as mangrove associates rather than true mangroves. The term 'mangrove' often refers to both the plants and the forest community. To avoid confusion, MacNae (1968) stated that 'mangrove' should refer to halophytic plant species, while the entire forest community

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including micro- and macro-organisms should be considered as 'mangal'. The mangal is therefore a broad domain encompassing the entire biotic community comprising of individual plant species, associated microbes (like bacteria and fungi) and animals. The mangal and its associated abiotic factors constitute an ideal *mangrove ecosystem*, which is a unique ecosystem of the planet Earth.

The mangrove forests are highly productive ecosystems with productivity about 20 times more than the average oceanic production (Gouda and Panigrahy 1996). Moreover, it is a 'detritus-based' ecosystem unlike other coastal ecosystems, which are usually 'plankton-based'. The detritus supplied by the ecosystem saturates the ambient water with nutrients, which triggers the growth and development of planktonic community in the water bodies on which the fishery resource is also dependent. The greatest concentration of mangrove species is observed usually at the mouth of tidal creeks and rivers where salt and freshwater mix in ideal proportion and floodwaters deposit plenty of material to build up the banks. This unique coastal ecosystem of the world sustains a rich spectrum of floral and faunal community in and around its vicinity. The mangroves enrich the coastal waters with nutrients, yield commercial forest products, protect coastlines and support coastal fisheries (Kathiresan and Bingham 2001). Generally, the mangrove vegetations are well adapted to extreme conditions of salinity, tides, winds and temperature, although they show a preference for freshwater. There are no floral groups in the plant kingdom, which possess such well-organized and highly developed morphological, biological and physiological as well as ecological adaptations to extreme environmental conditions.

Mangrove plants tolerate salinity of the soil and water through three basic processes as listed here:

1. *Salt excretion*: Mangrove plants take saline water as such through roots. However, in the tissues of some species of mangroves, only water molecules and essential salts are retained. Excess salts are excreted through *salt glands* that are present in the leaves. The salt-excreting species of the mangrove community like *Avicennia alba*, *Aegiceras corniculatum*, *Acanthus ilicifolius* and *Aegialitis rotundifolia* regulate their internal salt levels through foliar glands. In salt secreting (excreting) mangroves, the NaCl concentration of xylem sap is relatively high, about one-tenth of the concentration of salt in seawater. So, the salt-excreting species allow more salt into the xylem than do the non-excretors but still exclude about 90 % of the salts (Scholander et al. 1962; Azocar et al. 1992). Salt is only partially excluded at the roots. The absorbed salt is primarily excreted metabolically via specialized salt glands in the leaves. The salt in solution can crystallize by evaporation and either can be blown away or washed off. Since, in salt-excreting mangroves, superfluous salts are excreted by guttation through special salt glands, all these salt-excreting halophytes are often referred to as *crinohalophytes.*

   It is interesting to note that salt excretion is an active process, as evidenced by ATPase activity in the plasmalemma of the excretory cells (Drennan and Pammenter 1982). The process is probably regulated by leaf hypodermal cells, which may store salt as well as water (Balsamo and Thomson 1995).
2. *Salt exclusion*: In some of the mangrove plants, the roots possess an *ultrafiltration* mechanism called *reverse osmosis* by which water and salts in the seawater are separated in the root zone itself and only water is taken inside and the salts are rejected. Many mangrove species can exclude 90 % of salt in the ambient seawater or estuarine system (http://www.epa.qld.gov.au/nature_conservation/habitats/mangroves_andwetlands/man groves). *Rhizophora mucronata*, *Ceriops decandra*, *Bruguiera gymnorrhiza*, *Kandelia candel*, etc. are few salt excluders of the mangrove community. Scholander (1968) demonstrated experimentally that the salt separation process in mangroves occurs at or near the root surface. This is mediated by physical processes alone, since it is not inhibited by poisons or high temperature, which may cause an inhibitory effect on metabolic process. In the root area, the physical mechanism for salt separation involves ultrafiltration which occurs either at

the root surface (epiblema) or at the root endodermis. However, the latter region might be the most preferable site (Tomlinson 1986) because the ultimate absorbing roots in most of the mangroves lack root hairs (e.g. capillary rootlets of *Rhizophora* sp.). This indicates that the absorbing area of mangroves is reduced in comparison to non-mangrove plants.

3. *Salt accumulation*: In this type of mangrove plants, the species possess neither salt glands nor ultrafiltration system, but they have the capacity to accumulate a large amount of salts in their leaves. This imparts succulence to their leaves. *Sonneratia apetala*, *Lumnitzera racemosa*, *Excoecaria agallocha*, *Sesuvium portulacastrum*, *Suaeda maritima* and *Suaeda nudiflora* are included in this category. Leaf succulence in mangroves has a simple explanation in terms of salt balance. The osmotic potential of the leaf cells of mangroves is high (Scholander et al. 1964) which is essential if mangroves are to draw water from the sea with its high negative water potential. However, Scholander (1968) noted that the salt concentration of mangrove leaves remains constant and independent of age. Measurement of salt content in xylem sap demonstrates incomplete salt exclusion at the roots. But, mangroves accumulate salt, and so, this accumulation is partly compensated by salt glands, mainly in the less efficient salt excluders. Since salt concentration is constant and independent of leaf age, salt must accumulate by an increase in the volume of the leaf cells inducing succulence. The leaf succulence in mangroves may therefore be accepted as a part of their adaptation in an environment that provides ample water at the expense of some compensation for high aquatic salinity.

   Studies on salt tolerance in *Aegiceras corniculatum* and *Sesuvium portulacastrum* generated few interesting findings: (i) NaCl salinity has a considerable effect on the degree of succulence. With the increase of NaCl salinity in the ambient media, the mass and volume of the leaves increase due to increment in the water content. (ii) The effect of NaCl and Na_2SO_4 is more pronounced in *Sesuvium* than *Aegiceros*. (iii) In *Sesuvium* sp., the effect of chloride salinity is more prominent than that of sulphate salinity. (iv) NaCl is the most effective salt in promoting succulence (Van Eijk 1939). Succulence is due to expansion of the cell wall leading to increase in the size of cells. (v) Accumulation of NaCl is more in *Sesuvium* than *Aegiceros* due to their difference in the mode of salt regulation. (vi) Chlorophyll content decreases sharply at high concentration of NaCl in both the plant species. (vii) High concentration of Na_2SO_4 stimulates the synthesis of chlorophyll in *Aegiceras corniculatum* but inhibits the same in *Sesuvium* sp.

The mangroves not only stabilize the shoreline and act as a bulwark against the encroachment by the sea, but they also act as the abode of several species of fin fish, nursery of a wide range of finfish and shellfish juveniles and biopurifying matrix of wastes generated as a result of industrialization and urbanization. In mangrove ecosystem, different kinds of unrelated fauna and flora get themselves adapted to thrive under the influence of tidal inundation and brackish water. This ecosystem is thus a zone of adaptive convergence, which is a critical issue in the sphere evolutionary biology.

Mangroves are circumtropical in distribution, and this forest community occupies approximately 75 % of the total tropical coastline. Northern extension of this coastline occurs in Japan (31°22′ N) and Bermuda (32°20′ N), whereas southern extensions are in New Zealand (38°03′ S), Australia (38°45′ S) and on the east coast of South Africa (32°59′ S). Globally, mangroves are distributed in 112 countries and territories. It is interesting to note that mangrove plants are not native to the Hawaiian Islands – six species have been introduced there since the year 1900. The mangrove diversity is more in Southeast Asian countries (Fig. 2.1). The region holds nearly 75 % of the world's mangrove species with the highest species diversity found in Indonesia with 45 species, followed by Malaysia (36 species) and Thailand (35 species). India is no less in terms of the number of mangrove

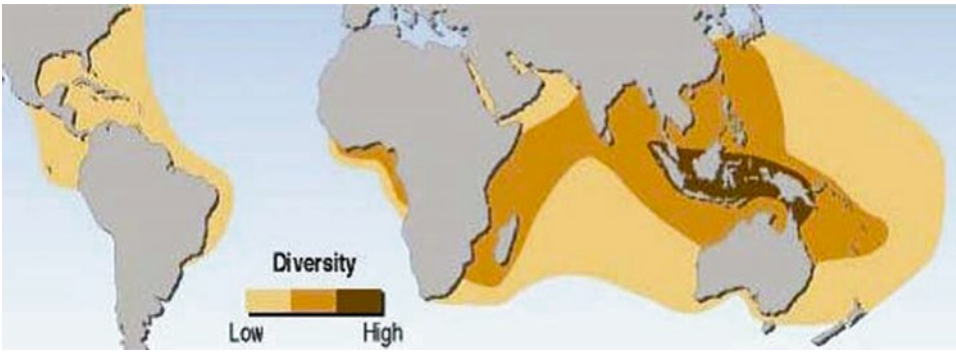


Fig. 2.1 Global distribution of mangrove diversity (After UNEP 2002)

Table 2.1 Estimates of mangrove areas (ha)

Reference	Reference year[a]	No. of countries included	Estimated total area
FAO/UNEP (1981)	1980	51	15,642,673
Saenger et al. (1983)	1983	65	16,221,000
FAO (1994)	1980–1985	56	16,500,000
Groombridge (1992)	1992	87	19,847,861
ITTO/ISME[b] (1993)	1993	54	12,429,115
Fisher and Spalding (1993)	1993	91	19,881,800
Spalding et al. (1997)	1997	112	18,100,077
Aizpuru et al. (2000)	2000	112[c]	17,075,600
FAO (2003)	2003	112	14,653,000

[a]Except for FAO/UNEP (1981) and Aizpuru et al. (2000), the reference year is the year of the publications in which the estimate is cited, not the weighted average of all the national area estimates
[b]Combined figure from three publications by Clough (1993), Diop (1993) and Lacerda (1993)
[c]New estimates were provided for 21 countries, and for the remaining countries, the study relied on Spalding et al. (1997)

species (34 species of true mangroves) and hence is considered as one of the mega-biodiversity countries in the world.

