

Response and adaptability of mangrove habitats from Indian subcontinent to changing climate

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Abstract:

Mangroves, a predominant coastal habitat in the tropics, are constantly threatened by various anthropogenic pressures deteriorating them to a great extent. Global emissions of green house gases (GHGs) are likely to raise the world temperature and the sea level at the rate of 0.3 °C and 6 mm 10 Yr⁻¹ by the year 2100. Mangrove habitats would be more vulnerable to climatic changes and resultant sea level rise (SLR) because of their unique location at the interface of the sea, by altering eco-biological processes. It may extend the intertidal and supra tidal zones further inland resulting changes in existing ecological set up. The limitation of the landward margin would cause vertical rise resulting in water logging ultimately killing mangroves and dependent biota. The present document describes mangrove habitats and related issues from the Indian subcontinent in the context of climate variations and SLR, and recommends integrated long term monitoring.

Key words: Climate change, SLR, Vulnerability, Adaptability, Mangroves, Indian subcontinent

Introduction:

Mangrove habitats of a great ecological and socioeconomic values (1-2), predominately exists in the tropical belt extending from 30° S to 30° N. However, presently such habitats in the world, and particularly from Indian subcontinent, have been deteriorated (3-6). The larger scale damage in the recent past could mainly be attributed to lack or poor management. Major portions of coastal mega cities from Asia such as Mumbai (earlier Bombay), have been established by reclaiming islands and tidal swamps harboring mangroves. Lately, though protected vide coastal and biodiversity regulations, marine habitats face constant threats from ever growing population and their demand for shelter and livelihood. Increased anthropogenic activities and resultant temperature are likely to cause thermal expansion and melting of ice rising sea level. The potential impacts of global warming and sea level rise (SLR) is of a great concern to eco-sensitive marine habitats because of their locations. The present document discusses, response and adaptability of mangrove habitats from India and adjacent countries, in the context of future climate changes.

Description of region:

The region of Indian subcontinent lies in between 4° 46'- 24° 32' N and 67° 36'- 94° 54' E (Fig. 1), and it's climate is largely governed by Arabian sea and Bay of Bengal. The west coast of India is characterized by steep slopes, rises, promontories and drowned estuaries while the east coast exhibits a sequence of delta formations (7). The Gulf of Kutchchh represents the deltaic environment to a smaller extend towards northwest of India. Indus delta in the west (Pakistan) and Sunderban delta in east (India and Bangladesh) are prominent in the Indian subcontinent. The deltaic regions show alluvial deposits of 3.4 m thick and composed of fine clay and silt and clay looms. Lakshdweep group of island in the Arabian sea are emerging type distinguished by coral reefs and lagoons. Andaman and Nicobar group of island in the Bay of Bengal are of volcanic origin. The west coast of Sri Lanka is flanked by rocky headland, beaches, lagoons and small estuaries, while Mahaveli delta exists on the east coast. Sediments in the deltas, estuaries and lagoons of Sri Lanka are mainly of alluvial deposits of terrestrial origin and to the sea level residual formations including deep weathered soils (8).

The coastal climate varies from warm and arid in Indus and Gulf of Kutchchh to warm and humid in remaining part of the region (Table 1). The average monthly temperature and annual rainfall have been recorded in the range of 18-30 °C and 200- 2831 mm, respectively. Tidal amplitude along the coast of Sri Lanka remains <1 m while maximum amplitude of 5-6 m

occur by the northwest of Indus and Gulf, and Sunderbans in the northeast (Table 1). Mangroves thrive better in warm and humid regions receiving more rains, and occur >0.4m above mean sea level (9).

Status of mangroves:

Indian subcontinent harbours ~9700 km² of mangrove area (Table 1). The major formations occur in the regions of Indus, Sunderban and Mahanadi delta, Gulf of Kutchchh, Andaman and Nicobar group of island and a part of west coast and Jaffana peninsula in the north of Sri Lanka (Plate I). The maximum extent of delta ~ 4050 km² exists in Sunderban delta of Bangladesh (10) while Sri Lanka has 120 km² (6). Indus delta has ~1300 km² of area and is one of the largest arid zone mangrove forest in the world (5). Almost 70 % of mangrove cover in India is restricted to the deltaic environment of east coast and in the Gulf of Kutchchh along northwest coast (11). Andaman and Nicobar group of island represent ~770 km² however, > 60 % of the mangrove from Great Nicobar island have been damaged (SAC-unpublished data) by recent tsunami (26th December 2004). The Lakshdweep island being unstable and devoid of mangrove except in a small area (500 m²) at Minicoy (11). The mangroves of Sri Lanka are estimated to be ~120 km², and ~ 60 % of it confined to the west coast (Table 1).

The steep topography and narrow intertidal expanses along the west coast of India, around the Andaman and Nicobar group of island as well as from Sri Lanka has caused fringing and riverine nature of mangroves. The gradual slope and vast intertidal flats in the deltaic and Gulf of Kutchchh regions support largest patches and extensive stretches of mangrove formations. Lakshdweep island exhibit basin type of mangroves, and comprised mainly of *Bruguiera sexangula*. Stray occurrence of *Ceriops tagal* and *Avicennia marina* have also been reported from some of the islands of Lakshdweep (11). Flora of these habitats from Indian subcontinent comprised of 72 spp of exclusive mangroves, 165 species of associate and 676 species of sub aerial angiosperms, respectively (Table 2). However, number of species like *Bruguiera rheedii*, *Sonneratia persica*, *Rhizophora annamalayana*, *Heretiera macrophylla*, *Xylocarpus obovata* and *X. obovatus*, etc. need further confirmation for their Identity, using molecular technique. The maximum number of species occur in the deltaic regions of Sunderbans and Mahanadi delta of east coast of India and Andaman and Nicobar group of island. Bangladesh has record of 22 spp, which need to be reinvestigated as more number of species expected from this region, having similar geographical, geological, geomorphological, hydrological and climatological set ups to that of Indian Sunderbans. The Indus delta represented by 4 species, however, the Gulf of Kutchchh in India having similar climate harbor

11 spp of mangroves. *Avicennia marina* constituted > 90 % of mangrove cover from arid zones. In general, the *Avicennia* sp., *Sonneratia* sp., *Rhizophora mucronata*, *Acanthus ilicifolius*, *Excoecaria agallocha* form the dominant flora from the continent. These habitats harbor various kinds of biota of ecological and commercial importance (Table 2). Most of the species have been evaluated as threatened, endangered or critical by IUCN, and species such as *Xylocarpus* spp, *Kandelia candel*, *Bruguiera gymnorhiza*, *Sonneratia apetala*, *C. tagal*, *Heretiera* spp, *Nypa fruticans* etc. have been reported to be disappearing from the continent (4,6,12).

Threats:

Natural destruction is caused due to cyclones, storms, occasional tsunamis, floods, intensive grazing and infestation by pest, insects, oyster and woodborers. The cyclones are common phenomenon along the east coast of India and Sunderbans. Northeast coast (Orissa) and Sunderbans of India experiences a high frequency of cyclone during August September while southeast coast is subjected to low cyclone frequency during the months of October to November. The west coast of India, Indus delta and Sri Lanka very rarely experience cyclonic phenomenon. The recent tsunami has caused intensive damage to the mangroves from Andaman and Nicobar group of islands (SAC-unpublished data). Occasionally floods cause water logging as well as erosion of estuarine and creek banks damaging mangroves. Cattle graze on young seedlings and leaves of mangroves, particularly on *Avicennia* species. Mangrove thickets are intensively grazed by camals and goats in the arid zones in the Gulf of Kutchchh and Indus delta resulting in the low productivity and formation of dwarf mangroves. Oysters commonly attack lower portions of the trunks as well as roots weakening the plants. Woodborers feed on soft tissue (phloem and xylem) of stem, trunk and roots as well as young seedlings. Insect and pest invasion commonly occur during August to October when humidity in the region remains at large. In general, most of the mangroves species survive pest and insect attack (13), however, occasionally heavy infestations kill them (Plate II). Barnacle and oyster infestation on roots and trunks of young mangroves cause a large mortality in the downstream and bay regions.

Wide range of anthropogenic activities (Plate III) have been the major cause of large-scale deterioration and reclamation of mangroves. These activities include urbanization, agricultural (paddy, coconut, aquaculture, salt pans etc), industrial, constructions of jetties and ports, dumping of waste, material and garbage, effluent release (pollution), mining, deforestation (construction, fuel), fodder and leasing area for grazing purpose, reduction or increase of the quantum of fresh water by dam constructions or diverting the flows respectively. Among the

pollution oil could be the serious problem as it covers pneumatophores suffocating mangroves resulting their mortality. About 20,000 tonnes of oil finds its way to Pakistan shores annually (5). Deforestation and mining forms major culprits of sediment source to the near shore and estuarine regions. Excessive deposition of sediments reduces the productivity of mangroves as well as cause water logging thereby killing mangroves. During last 2-4 decades ~ 40 % of mangrove area has been estimated to be reduced from the Indian subcontinent (3,10,14,15). The ever increasing population and their demands for livelihood and shelter, as well as increased emission of green house gases (GHGs) and resultant global warming and sea level rise form the major threats for marine habitats, in the intertidal and shallow regions.