The total global coverage of mangroves has been variously estimated as 14–15 million hectares (Schwamborn and Saint-Paul 1996), 10 million hectares (Bunt 1992) and 24 million hectares (Twilley et al. 1992). Spalding (1997) gave a recent estimation of global mangrove coverage at around 18 million hectares with 41.4 % in South and Southeast Asia and additional 23.5 % in Indonesia. The most recent estimates suggest that mangroves presently occupy about 14,653,000 ha of tropical and subtropical coastline (Wilkie and Fortuna 2003) (Table 2.1).

A list of mangrove-dominated countries in and around Indian Ocean is shown in Table 2.2.

Table 2.2 Mangrove-rich countries in the Indian Ocean region

Country	Area (km^2)
Indonesia	42,500
Myanmar	6,950
Malaysia	6,410
India	4,871
NW Australia	4,513
Bangladesh	4,500
Madagascar	4,200
Mozambique	4,000
Pakistan	2,600
Thailand	1,900

In the Indian Ocean region, the mangroves are found in a variety of coastal settings, ranging from arid areas through estuaries, lagoons and deltas to coastal fringes. The functional types of mangroves in the Indian Ocean region are:

1. Overwashed mangrove forests – small mangrove islands, frequently overwashed by the tides

2. Fringing mangrove forests – found along the waterways influenced by daily tides
3. Basin mangrove forests – stunted mangroves, located in the interior of swamps
4. Hammock mangrove forests – similar to basin type, but existing in more elevated sites
5. Scrub mangrove forests – dwarf stands of mangroves, existing on flat coastal fringes

The sheltered coasts support a luxuriant growth of mangroves and a higher biodiversity, and this is because of the favourable conditions, such as muddy sediment, frequent water exchange, high rainfall and high humidity, prevailing in the areas. The best examples are mangroves of Sundarbans (India and Bangladesh), Malaysia and Indonesia. In contrast, the arid regions of Arabian Gulf countries, Pakistan and Gujarat (India), where the sediment is sandy, highly saline and poor in nutrients have only dwarf mangrove stands.

2.1.1 Mangroves: A Multivalued Ecosystem

Mangroves have immense ecological value. They protect and stabilize the coastal zone, fertilize the coastal waters with nutrients, yield commercial forest products, support coastal fisheries and provide a surprising genetic reservoir that are the sources of several bioactive substances and extracts having high medicinal values. Thus, this unique vegetation of the globe provides various direct and indirect benefits to the stakeholders. The direct uses focus mainly on the timber, fire wood and honey production. The indirect uses may be related to litter and detritus contribution by this ecosystem due to which a food web is generated and large spectrum of finfish and shellfish juveniles are attracted and nourished. Mangrove forests are among the world's most productive sites, producing organic carbon well in excess of the ecosystem requirements and thus contributing significantly to the global carbon cycle. The carbon sequestration property of mangrove flora has added another feather to the crown of this vegetation particularly after the Clean Development Mechanism (CDM) concept has been introduced. The mangrove ecosystem forms the backbone of coastal economy in certain pockets of the globe for its various benefits to coastal population. The multiple ecological, economic and aesthetic benefits offered by this luxuriant ecosystem are pointed here in brief.

Table 2.3 Some traditional uses of true mangrove species

Mangrove species	Uses
Aegiceras corniculatum	Bark used as fish poison. Also contains tannin
Avicennia alba	Used as fodder and fuel
Bruguiera caryophylloides	Wood used for firewood and timber. Bark used for tannin production
Bruguiera gymnorrhiza	Wood used for house posts. Bark used as tannins. Also provides fuel
Bruguiera parviflora	Source of fuel. Leaves and barks contain tannin
Bruguiera sexangula	Timber used in house building
Ceriops tagal	Used for keel of boats and house posts. Provides good fuel charcoal. Bark is rich in tannin, used for dyeing fishing nets
Rhizophora mucronata	Bark is used for tannin and cattle fodder
Sonneratia apetala	Wood used in house building, packing cases and yield excellent fuel
Xylocarpus granatum	Yields gum, resin which are used in local medicines. Bark contains tannin

Source: Chaudhuri and Choudhury (1994)

1. The mangrove vegetations and their associates are economically very important for their products like timber, firewood, honey, wax, alcohol, tannins (Table 2.3) and even extracts having surprising medicinal properties.
2. Mangroves are thought to possess the ability to control coastal water quality. The complexity of the mangrove forest habitat increases the residence time, which assists in the assimilation of inorganic nutrients and traps suspended particulate matter. The mangroves also function as flood control barrier and binder of sediment particles (http://www.fao.org/gpa/sediments/habitat.htm). This feature of mangroves is very important in context to climate-change-induced sea-level rise.
3. The ecosystem forms an ideal ecological asset because the production of leaf litter and

detritus matter from mangrove plants fulfils the nutritional requirements of prawn juveniles, adult shrimps, molluscs and fishes of high economic value. It is for this reason mangrove ecosystem is recognized as the world's most potential nursery.

There are three main factors to justify the nursery role of the mangrove habitat. They are:

- High levels of water turbidity, which increases the survival rate of larvae through reduced perception distance of predators.
- Tidal mixing, nutrient trapping and freshwater inflow that result in considerable primary productivity and provide base of a food web from zooplankton to post larval fishes and juveniles.
- The physical and structural complexity of the habitat itself provides a variety of niches favourable to survival of juveniles. Niche segregation often leads to minimization of inter- and intraspecific competition resulting in a high survival rate of finfish and shellfish juveniles.

4. The vibrating mangrove ecosystem provides nutritional inputs to adjacent shallow channels and bay system that constitute the primary habitat of a large number of aquatic species, algae of commercial importance, seaweeds, phytoplankton, etc.
5. Mangroves and mangrove habitats contribute significantly to the global carbon cycle. Twilley et al. (1992) estimated the total global mangrove biomass to be approximately 8.70 gigatons dry weight (which is equivalent to 4.00 gigatons of carbon). Accurate biomass estimation however needs the measurement of the volumes of individual trees. Thus, mangroves are vital carbon sink in the coastal ecosystem. Mangrove destruction can release large quantities of stored carbon and exacerbate global warming trends, while mangrove rehabilitation will increase sequestering of carbon (Kauppi et al. 2001; Ramsar 2001; Chmura et al. 2003). A case study on carbon storage by a widely distributed mangrove tree species *Avicennia marina* is presented at the end of this chapter as Annexure 2A.1. The study clearly demonstrates the adverse impact of saline water intrusion (because of sea-level rise) on the biomass and carbon sequestration potential of mangroves.
6. Mangroves trap debris and silt, leading to the stabilization of the near shore environment (http://www.reefrelief.org/Documents/mangrove.html).
7. The highly specialized mangrove ecosystem also acts as the protector of the coastal landmass from storm surges, tropical cyclone, high winds, tidal bores, seawater seepage and intrusion. Large numbers of references are available in context to tsunami of 26 December 2004, suggesting that mangroves both dissipated the force of the tsunami and caught the debris washed up by it and thus helped to reduce damage (IUCN 2005). In several cases, mangroves were also instrumental in saving lives by preventing people caught in the backwash of the wave from being pulled out to sea. However, as with coral reefs, subsequent studies showed that the benefit of mangrove protection was rather variable. In India, bathymetry and coastal profile are most important in determining the impact, but less erosion was observed in the Andamans behind mangroves than where there were no mangroves (Department of Ocean Development 2005). A survey of 24 lagoons and estuaries along the southwest, south and southeast coasts of Sri Lanka which suffered the greatest damage showed that there was little destruction to the coast where good quality mangrove communities occurred, and the mangroves themselves were not badly harmed. However, forests dominated by less typical mangrove species (i.e. those that had been degraded in the past and were no longer dominated by genera such as *Sonneratia* or *Rhizophora*) were damaged (Dahdouh-Guebas et al. 2005). It therefore seems that the 'quality' of the mangrove forest contributes in large measure to its buffering capacity, in addition to its size and the extent of regrowth, if it had previously been cleared. Tree density is also an important factor related to the defensive property of mangroves: one study indicated

that a 100 m-wide belt of mangroves, with trees at a density of 30 per 100 m^2, would be sufficient to reduce the flow pressure from a tsunami by as much as 90 % (Hiraishi and Harada 2003).

8. Bioaccumulation of heavy metals by certain mangrove species reveals the most surprising feature about these plants as they can act as bio-purifier or bio-filter. Few species of mangroves are highly efficient in detecting or assessing the change of ambient environment. The concentration of heavy metal pollutants in different parts of mangrove plants may act as a pathfinder for water quality monitoring programme (Mitra et al. 2004).
9. Mangroves filter groundwater and storm water run-off that often contain harmful pesticides, herbicides and hydrocarbons. Mangroves also recharge underground water table by collecting rainwater and slowly releasing it into the underground reservoir.
10. Mangrove prop roots protect and offer habitat for mammals, amphibians, reptiles, countless unique plants, juvenile fish and invertebrates that filter water such as sponges, barnacles, oysters, mussels, crabs and shrimps.
11. Mangroves are ideal nesting grounds for many water birds such as the great white heron, reddish egrets, roseate spoonbills, white-crowned pigeons, cuckoos and frigate birds. The excretory materials of these birds (rich in phosphorus) serve as the fertilizers of the adjacent water bodies on which the primary production of the aquatic phase depends.
12. Mangrove forests are the housing complexes for bees, birds, mammals and reptiles from which honey, wax, food, etc. are obtained.
13. The molluscan species in the mangrove ecosystem (like oysters and gastropods) are the sources of lime.
14. Mangrove leaves are used as fodder and green manure. The cyanobacterial strains present on the forest floor of mangrove ecosystem are important sources of biofertilizer.
15. Extracts from mangrove and mangrove-dependent species have proven activity against some animal and plant pathogens. Moreover, mangrove extracts kill larvae of the mosquitoes, e.g. a pyrethrin-like compound in stilt roots of *Rhizophora apiculata* shows strong mosquito larvicidal activity (Thangam 1990).
16. Bioactive compound (ecteinascidin) extracted from the mangrove ascidian *Ecteinascidia turbinata* has shown strong in vivo activity against a variety of cancer cells.
17. Phenols and flavonoids in mangroves leaves serve as UV-screening compounds. Hence, mangroves can tolerate solar UV radiation and create a UV-free, under-canopy environment (Moorthy 1995).
18. Bark of *Ceriops* sp. is an excellent source of tannin, and a decoction of it is used to stop haemorrhage and as an application to malignant ulcers. Flowers of this plant are a rich source of honey and bee wax.
19. Mangrove ecosystem affords recreation to hunters, fishermen, bird watchers, photographers and others who treasure natural areas. However, the intrusive actions of noisy jet skis, campers and others, which disturb nesting and breeding areas, chop down mangroves and otherwise damage this fragile environment, threatening its existence. The recent trend of expanding shrimp culture activity at the expense of mangroves is another major threat to mangrove biodiversity.
20. Mangroves can adapt to sea-level rise if it occurs slowly enough (Ellison and Stoddart 1991), if adequate expansion space exists and if the ambient environmental conditions are congenial for their survival and growth. They have special aerial roots, supporting roots and buttresses to live in muddy, shifting and saline conditions. Mangroves may adapt to changes in sea level by growing upward in place or by expanding landward or seaward. This property of mangroves is known as *resilience*. Mangrove vegetation can expand their range despite sea-level rise if the rate of sediment accretion is sufficient to keep up with sea-level rise. However, their ability to migrate landward or seaward is also determined by local conditions, such as infrastructure (e.g. roads, agricultural fields, dikes, urbanization, seawalls and shipping channels) and topography (e.g. steep slopes). If inland migration or growth cannot occur fast enough to account

for the rise in sea level, then mangroves will become progressively smaller with each successive generation and may perish (UNEP 1994). The mangrove vegetation band width is thus directly proportional to their migration rate. A report published by McLeod and Salm (2006) identified important mangrove resilience factors related to site selection in context to climate-change-induced sea-level rise. These are listed here:

(a) *Factors that allow for peat building to keep up with sea-level rise*
  - Association with drainage systems including permanent rivers and creeks that provide freshwater and sediment
  - Sediment-rich macrotidal environments to facilitate sediment redistribution and accretion
  - Actively prograding coast and delta
  - Natural features (bays, barrier islands, beaches, sandbars, reefs) that reduce wave erosion and storm surges

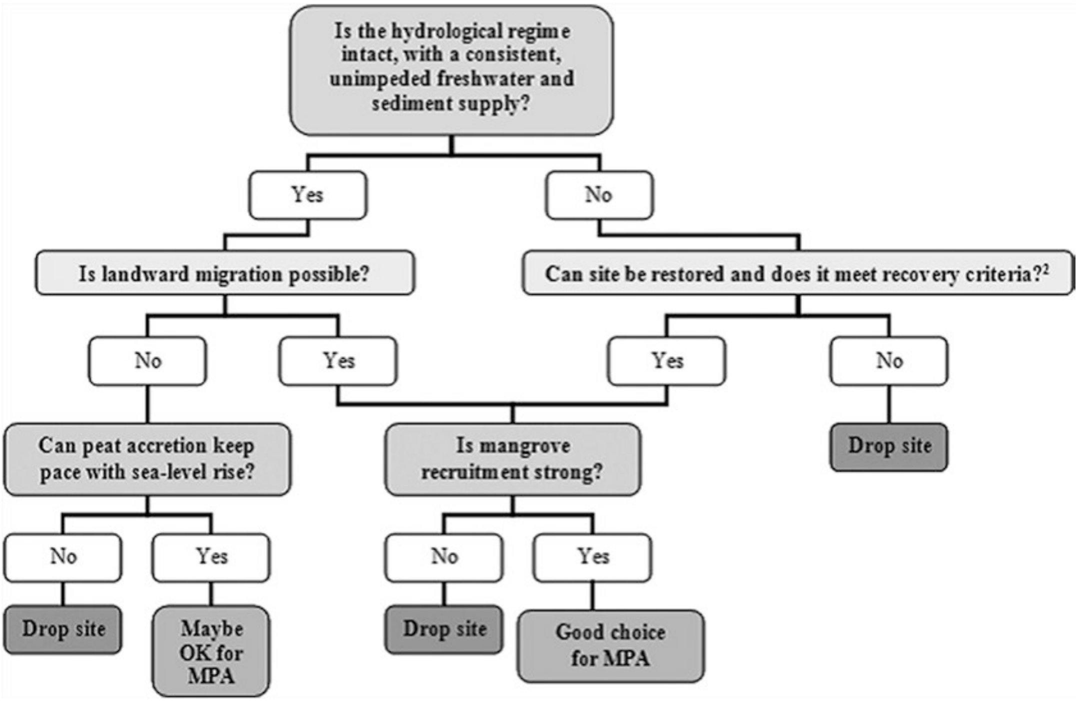
(b) *Factors that allow for landward migration*
  - Mangroves backed by low-lying retreat areas (e.g. salt flats, marshes, coastal plains) which may provide suitable habitat for colonization and landward movement of mangroves as sea level rises
  - Mangroves in remote areas and distant from human settlements and agriculture, aquaculture and salt production developments
  - Mangroves in areas where abandoned alternate land use provides opportunities for restoration, for example, flooded villages, tsunami-prone land and unproductive ponds

(c) *Factors that enhance sediment distribution and propagule dispersal*
  - Unencumbered tidal creeks and areas with a large tidal range to improve flushing reduce ponding and stagnation and enhance sediment distribution and propagule dispersal
  - Areas with a large tidal range may be better able to adjust to increases in sea level due to stress tolerance
  - Permanent strong currents to redistribute sediment and maintain open channels

(d) *Factors that indicate survival over time*
  - Diverse species assemblage and clear zonation over range of elevation (intertidal to dry land)
  - Range in size from new recruits to maximum size class (location and species dependent)
  - Tidal creeks and channel banks consolidated by continuous dense mangrove forest (which will keep these channels open)
  - Healthy mangrove systems in areas which have been exposed to large increases in sea level due to climate-change-induced sea-level rise and tectonic subsidence

(e) *Factors that indicate strong recovery potential*
  - Access to healthy supply of propagules, either internally or from adjacent mangrove areas
  - Strong mangrove recruitment indicated by the presence, variety and abundance of established mangrove propagules
  - Close proximity and connectivity to neighbouring stands of healthy mangroves
  - Access to sediment and freshwater
  - Limited anthropogenic stress
  - Unimpeded or easily restorable hydrological regime
  - Effective management regime in place such as the control of usual threats like dredging and filling, conversion to aquaculture ponds and construction of dams, roads and dikes that disrupt hydrological regime
  - Integrated Coastal Management Plan or Protected Area Management Plan implemented

The decision tree related to site selection in context to climate-change-induced sea-level rise is presented in flowchart No. A.



Flow chart No. A. Decision tree for mangrove recruitment/restoration in context to climate change induced sea level rise

21. The mangrove soil acts as unique reservoir of carbon. The carbon budget in the intertidal mudflat is, however, regulated by biological and physical factors. For interested readers, a technical report on mangrove soil carbon is presented as Annexure 2A.2 at the end of this chapter.
22. Mangroves, by way of fertilizing the adjacent estuarine and coastal water bodies, promote the growth of phytoplanktons that are unique sink of carbon dioxide. The hypersaline condition, however, limits the carbon sequestering potential of phytoplankton community by way of shrinking their volume. A detailed technical report on the role of salinity in regulating stored carbon in phytoplankton species is highlighted as Annexure 2A.3.