Conservation measures:

Considering the ecological and socioeconomic values as well as threats of biotic, abiotic and anthropogenic factors, mangrove habitats have been protected vide coastal regulation zone. National committees have been established by the governments of the respective countries to coordinate education, training, research and management activities relevant to these habitats. A number of localities rich in mangroves (Table 1) have been protected as parks, sanctuaries, germplasm centers and nature reserve. Environmental impact assessment has been made mandatory prior to initiate any interference influencing the existing mangroves. The rehabilitations of protected open mudflats are being carried out by mangrove afforestation (Plate IV). The compensatory afforestation has been implemented to organization or industries responsible (directly or indirectly) for the damage to the existing mangroves. Such organizations have also been asked to prepare their contingency or disaster management plans. The awareness and training programmes have been initiated at various public sectors. The village punchayat and locals are being involved in the conservation and restoration programmes in India, some of the mangrove sites such as Achara in Maharashtra (central west coast) are protected as 'Devrai' meaning 'Gods gardens' and looked after by villagers. In general the conservation status of mangrove environments from the southeast regions is considered to be critical or endangered.

The effective management of marine habitats could only be possible by the participation of locals and stake holders.

Climate Change and Impacts on Mangrove Habitats:

The major culprits responsible for global warming are emissions of GHGs, mainly CO₂, and others like CH₄, N₂O (16), Halogenated gases and Ozone. Prediction models (16) indicate rise

of CO₂ concentration in the atmosphere to a level of 840 ppm by the year 2100 increasing global temperature and sea level by 0.3 °C and 6 mm 10 Yr⁻¹, respectively. Even though CO₂ emissions would have stabilized at 750 ppm, sea level may be up by 94 cm from the present mark (17). The warming mostly occurred during the period of 1910-1945 and 1976-2000, and the decade of 1990 was reported to be the warmest (18). The rainfall increased by 0.5-1 % 10 Yr⁻¹ and 0.2-0.3% 10 Yr⁻¹ from mid and high latitudes in Northern Hemisphere, and tropics (10° N -10° S), respectively. However, it decreased by 0.3 % 10 Yr⁻¹ in the subtropics. The global sea level has risen between 10-20 cm during 20th century (19). The SLR of 5 mm Yr⁻¹ with uncertainty of 2-9 mm Yr⁻¹ has been estimated (20), and it will vary with currents, winds, quantum of warming, circulation pattern and, regional and local atmospheric effects.

Annual relative SLR of 0.67 mm Yr⁻¹ has been estimated for South Asian region (21). In last five decades relative sea level changes in the region ranged from fall (i.e. land emergence) of 1.33 mm Yr⁻¹ to a rise (i.e. land submergence) of 2.27 mm Yr⁻¹ (21). General Circulation Models (GCM) based on data of 1990 – 2000 projected 9-88 cm rise in sea level, increased extreme weather events and precipitation over Asian region (16,19,22), which may be attributed to the thermal expansion and melting of ice. The rise of 0.4°C 100 Yr⁻¹ has been estimated from the temperature data for the period of 1901-2000 over the part of Indian subcontinent (23). The tide gauge and the recent satellite altimeter data indicated SLR of 10-25 cm 100 Yr⁻¹ along the Indian coast. Das (24) has reported average SLR of 3-5 mm Yr⁻¹ along the Indian coast. The most vulnerable regions under the unmitigated emissions scenario are South Asia, and particularly coast from Indian subcontinent (Fig. 1). The maximum (4-7.8 mm Yr⁻¹) of SLR has been observed along the coast of Bangladesh (Table 3).

Intensive anthropogenic pressures in the past and present have been the major threats for the global biodiversity (25-27). The Indian subcontinent is reported to lost ~ 30-50 % of mangrove area during last three decades. Lately, the climatic changes resulting from natural as well as human activities have been serious concern. Marine habitats in general, and mangroves in particular from the would be immediate target from SLR due to their proximity to seas (Fig. 2). Besides, individual component of the habitat may change their response pattern to increased temperature and CO₂ levels, and alteration in hydrological regime in ambiance. However, climate variations and subsequent SLR are extremely slow phenomenon. Marine habitats, particularly mangroves bear high fidelity for adapting to a stressful surroundings (28-29), and could keep the pace with SLR. Adequate supply of allochthonous sediments would be predominant factor in determining the persistence of mangroves during relative SLR. The

estuarine and backwater regions are under constant threat from reclamation, particularly for urbanization, agriculture and industrialization. Similarly, most of the backwater bodies are silting due to massive deforestation activities causing severe erosion (30-31). Mangroves could cope with SLR of 8-9 cm 100 Yr⁻¹ but remain under stress at rates between 9-12 cm 100 Yr⁻¹ (32). They would neither grow nor form peat at rates of SLR of 12 cm 100 Yr⁻¹. In case of excess sedimentation rate (> 12 cm Yr⁻¹), existing mangroves from the study region would be subjected to physiological stress of choking of pneumatophores, and ultimately their survival may be very difficult. Heavy sediments arising from floods may result in the shallowing of waterways, inundation and water logged conditions harmful to the existing mangroves. It is therefore, projected that sea level rise of 50-350 cm during next 100 years (33-35) will have devastating impacts on the low lying mangrove areas. The present day mangroves occur between 0.4-0.9 m above mean sea level (9). Moreover, autochthonous organic production, accumulation and export of the same may further increase as a result of global warming and rise in sea level.

The change in atmospheric temperature may greatly influence the precipitation and evaporation, ultimately affecting the salinity from the marine habitats. Individual mangrove species have particular salinity tolerance. Species like *A. marina* and obligate halophytes in the supralittoral regions are adapted to the high salinity while *Kandelia candel*, *Sonneratia caseolaris*, *S. apetala* and *Nypa fruticans* are adapted to the lower salinity (13). Species of *Rhizophora*, *A. officinalis* are confined to polyhaline (salinity 18-30 ppt). The seedlings of all species require very low salinity for their early growth (13). Therefore, the change in temperature may alter precipitation pattern, and thus causing salinity stress affecting productivity, growth and survival of individual mangrove species. Similarly, plant productivity remains higher at particular optimum temperature and hence mangrove productivity may also get affected if temperature in ambience exceed their optimum temperature range. Small change in temperature may lead to existing seasonal pattern in flowering and fruiting, root respiration, growth and turnover rate in mangrove species. The increased canopy respiration may greatly reduce photosynthetic rate falling close to zero at leaf temperature > 40 °C (36). The increased respiration would cause rise in humidity, intensifying infestation of mangroves by insects and pests. Increased CO₂ concentration may cause reduction in stomata conductance to check transpiration, improving growth and productivity rates, due to an improved water budget. Mangroves are highly efficient in converting atmospheric carbon into autochthonous organic carbon sustaining the productivity in near shore waters (2,29,37-38). However, optimum limit by individual species to CO₂ concentration limit it's production. Increase in productivity was

reported to an atmospheric concentration of 700 ppm of CO₂ at a salinity of 25 ppt but not at higher salinities (36). Therefore, cumulative impact of increased temperature, CO₂ and salinity concentrations in the ambient environment would obviously increase stress on mangroves. Phenological responses may have wide ranging implications for interactions between species (39).

Various kinds of biota in association adjust rapidly to the changing temperature (40-41). However, soft-bodied benthic fauna from the mangrove habitats are highly sensitive to temperature rise (42-43). The temperature rise resulting in extreme salinity regimes may adversely effect snail and crab population as well as juvenile forms of commercially important shell fishes and fishes. The intertidal zonation of benthos can be used as indicator of different environment features. Many mangrove dependent benthic forms have precise depth requirement for their development and may be unable to grow quickly under the influence of climate change due to global warming. The biota with specific tolerances within the tidal spectrum will migrate further landward as their former habitat become increasingly marine due to SLR. The regions with limited land margins will have no scope for further expanse (Fig. 3). The mangroves from such regions may totally disappear as a result of permanent submergence of roots and pneumatophores. Rapid changes in salinity may cause disappearance of existing biota and formation of totally new assemblage. Resultant extreme weather events like increase in frequencies and intensities of cyclone, storms, hurricanes, tsunamis as well as excess of precipitation, droughts etc. would cause devastating impacts on coastal habitats. High-energy waves resulting from SLR may accelerate erosion in the regions devoid of mangroves, ultimately causing damage to the landward properties (44-45). A one meter of SLR could inundate entire, 17% and 1700 km² of low lying lands in Sri Lanka, Bangladesh and Orissa and west Bengal in India, respectively (46).