2.2 Threats to Mangrove Ecosystem

The mangrove ecosystems are gradually disappearing especially in the Indian Ocean region (Kathiresan and Rajendran 2005). The universal causes of the destruction are shrimp culture, woodchip and pulp industry, urban development and human settlements and domestic uses for timber, firewood and fodder. In dry areas, grazing by buffaloes, sheep, goats and camel can also lead to destruction of mangroves. In areas such as Gulf countries, oil pollution is often harmful for survival of mangroves. A natural cause that results in large-scale destruction of mangroves is cyclones in Bay of Bengal that gets aggravated with human interference (Blasco et al. 1994). Diversion of river water leading to hypersalinity in the downstream areas is a serious problem in the Indus delta of Pakistan and Cauvery and Sundarban deltas of India. Due to reduction in freshwater inputs, the freshwater-loving mangrove species like *Nypa fruticans* and *Heritiera fomes* become reduced in population density. In several coastal and estuarine sectors (e.g. in the upper stretch of Indian Sundarbans), because of low salinity of tidal water, tiger prawn hatcheries cannot be developed. In these areas, prawn seeds are collected by local villagers to meet the needs of shrimp farms. During this activity, finfish and shellfish seed resources of mangroves are largely destroyed. To cite an example, in Sundarban, about 40,000 people harvest about 540 million seeds of tiger prawn (*Penaeus monodon*) every year, and in this process, about 10.6 billion seeds of other fishes and shrimps are killed, which may have serious impact on fish diversity and fisheries resources (Chaudhuri and Choudhury 1994).

During the last two centuries, the highly productive mangrove ecosystems have been destroyed or degraded very rapidly. Although mangrove ecosystems have tremendous value for coastal communities and associated species, they are being destroyed at alarming rates. Over the last 50 years, about one-third of the world's mangrove forests have been lost (Alongi 2002). Human threats to mangroves include the overexploitation of forest resources by local communities; conversion into large-scale development such as agriculture, forestry, salt extraction, urban development and infrastructure; and diversion of freshwater for irrigation (UNEP 1994). The greatest human threat to mangroves is the establishment of shrimp aquaculture ponds. Because mangroves are often viewed as wastelands, many developing countries are replacing these forests with agricultural land and/or shrimp aquaculture production (Franks and Falconer 1999). Shrimp aquaculture accounts for the loss of 20–50 % of mangroves worldwide (Primavera 1997). Projections suggest that mangroves in developing countries are likely to decline another 25 % by 2025 (Ong and Khoon 2003). In some key countries like Indonesia, which has the world's largest intact mangroves, the projected rate of loss is even higher with 90 % loss in some provinces like Java and Sumatra (Bengen and Dutton 2003). In addition to these anthropogenic threats, mangroves are also threatened by the impact of global climate change. Global climate change and concomitant effects, such as changes in temperature and CO_2, altered precipitation patterns, storminess and eustatic sea-level rise as observed over recent decades, are primarily due to anthropogenic activities. Most of the observed warming over the last 50 years is attributed to an increase in greenhouse gas concentrations in the atmosphere (Houghton et al. 2001).

The alteration of hydrological parameters particularly salinity, pH, soil composition, etc. has degraded the mangrove ecosystem and posed threat to the survival and growth of few important mangrove species. The gradual vanishing of Sundari (*Heritiera fomes*) from the Indian Sundarbans sector (particularly from the central sector around the tide-fed Matla River) is a prominent example in this context. Over a period of 27 years, the salinity has shown an increasing trend (Fig. 2.2) in the central Indian Sundarbans.

Sundari (*Heritiera fomes*), being a freshwater-loving mangrove floral species, could not withstand this rising salinity of the ambient water and gradually vanished from the region. The authors of this book conducted an extensive comparative research on the impact of salinity on the growth of *Heritiera fomes* thriving in the Gangetic delta complex. The relatively higher growth rate of above-ground biomass of *Heritiera fomes* in the western sector of the deltaic complex (2.90 ± 0.26; range 2.65–3.3 t/ha during 2004, 3.56 ± 0.28; range 2.92–3.87 t/ha during 2005, 3.98 ± 0.29; range 3.15–4.08 t/ha during 2006, 4.32 ± 0.31; range 3.34–4.75 t/ha during 2007, 4.86 ± 0.37; range 3.92–5.45 t/ha during 2008 and 5.71 ± 0.43; range 4.62–6.38 t/ha during 2009) in comparison to that of the central sector (0.52 ± 0.09; range 0.3–0.77 t/ha during 2004, 0.53 ± 0.10; range 0.32–0.65 t/ha during 2005, 0.55 ± 0.13; range 0.34–0.70 t/ha during 2006, 0.59 ± 0.10; range 0.37–0.80 t/ha during 2007, 0.59 ± 0.19; range 0.39–0.83 t/ha in 2008 and 0.61 ± 0.17; range 0.42–0.93 t/ha during 2009) confirms the freshening and salinification of the western and central sectors, respectively, in the framework of lower Gangetic delta region. There are numerous studies on mangroves in terms of wood production, forest conservation, and ecosystem management (Putz and Chan 1986; Tamai et al. 1986; Komiyama et al. 1987; Clough and Scott 1989; McKee 1995; Ong et al. 1995; Chaudhuri and Choudhury 1994; Mitra and Pal 2002). This study is the first attempt from Indian subcontinent showing the impact of dilution of the estuarine system on the biomass of *Heritiera fomes*. Mangroves like other halophytes also decrease their water and osmotic potentials to maintain turgor pressure at higher salinity (Naidoo 1987; Khan et al. 1999; 2000a, b). There is a great deal of variation in the level of salinity required for

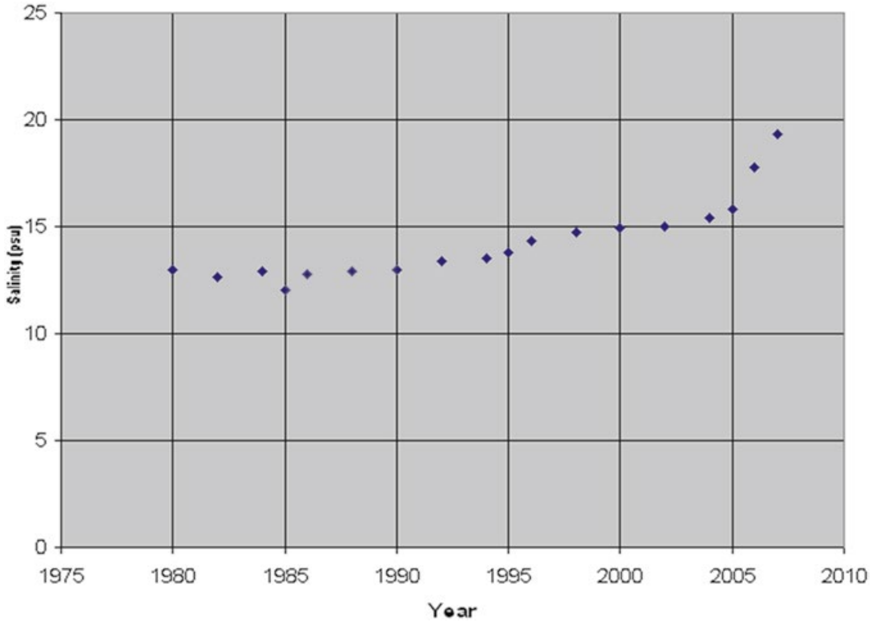


Fig. 2.2 Increasing salinity trend in the central part of Indian Sundarbans (*Data Sources*: A long term multi-disciplinary Research approach and Report on Mangrove ecosystem of Sundarbans (1980–1986 compilation) published by Department of Marine Science, University of Calcutta; Chakraborty and Choudhury (1985), Mitra et al. (1987, 1992, 2001, 2004, 2009), Mitra and Choudhury (1994), Saha et al. (1999), Banerjee et al. (2002, 2003), ADB – Asian Development Bank (2003))

optimal growth which varies from 10 to 50 % seawater (Downton 1982; Clough 1984; Naidoo 1987; Lin and Sternberg 1992, 1995; Karim and Karim 1993; Ball and Pidsley 1995; Smith and Snedaker 1995), and a decline in their overall growth is observed with a further increase in salinity. Similarly, decreased stomatal conductance, lower water potential and accumulation of inorganic ions are the result from extreme saline environments for most of the plants (Ball and Farquhar 1984; Naidoo 1987). *Heritiera fomes* is absolutely a freshwater-loving species, and hence, its growth has been greatly reduced in Central Indian Sundarbans over a period of time. The relatively higher growth of the above-ground biomass of the species in the western sector in comparison to that of the central sector (457.69 % higher in 2004, 571.70 % higher in 2005, 623.64 % higher in 2006, 632.20 % higher in 2007, 723.73 % higher in 2008 and 836.07 % higher in 2009) indicates the adverse impact of high salinity on *Heritiera fomes* due to difference in geophysical set-up (Fig. 2.3).

The study clearly demonstrates the response of certain mangrove species to changing salinity that may serve as indicator for climate-change-related studies. Similar works in Bangladesh revealed adverse impact of salinity on *Heritiera fomes* (Hoque et al. 2006). The species was detected as a rare species in strong salinity zones, whereas its presence was observed in the moderate and the low salinity zones of the Sundarbans forest of Bangladesh. Death of the species was also reported due to top dying disease which was frequently observed beside the river or the canals where inundation by the saline water is much and has water logging problem. Rahman et al. (1994) reported that top dying symptom was seen in areas where most of the pneumatophores have been buried partially and exposed to high salinity. The basic moral of the present study is the adverse role played by high aquatic salinity on certain mangrove species like *Heritiera fomes* and *Nypa fruticans* that may become very prominent in the near future due to climate-change-induced sea-level

Fig. 2.3 Above-ground biomass of *Heritiera fomes* in Central and Western Indian Sundarbans

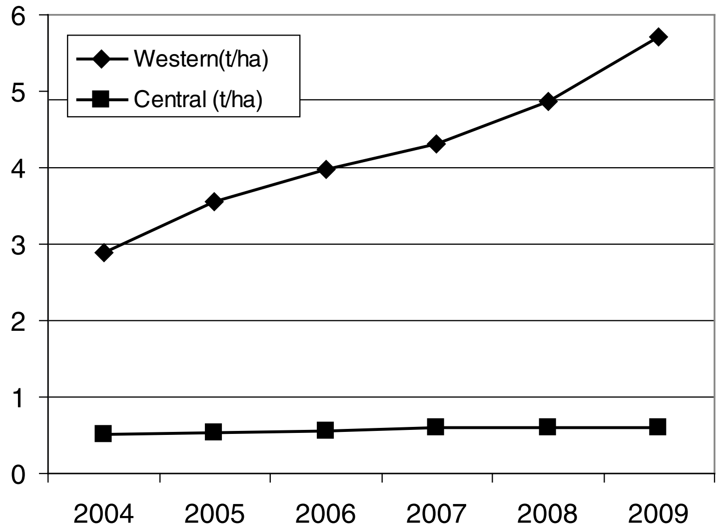


Fig. 2.4 *Heritiera fomes*

Fig. 2.5 *Nypa fruticans*

rise and subsequent salinification of the deltaic or coastal soil. The freshwater-loving mangrove species (Figs. 2.4 and 2.5) can thus act as indicator of sea-level rise and subsequent intrusion of seawater in the brackish water system.

Apart from fluctuation of hydrological parameters, mangroves are also degraded due to human factors. Due to extensive magnitude of human activity starting from agriculture to industry, the mangroves are degraded in various ways. Although the exact damage caused by pollution is difficult to assess, the mangroves are threatened by various kinds of pollutants that reach the coastal environment, namely, silt in the form of terrestrial and alluvial sediment, crude oil and petroleum derivatives, sewage, pesticides and solid and industrial wastes including toxic chemicals. Apart from this, logging and land development including agriculture, terrestrial and seabed excavations, insecticides and pesticides used in agriculture and their run-off, deliberate and operational discharges from ships, oil spills due to accident and industrial outflows also add to the pollution in the mangrove areas.

In context to Indian Sundarbans, sustaining about 34 true mangrove species, mangrove degradation is attributed in most cases to mushroom growth of shrimp farms along the tidal creeks and estuarine inlets. Ecologists have given their attention regarding the importance of mangrove and mangrove ecosystems only during the last two decades. Today it has been established that natural factors along with direct and indirect interference have largely changed the biological composition, ecosystem function and extent, productivity, regeneration and succession patterns within mangrove ecosystems.

The use of natural resources by man changes according to his needs. In turn, the needs of human populations vary locally and seasonally and may change also as a consequence of unpredictable episodic events and long-term climatic rhythms. Anthropogenic use and overexploitation of the mangrove forests have in many instances caused drastic changes of various extents in the coastal zone (Table 2.4). Major changes vary from total elimination of mangroves with consequent local edaphic, erosion or accretion processes to decreased productivity in terms of timber, firewood, charcoal and woodchip production, dependent fisheries and many others including the depletion of carbon sinks and its little known implication to global carbon budget and climate change (Gattuso et al. 1998). Total felling and overexploitation of mangrove forests are the historically recorded root causes of the desertification that has taken place in many coastal areas, as, for instance, along the coasts bordering the Arabian Gulf or the northern coast of the island of Socotra in the Indian Ocean.

The basic template of mangrove ecosystem conservation does not lie within the narrow band of afforestation of selective mangrove species, nor it is related to enforcement of laws, but community participation and generation of alternative source of income are some important strategies for conserving this fragile ecosystem. Conservation of mangrove ecosystem should be the priority to impart long-term sustainability to the entire matrix as all the species of the ecosystem are intra- and interconnected. In context to large-scale threats like sea-level rise, few important strategies have been identified that collectively hold promise to increase the viability of mangroves by enhancing their resilience. These are as follows:

1. Apply risk-spreading strategies to address the uncertainties of climate change.
2. Identify and protect critical areas that are naturally positioned to survive climate change.
3. Manage human stresses on mangroves.
4. Establish greenbelts and buffer zones to allow for mangrove migration in response to sea-level rise and to reduce impacts from adjacent land-use practices.
5. Restore degraded areas that have demonstrated resistance or resilience to climate change.
6. Understand and preserve connectivity between mangroves and sources of freshwater and sediment and between mangroves and their associated habitats like coral reefs and seagrasses.
7. Establish baseline data and monitor the response of mangroves to climate change.
8. Implement adaptive strategies to compensate for changes in species ranges and environmental conditions.
9. Develop alternative livelihoods for mangrove-dependent communities as a means to reduce mangrove destruction.
10. Build partnerships with a variety of stakeholders to generate the necessary finances and support to respond to the impacts of climate change.

Table 2.4 World mangrove loss and degradation approximate assessment in 2000 (in km^2)

Country	Approx. total area 1990[a]	Approx. total area 2000	Closed-dense mangrove (forest or thickets)	Open-degraded or very degraded mangroves	Main causes of degradation[b]									
					Clear felling conversion to									
					Aquaculture	Agriculture	Freshwater diversion, damming	Salt industry	Urban development	Oil spills	Other pollutions	Excessive siltation	Climate change[c]	Sea-level change
Australia	11,500	11,500	9,200 (80 %)	2,300 (20 %)	[d]				x		x			
Bangladesh	6,000	6,300	4,095 (65 %)	2,205 (35 %)	xx		xxx					x	?	x
Brazil	13,800	10,150	6,090 (60 %)	4,060 (40 %)		xx			xx	xx	xx	?	?	?
Cameroon	2,500	2,400	1,680 (70 %)	720 (30 %)		xx			x	x	x		?	?
Columbia	4,000	3,600	2,520 (70 %)	1,080 (30 %)		xxx	xxx		xx		x	xx		?
Cuba	5,300	5,500	4,565 (83 %)	935 (17 %)					x		x			?
Ecuador	1,900	1,600	1,040 (65 %)	560 (35 %)	xxxx			xx	xx		x			
Guinea	3,100	2,900	2,320 (80 %)	580 (20 %)		xx			xx					?
Guinea Bissau	2,400	2,400	1,560 (65 %)	840 (35 %)		xxx			xx		x			?
India	6,700	6,700	3,015 (45 %)	3,685 (55 %)		xxx		xxx	xxx		xx	xx	?	x
Indonesia	42,500	40,000	20,000 (50 %)	20,000 (50 %)	xxx	xxx			xxx	x	xx	xx		?
Madagascar	3,500	3,300	1,980 (60 %)	1,320 (40 %)	xxx	x			x			xx		?
Malaysia	6,400	6,400	5,120 (80 %)	1,280 (20 %)	xx	x			x		x			
Mexico	5,300	5,000	3,000 (60 %)	2,000 (40 %)	xx	xx			xx	xx	xx			?
Myanmar	7,500	6,900	2,280 (33 %)	4,620 (67 %)	xxx	xxx			xx		x	xx		?
Nigeria	10,500	10,500	2,625 (25 %)	7,875 (75 %)		xxx			xxx	xxxx	xx	xx		?
Papua N. Guinea	4,100	4,100	3,690 (90 %)	410 (10 %)		xx			x					?
Senegal	2,000	1,800	900 (50 %)	900 (50 %)		xxx	xxx	xx	xx		xx	xx	?	?
Philippines	1,400	1,300	780 (60 %)	520 (40 %)	xxxx									?
Venezuela	2,700	2,500	1,500 (60 %)	1,000 (40 %)		xx	xx		xx			xx	?	?
Vietnam	2,500	2,500	1,125 (45 %)	1,375 (65 %)	xxxx	xxx	xxx		xx		xx	xx		?
Total of 21 countries	145,600	137,350	79,085 (58 %)	58,265 (42 %)										
World Total	181,077	170,756	99,038	71,718										

Source: Laboratoire d'Ecologie Terrestre, Toulouse

Logs or conversion: 8,250 km^2 in the decade (5.7 %) or 825 km^2/year. This result is based on the main 21 countries having mangroves representing about 80 % of the global total

World's mangrove loss during the decade has been about 10,321 km^2 or about 1,030 km^2/year

[a]These figures should be used with caution; the year 1990 is only a reference; in many cases, essentially in SE Asia, the latest available figures for the decade 1980–1990 are those published by UNESCO/UNDP 1986

[b]Scale of impacts: xxxx, extreme; xxx, severe; xx, medium intensity; x intensity? Possibly, to be confirmed

[c]For instance:

Higher frequency of low rainfall years in West Africa or Coastal Peru and Ecuador

Higher frequency or intensity of cyclonic storm

[d]Blanks: No data or not observed from space

2.3 Conservation of Mangroves: Case Study of Indian Sundarbans

IUCN in 1980 defined conservation as '… the management of human use of the biosphere (i.e., all living things) so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the need and aspiration of future generations…'. Maintaining biodiversity is thus a central tenet of nature and wildlife conservation. To conserve marine life, information on the resource (the habitats, communities and species) needs to be collected and arranged in a structured way in order to identify the nature conservation importance of sites and to manage areas to conserve their important features (Hiscock 1997). It is to be noted that the conservation policy is not uniform throughout the globe; it varies from place to place depending on the resource base, pattern of exploitation and nature and magnitude of threat, e.g. the pattern of exploitation in Arctic or Antarctic zone is totally different from the tropical seas or mangrove regions. To make it clearer, the example of regional resource base can be cited. The coral is a biological resource scattered around the archipelagos of Andaman and Nicobar Islands of Indian subcontinent, which is gradually eroding due to temperature fluctuation or changes in physico-chemical properties of the seawater. However, in Indian Sundarbans region, fish germplasm constitutes an important resource, which is under threat due to wild harvest of prawn seeds, illegal fishing practice, etc. Thus, threats are always site specific in nature and intricately related to the nature of resource, their exploitation pattern and socio-economic profile of the area. On this basis, it has been suggested by Hiscock (1997) that there is a need for five main areas of information prior to conservation. These are:

1. Physical and biological resource data
2. Physical and chemical environment-related information
3. Information on the structure of biotic communities and on the key elements in their functioning
4. Information on natural variability
5. Information on effects of human activities

All these information will require a systematic approach to its application to conservation and management through:

1. Classification systems for resource data
2. Criteria to identify the nature conservation importance of an area including those to identify a comprehensive series of marine protected areas

The mangrove ecosystem of Indian Sundarbans is one of the most biologically productive, taxonomically diverse and aesthetically celebrated gene pool of the country sustaining 34 species of true mangroves along with a variety of associate species (Mitra and Pal 2002). This deltaic lobe is the cradle of several species of finfish, nursery of different variety of shellfish and reservoir of various nonliving resources of marine origin and encompasses a wide range of riverine, estuarine, coastal and marine habitats. On one hand, it exhibits enormous diversity based on its genesis, geographical location, hydrological regimes and substrate factors, and on the other hand, it also exhibits rare endemic genetic material, which demands preservation and proper sustainable utilization for the benefit of mankind. The biodiversity of this unique ecosystem has not yet been comprehensively assessed for several reasons. In India, due to lack of trained taxonomists and low emphasis on brackish water wetland micro-biodiversity studies, the exact role of micropelagic community is still not clearly known. Meiobenthos communities are seldom identified to the genus level and rarely into species. In general, very little information is available on microorganisms. A very important aspect of biodiversity is species-level genetic diversity, which has not received much attention. Both conservation and management of this unique ecosystem therefore demand a holistic approach and are very much dependent on the sciences and skills of geology, pedology, climatology, hydrology, botany, ecology, silviculture, forest technology and economics.

The landscape of Indian Sundarbans has changed remarkably due to large-scale human intervention since the beginning of the last century. As a result of overexploitation, demographic pressure, loss of habitat and change of ecological condition, several of the earlier reported species have become extinct or are in a very threatened or degraded state.

Large-scale clearing of the Sundarbans mangroves in the last 200 years for settlement of human population, aquaculture, etc. has invited a situation of great stress to the pristine mangrove ecosystem in this part of the Indian subcontinent. Hence, effective conservatory measures are essential to protect this gene pool. The integrated management of mangrove resources depends not only on an understanding of the ecological and silvicultural parameters for forest management but also on the biological role that the primary production from the forest plays in sustaining the food web of the adjacent aquatic subsystem (secondary production). An understanding of the role of key stone species in maintaining the equilibrium of this particular ecosystem is also very essential.

Being a mega-diversity country, India accounts for 7–8 % of the total recorded species of the world though occupying only 2.4 % of the land area. The Convention on Biological Diversity (CBD), to which India is a contracting party, deals with various aspects, like conservation of natural resources, their sustainable use and fair and equitable share of benefits. The convention has also identified forests, coastal and marine ecosystems, grasslands, wetlands and deserts as priority ecosystem for biodiversity conservation. Based on this convention, several strategies have been adopted to conserve the vibrating mangrove ecosystem of Indian Sundarbans. The important ones are listed here:

- Encouragement towards alternative livelihood scheme
- Afforestation
- Introduction of silviculture system
- Ecological rehabilitation of the Sundarbans under the Integrated Wasteland Project
- Captive breeding programmes
- Conservation policies

Each of the above strategies is discussed in detail.

2.3.1 Encouragement Towards Alternative Livelihood Scheme

Among 4.2 million people in the Sundarbans Biosphere Reserve area of Indian part, 50 % survive below poverty level (BPL). Improving the economic conditions of these people through promotion of sustainable utilization of natural resources is an optimistic and valid step towards ensuring the long-term sustainability of the adjacent mangrove ecosystem. Government departments and several nongovernmental organizations have undertaken important programmes on alternative livelihood in the deltaic complex to wean away people from random exploitation of mangrove resources.

2.3.1.1 Environment Education and Awareness Generation

Teacher-training workshop is used as one of the tools of conservation for generating environment awareness and imparting knowledge of endemic biotic resources. Teachers of the islands are exposed to modern pedagogic techniques to make environment education interesting rather than routine. As a part of awareness generation programme, a number of nature clubs have been opened by the nongovernmental organizations. The main purpose of such programmes is to imbibe the conservation ethics among the students through their education system. Finally the student community is motivated to spread the light of conservation in different tiers of the society.

2.3.1.2 Vocational Training for Prawn Seed Collectors

Most of the women in Sundarbans are involved in collection of tiger prawn (*Penaeus monodon*) seeds in the estuarine water. This creates a major loss in population of finfish and shellfish juveniles, which may cause an adverse impact on the pelagic and demersal fish stock of the aquatic subsystem in the near future. To divert the prawn seed collectors from such destructive practice, vocational trainings on several aspects are given, which include training on tailoring, net making

Table 2.5 Total coliform load (five test tube method) in water samples collected from the sampling stations during April 2007

Sl. No.	Stations	MPN/100 ml in LST	MPN/100 ml in BGL
1	Namkhana	>1,600	>1,600
2	Frasergaunge	1,600	1,600
3	Sajnekhali	550	350

and handicrafts. Apart from these, trainings on kroiler rearing, piggery, campbell duckery, etc. are also conducted on a regular basis. Kroiler (a breed of hen) rearing has involved large number of villagers in eastern Indian Sundarbans as the economic returns are quite high and had enthused youth of the village to start small-scale business venture dealing only with kroiler poultry. Presently pig farming has been taken up by a group of beneficiaries on an experimental basis. Fish feed preparation using seaweed-based protein is also taught to some group of beneficiaries through which they can boost up fish production in their household ponds and brackish water bodies. The Department of Science and Technology, Government of India, also completed successfully a pilot project on fish feed preparation using the red seaweed *Catenella repens* (Sanction No.SSD/SS/046/2006; date: 05.07.2007). Researchers from University of Calcutta documented the biochemical composition of the seaweed species (Banerjee et al. 2009) as baseline data of the livelihood project.

2.3.1.3 Canal Excavation

Excavation of canals is done to stock freshwater or to harvest the rainwater so that agricultural activity may be carried out throughout the year in this saline belt of the country. Government departments like Forest Department and Fishery Department are regularly involving considerable village population in canal excavation. The canal excavation has brought about a radical change in the sphere of agriculture through a shift from mono-cropping system to multiple-cropping system. Today, the people of the islands are growing chilli, tomato, potato, brinjal, cauliflower, cabbages, etc. along with the main crop paddy. Many beneficiaries have also initiated freshwater prawn culture (*Macrobrachium rosenbergii*) in these canals. It is expected that this constructive activity will defray a sizeable chunk of the population from penetrating into the adjacent forest zone.

2.3.1.4 Oyster Culture

In Indian Sundarbans, edible oyster species like *Saccostrea cucullata* and *Crassostrea madrasensis* are common. These species have high export value and are also good source of calcium, which can be used in poultry and cattle feed industry. The ability to produce, transport and market healthy disease-free shellfish is crucial to the success of the Indian oyster industry. Hence, microbial load in the oyster tissue and ambient media was monitored by Mitra et al. (2006) to evaluate the quality of the product and the suitability of the environment to initiate the culture (Tables 2.5, 2.6, 2.7, and 2.8).

The culture of edible oyster can open up a new avenue in the livelihood sector of the Sundarban people, but due to drastic fall of aquatic salinity in the monsoon, the species may face high mortality. Turbidity of the aquatic phase is another hindrance to oyster culture in the lower Gangetic region. Construction of sheltered closed system with provisions of brine and sedimentation tank may be effective to initiate oyster culture in the area.

2.3.1.5 Crab Fattening

The Fisheries Department, Govt. of West Bengal, and few local NGOs working in Indian Sundarbans have taken up this venture. *Scylla serrata* is the most common crab species in this deltaic lobe with high market value and demand. Megalops of this species collected from the wild are stocked in brackish water ponds and fed voraciously with trash fishes to increase the fat content of the species within 120 days. The male crabs usually attain a weight of 300–350 g, while

Table 2.6 Total coliform load (three test tube method) in sediment samples collected from the sampling stations during April 2007

Sl. No.	Stations	MPN/g in LST	MPN/g in BGL
1	Namkhana	30	30
2	Frasergaunge	24	24
3	Sajnekhali	9.5	9.5

Table 2.7 Total coliform load (three test tube method) in edible oyster samples collected from the sampling stations during April 2007

Sl. No.	Stations	MPN/g in LST	MPN/g in BGL
1	Namkhana	>110	>110
2	Frasergaunge	110	110
3	Sajnekhali	46	45

Table 2.8 Total faecal coliform load (five test tube method) in water samples collected from the sampling stations during April 2007

Sl. No.	Stations	MPN/100 ml in EC
1	Namkhana	40
2	Frasergaunge	50
3	Sajnekhali	4

the female crabs attain a weight of 180–250 g, which fetch good price in the market.

2.3.1.6 Apiculture

Several cooperatives have initiated apiculture in Indian Sundarbans including the Forest Department, Govt. of West Bengal. Schemes involving the harvest of honey from wild *Apis indica* by placing artificial beehives inside the forest have also been adopted. Although this species cannot be tamed, the yield has been about 20–25 kg per box over a period of 2 months during trials in comparison to yields generated from *Apis dorsata*, which is usually 3–4 kg per box. An annual harvest of 65,000 kg of honey from the *Apis indica* beehives is expected.

2.3.1.7 Pisciculture

Considering the water resources in and around Indian Sundarbans and the seed resources of several commercially important fish species in the brackish water system, several private industries initiated polyculture in islands of central Sundarbans during March 2008. Such programmes aimed the blending of biotechnology with pisciculture practice. The species of polyculture like tiger prawn (*Penaeus monodon*), parse (*Liza parsia*) and bhangone (*Liza tade*) was fed with specially formulated feed having seaweeds and other plant extracts. The feed also improved the water quality and controlled the disease problem of tiger prawn to a great extent. This programme of sustainable polyculture through formulated fish feed created an impulse among the local people, and an overwhelming response was observed in terms of the number of beneficiaries. The Department of Science and Technology, Govt. of India, also funded similar type of projects through WOSB scheme during 2009–2012 with the aim to boost up sustainable pisciculture and put momentum to conservation process of mangroves (Fig. 2.6).

2.3.2 Afforestation

There are enormous degraded areas in Sundarbans forests, which may be categorized as follows:

1. Degraded areas devoid of any vegetation (Category 1)
2. Degraded areas under scrubby growth of *Ceriops decandra* (Category 2)
3. Degraded areas under scrubby growth of *Excoecaria agallocha* (Category 3)

Category 1 is characterized by saucer-shaped areas with no vegetation. Floodwater remains in the depressions from March to December. Salt accumulates on the topsoil and no plantation can be undertaken. Salinity can be reduced by improved drainage of these areas, and the soil may be improved through the use of gypsum, sulphur and natural grasses.

The area under *Category 2* is covered with a scrubby growth of *Ceriops decandra* and requires silvicultural improvement through planting of upper storey species. Some experiments have been carried out where strips are cleared and upper storey species have been planted.

Category 3 has hard soil and, apart from a scrubby growth of *Excoecaria agallocha*, no seed naturally transported or artificially dibbled germinates in this area.

Fig. 2.6 Harvested freshwater prawn (*Macrobrachium rosenbergii*) – an output of conservation-oriented DST, Govt. of India funded project

- A mangrove rehabilitation project recently launched envisages the afforestation of embankments with mangrove species over 3,300 ha and protection of degraded mangrove forestland covering 25,000 ha, through Forest Protection Committees (FPCs). More recently, NGOs have also taken active role in afforestation programme involving the local population.

2.3.3 Introduction of Silviculture System

The silviculture systems are designed to harvest the mature crop while allowing regeneration of the forests. Trees above a certain fixed diameter are harvested as long as these do not create a permanent gap in the canopy.

Until 1931, the system of exploitation was based upon the issue of permits from the revenue stations along the forest border. Following the introduction of *Curtis's plan* in 1931, a system of ranges, working circles, felling cycles and coupes were introduced. Natural regeneration was regarded as healthy, and therefore, a system of selection felling on cycles varying from 16 to 40 years was prescribed.

Choudhuri's plan was a modified version of Curtis's plan, which made the exploitation and laying out of coupes easier but did not put adequate stress on the silviculture of mangrove species. In the late 1950s, the assumption still remained that the mangroves were capable of regenerating themselves with considerable recovery rate and in sufficient numbers to justify the selection method of felling.

The *Forest Working Plan for 24 Parganas Forest Division*, following the partition of India in 1947, adopted a felling cycle of 20 years. The rules under this plan, for the most part, exist till the present day. According to this plan, the exploitable diameter at breast height (i.e. 130 cm from the ground level) of different mangrove plants is mentioned in Table 2.9.

Fishing was allowed free in tidal water, provided that the fishing boats are registered with the Forest Directorate on payment of a registration fee and royalty for dry fuel wood to be consumed during each fishing trip. However, no fishing was allowed within the core area of the Sundarbans Tiger Project. Permits were only issued for entry inside the reserved forest for exploitation of fuel, timber and other forest products. The number of persons and quantity of production to be allocated

Table 2.9 Exploitable diameter at breast height of different mangrove plants

Mangrove plants	Exploitable diameter at breast height (cm)
Avicennia sp.	12.5
Bruguiera sp.	15.0
Excoecaria agallocha	10.0
Heritiera fomes	7.5
Xylocarpus granatum	12.5
Xylocarpus mekongensis	15.0
Avicennia sp.	22.5–40.0
Sonneratia apetala	23.5–45.5

to each permit holder was fixed by the Divisional Forest Officer (DFO). For this, an essential prerequisite was to register a boat, and only boats with carrying capacities ranging from 50 to 400 quintals were registered. A published schedule of prices for different species of timber, fuel wood and other forest products was used for the assessment of the value of the harvested products.

From 1981 to 1982, regular coupes were laid out in the buffer zone. The first Management Plan of Tiger Project prescribed a felling cycle of 20 years. Felling was controlled by area, where a selection-cum-improvement system was followed. Permits were granted for the collection of honey, wax, *Nypa* palm and minor forest products, although the collection of *Nypa* palm was prohibited in 1978. Fishing was permitted in the buffer zone of the project area to permit holders who had registered boats. These permit holders generally apply to get permission for fuel wood collection as well.

In the core area of Tiger Project, no harvesting has been allowed since 1984. Felling has also been prohibited in the wildlife sanctuaries, following their gazettement. The remaining areas utilized for silviculture are managed on a selection-cum-improvement felling cycle. Selective felling of trees for fuel wood and timber over the non-sanctuary area in the buffer zone each year is conducted in a felling series over 1/20th of the area. Plantations are raised in the mangrove blocks mainly with the species like *Heritiera fomes*, *Xylocarpus granatum* and *Xylocarpus mekongensis*. Dry fuel wood permits are also issued.

Table 2.10 Zonation within the Project Tiger area

Zone	Area (km^2)
Revised core area	1,699.50
Buffer area	885.27
Wildlife sanctuary area	362.33
Available exploitable area	496.78
Erosion buffer	26.16

Source: Chaudhuri and Choudhury (1994)

Previously the total area of reserved forest was estimated at 2,585 km^2 and the core area of the tiger reserve as 1,330 km^2. Based upon satellite imagery, the size of the core area has been revised as 1,699 km^2 (Table 2.10).

The actual area available for timber harvest is therefore 587.35 km^2 where 29.26 km^2 is exploited annually on a 20-year felling cycle. This area was further divided into fair weather and rough weather coupes to account for potentially hazardous working conditions, such as strong winds. Following the policy to restrict felling in the Sundarbans, the area covered by these coupes was systematically reduced and the present coupe area is 800 ha, to be worked annually in fair weather only. Hence, the annual felling area in the Project Tiger area, calculated for a 20-year felling period, amounts to 1/20th of the total available exploitable area or 24.84 km^2. The present felling regulations in the felling area are:

1. Fair and rough weather coupes are to be marked from the north.
2. The exploitable diameter for *Excoecaria* trees is 25 cm.
3. *Heritiera fomes*, *Sonneratia apetala* and *Xylocarpus mekongensis* are not to be felled.
4. Dry fuel wood may be collected by villagers for local consumption, only from coupes already worked over.

In the 24 Parganas district, outside the Project Tiger area, a new scheme has been drawn for the 10-year period 1992–1993 to 2001–2002. Under this scheme, the annual coupe will be maintained at 1,150 ha, under four felling series. The felling cycle has been fixed for 15 years. Felling of *Heritiera fomes*, *Sonneratia* sp., *Xylocarpus granatum* and

Xylocarpus mekongensis has been restricted. The rough weather-felling coupe has been closed in 1989–1990.

2.3.4 Ecological Rehabilitation of the Sundarbans Under the Integrated Wasteland Project

The project envisages a total economic uplift of local communities presently living below the poverty line in remote areas of Sundarbans. The project is being implemented through the Sundarbans Biosphere Reserve (SBR), and the scheme has been designed to combine a full spectrum of activities comprising afforestation, conservation of fragile areas, development of pasture, soil conservation, minor irrigation, cottage industries and other socio-economic and ecological components.

2.3.5 Captive Breeding Programmes

2.3.5.1 Crocodile

The estuarine crocodile (*Crocodylus porosus*) is one of the largest saline water reptiles, which was indiscriminately killed for the purpose of making luxury goods from its skin. The level of poaching became so severe that the population subsequently declined, making the species endangered.

On 1 April 1975, the Government of India, with the assistance of FAO and UNDP, requisitioned the services of an FAO expert and initiated crocodile farming in India. The saltwater crocodile scheme was initiated in the Sundarbans in March 1976 at Bhagabatpur on Lothian Island, and efforts were focused on reducing the high mortality rate of the egg and newly hatched stages. Today, the saltwater crocodile scheme in the Sundarbans is one of the principal crocodile breeding centres in India. By 1990, more than 197 crocodiles had been released into the Sundarbans (Chaudhuri and Choudhury 1994). This is a success indicator of the crocodile breeding programme.

2.3.5.2 Olive Ridley Turtles

Marine turtles are protected under Schedule 1 of the Wildlife Protection Act. The olive ridley turtle (*Lepidochelys olivacea*), which extends its migration to the Sundarbans deltaic region, is an endangered species. Previously there was a period when millions of olive ridley eggs were harvested immediately after the breeding season. The poaching of mating pairs was a lucrative business during the breeding season (January and February) when thousands of animals were brought to the shore at Digha, West Bengal, for selling in the Calcutta market. This reduced their population to a great extent, and, therefore, attempts were made to rear and rehabilitate this species at the Bhagabatpur Crocodile Breeding-cum-Rearing Centre and at the Saptamukhi Hatchery by the Department of Forests, Government of West Bengal. The programme showed encouraging results when out of 117 hatchlings that emerged from artificial nests at Bhagabatpur, 99 healthy hatchlings were released into the ambient water and 18 were segregated for further research work (Banerjee 1985).

2.3.5.3 Horseshoe Crabs

Horseshoe crabs, chelicerate arthropods belonging to the class Merostomata, are considered to be the oldest 'living fossils'. They have been considered as Schedule IV animal by the Ministry of Environment and Forests (Govt. of India) in 2008 under Wildlife Protection Act (1976). There are only four species of the horseshoe crab reported in the world, among which *Carcinoscorpius rotundicauda* is plentiful in the deltaic Sundarbans region. Although *Tachypleus gigas* is also reported from the deltaic Sundarbans, the frequency of occurrence is very low (3–5 %) among the total horseshoe crab population. The species is destroyed at random during the fish catch in the neritic zone and wild harvests of tiger prawn seeds. With the unfounded belief that they can cure arthritis, the extracts of different organs of the species are sold in Calcutta markets. These activities caused a decline in the population of the species in recent years in the northeast coast of the Bay of Bengal. The species have been found to be a potential source of a bioactive substance, Carcinoscorpius amoebocyte lysate (CAL), from its blue blood (Chatterji and Abidi 1993). This reagent is highly sensitive and useful for the rapid and accurate assay of gram-negative bacteria, even if present in a very minute quantity, up to the level of 10^{-10} g. Hence, the CAL has been proved to be a valuable diagnostic reagent in the detection of endotoxins in several pharmaceutical products, especially injectables. Given the immense biomedical value of the species, a project entitled 'Application of biotechnology and molecular biology in the resource exploration and sustainable management of Sundarbans mangroves' was sanctioned to the S. D. Marine Biological Research Institute at Sagar Island by the Department of Biotechnology under the Ministry of Science and Technology, Government of India, on 26 December 1997. This aimed to develop culture technology for *Carcinoscorpius rotundicauda* and *Tachypleus gigas* suited to the Sundarbans environment. The project made a thorough study on the optimum range of various physico-chemical variables (such as water temperature, salinity, pH, nitrate, phosphate, silicate, dissolved oxygen, dissolved copper, organic carbon of sediment) in relation to the fertilization and condition value of the three different weight groups of horseshoe crabs. The development and standardization of culture technology of this species along with cell line culture may pave the way for manufacturing Carcinoscorpius amoebocyte lysate (CAL) and Tachypleus amoebocyte lysate (TAL) on commercial basis from the amoebocytes of these species without damaging their natural population.

2.3.6 Conservation Policies

A number of acts and policies have been adopted to protect India's biological diversity and its biotic and its associated abiotic components, which were also applicable for the protection of the Sundarbans mangrove ecosystem. There are three main acts for the protection of the environment. These are the *Wildlife Protection Act* (1972), the *Forest Conservation Act* (1980) and the *Environment Protection Act* (1986), with their various amendments (Government of India 1992a). The implementation of *Coastal Regulation Zone* (*CRZ*) is another bold approach towards conservation of natural resources in the marine, coastal and estuarine fronts of the country through restriction of certain activities.

The National Conservation Strategy and Policy Statement on Environment and Development (Government of India 1992b) provide directives for the integration and internalization of environmental issues in the policies and programmes of various sectors. The National Forest Policy (1988) complements the Forest Conservation Act (1980) by increasing the participation of local people in forest conservation activities.

The semi-intensive shrimp culture farms that deteriorated the coastal ecosystem by way of discharging (untreated) wastes have also been restricted by the Supreme Court of India on the basis of the Environment Protection Act (1986). On 11 December 1996, the Court ordered the coastal states with aquaculture farms other than traditional and improved traditional ones, operating within 500 m of the HTL in the coastal zone to demolish them by March, 1997. The Court also directed that no shrimp farms could be set up within 500 m of the HTL in the zone. In accordance with the principles of 'sustainable development' and 'polluter pays', the Court also directed the government to set up a body under clause (3) of Section 3 of the Environment Protection Act 1986. The said body would issue permits to the farmers of traditional aquaculture to adopt improved traditional farming systems. The Court also ruled that the owners of the closed aquaculture units would be liable to pay 6-year wages as compensation to the workers as well as for eco-restoration of the affected areas by way of creating an Environment Protection Fund. There was an excellent response to this notification and now only traditional and improved traditional shrimp farms exist in the northeast coast of the Bay of Bengal.

India has several legislative acts that are relevant to various uses of the oceans and coastal zones under which the Coastal Regulation Zone (CRZ) was notified in 1991 through the Ministry of Environment and Forests. Under Section 3(1)

Table 2.11 Structure and activities (permitted and restricted) in CRZ

Category	Area	Important conservation-oriented activities
CRZ – I	All the ecologically sensitive and important areas, namely, the Sajnekhali, Lothian and Halliday sanctuaries; reserve forests, wildlife habitat and mangrove forests in the Sundarbans; New Moore and Sandhead islands; important breeding sites of finfishes, shellfishes and other species; important hotspots from the point of biodiversity; the lower long sand area for its aesthetic beauty and biological diversity; historical and heritage sites at Sagar Island that fall within the high tide level (HTL) and low tide level (LTL)	Some eco-friendly communication facilities, construction of schools and hospitals will be allowed
		Aquaculture will not be permitted in mangrove-rich area
		Seed hatchery will be encouraged where by 5 % will be released in the creek
		A marine park will be established in the southern part of the Sagar Island
		Culture of algae and edible oyster will be encouraged
CRZ – II	Areas that have already been developed and close to the shoreline. Such areas include those within the municipal limits (e.g. Haldia along the Hugli river) and other legally designated areas which have drainage facilities, approach roads, water supply, etc. The Haldia town and eastern part of Digha fall within this zone	Shore protection measures will be adopted
		Dredging activities will be regulated
		EIA will be compulsory for any projects
		Regular monitoring of pollution will be carried out
CRZ – III	Areas that are yet to be developed and include Shankarpur and western Digha	A special body of the State Government will select aquaculture sites on the basis of recommendation
CRZ – IV	Coastal stretches in the Andaman and Nicobar, Lakshadweep and small islands	No new construction of buildings shall be permitted within 200 m of the HTL
		The buildings between 200 and 500 m from the HTL shall not have more than 2 floors (ground floor and first floor), the total covered area on all floors shall not be more than 50 % of the plot size and the total height of construction shall not exceed 9 m
		The design and construction of buildings shall be consistent with the surrounding landscape and local architectural style
		Dredging and underwater blasting in and around coral formations shall not be permitted

Source: Mitra and Pal (2002); examples of West Bengal coast have been cited except for CRZ IV
Remark: The distance from the High Tide Line *shall* apply *to both sides* in the case of rivers, creeks and back waters and may be modified on a case by case basis for reasons to be recorded while preparing the Coastal Zone Management Plans. However, this distance shall not be less than *50** (**This provision has been struck down by the Supreme Court of India*) 100 m or the width of the creek, river or backwater whichever is less

and (2) of the Environment Protection Act (1986) and Rule 5(3) (D) of the Environment Protection Rule (1986), the CRZ covers the coastal stretches of seas, bays, estuaries, creeks, rivers and backwaters which are influenced by tidal actions in the landward side up to 500 m from the High Tide Line (HTL) and the land between the Low Tide Line (LTL) and the HTL. In general, the HTL is estimated to be the line up to which the highest tide reaches during the spring time. In relation to the maritime states of the Indian subcontinent, the CRZ has been classified into four categories with distinct gradation of activities for a more scientific management of the ecosystem (Table 2.11).

The entire discussion pinpoints that resource base of any ecosystem may be claimed as sustainable, when it can be carried out over long term at an acceptable level of biological and economic productivity, without leading to ecological changes that reduce options for future generations. A sustainable resource base, therefore, has three major components – ecological, social and economic. Considering the salinity-based ecological zonation, social structure and weak economic level of Indian Sundarbans, a proper guideline needs to be developed not by considering the deltaic lobe as a whole, but by emphasizing on the segmental approach, since every segment of Indian Sundarbans is significantly different from the other in terms of environmental parameters, resource base, threats and social and economic structure. Community participation and alternative livelihood scheme implementations are mere experimental tools of conservation, which may have both positive and negative outputs. Hence, such experiment needs to be conducted in selective pockets of this deltaic lobe because failure of the experiment may produce severe risk on the gene bank.

Fact Below the Carpet

Conservation is never possible when man is hungry. Out of hunger he destroys nature, intrudes into the forests, exploits the seas and demolishes the mountains for minerals. Hunger has several dimensions. The affluent society becomes hungry when the dinner is not served in right time or the breakfast could not be consumed because of the morning meeting with the boss. However, for majority of the people on Earth, there is a different meaning for hunger. To them hunger is the result of starvation, the result of natural disaster that has snatched their only patch for growing crops. The essence of conservation cannot reach this section of the society unless they get minimum food for satisfying their beloved children. The island dwellers of Sundarbans are the representatives of this class of the society. In this mysterious land of tides and tigers, law becomes lawless, resource base becomes baseless and policy cries in the voice of non-implementation under the pressure of this poorer section of society.

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