Case study:

Kasargod, Kerala, West coast of India (31).

In general, the mangrove habitats in Kerala, in India are categories as the most degraded. However, some of the localities in Kasargod taluka (12° 30' - 12° 39' N and 72° 56' - 74° 59' E) harbour relatively better formations patchy and fringing mangroves in the region, could be attributed to the microtidal (< 1 m) nature and relatively steep and topography of the coast. The mangrove flora consisted of seven species and dominated by *Avicennia officinalis*. Approximately 0.45 km² of mangrove cover was estimated from Kayals and brackish water

regions. The stand density varied from 276-583 nos. ha⁻¹ with relatively high (720 nos. ha⁻¹) in the upstream zones.

The substratum in the habitats mainly composed of sand (37.7- 95.9 %) with rich (0.41-2.48 %) organic carbon. Benthic faunal density varied from 130-396 nos. 10 cm⁻². Polychaetes and nematodes formed the dominant groups of benthic fauna. The mangroves exists <1 m present low water level and influenced by water salinity ranging from 1.8 % in the upstream to 16.15 % in the downstream. Increased sea level may drastically impact mangrove habitat by altering the hydrological features and related processes. Kyalas and backwaters in the regions are limited by permanent bunds along both the banks. The vertical rise in the water column due to SLR and the limitations of landward margins may result in water logging, ultimately killing existing mangroves and dependent biota (Fig. 3) leading permanent genetic erosion.

Recommendations:

Mangrove ecosystems being complex in nature, multidimensional long-term approach for monitoring impact of climate variation is prerequisite. Mangroves in the state need to be evaluated for their reliable estimate of area coverage using greater scale remote sensing data. The protected mangrove regions need to be constantly monitored for the changes in their hydrological, ecological and biological characteristics. Global policies and coastal and biodiversity regulations to be implemented strictly for mitigating emissions of GHGs and conservation of marine habitats.

Climate change being slow, the impact of the same on the mangrove environment would be visible after long time. To develop mechanistic dynamic vegetation models (Sykes, personal communication), we need to have enormous data from the natural habitat and under simulated conditions. We need to develop international program for monitoring of such habitats from selected localities in understanding

-Rate of atmospheric CO₂ conversion into biomass and impacts of temperature and saturated CO₂ levels on carbon fixation of individual mangrove species -Change in forest structure such as density, biomass, annual growth, litter production, phenological pattern, gene regulation and manipulation of mangrove and dependent biota, organic carbon and sediment, associated biota, hydrological characteristics, and time lapse land use land cover pattern.
-Influence of temperature and salinity at organizational and functional levels of different species

A greater understanding of the potential impact of phenological change could be developed by adopting appropriate protocols at sites where a wide range of variables and other

biological responses are also recorded (39). Climate change integrated conservation strategies require a top down planning approach from the larger region to the locality. This means a substantial change in conservation planning schemes of many countries and regions. Mangrove habitats are closely linked with seagrass and coral ecosystems adjacent to them, at a number of sites in the subcontinent. In spite of mitigating emissions of GHGs, SLR would continue in future. It is therefore, necessary to formulate multidimensional holistic approach in understanding the impacts of climate variations and SLR on marine natural habitats. A combination of eco-regional and national conservation planning is recommended.

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Legends for Figures:

Fig.1 Geographical locations and vulnerability of coast (in red line) to SLR from Indian subcontinent

Fig.2. Likely impact of SLR on mangroves from Gulf of Kutchhh India

Fig. 3. Limited landward shift and vertical rise in water column. [Water lodging and killing of island (a) and fringing (b) mangroves]

Legends for Plates:

Plate-I. Major mangrove regions (in red colour) from the Indian subcontinent. (a- Indus delta Pakistan, b- Sunderban delta India and Bangladesh, c- Gulf of Kutchchh, India, d- Lagoon on the west coast of Sri Lanka)

Plate-II. Insect infestation on *Rhizophora mucronata*, from west of India (a- Infested *Rhizophora* trees, b- Close-up of infested leaf, c- Dead *Rhizophora* tree)

Plate-III. Common anthropogenic threats to mangroves (a- Wood extraction for fuel purpose, b- Leaves as fodder, c-f Reclamation for jetty construction, salt work and housing)

Plate- IV. Rehabilitation of mangrove habitats by afforestation (a- Nursery development, b- Nursery of mangrove seedlings, c- Preparation of intertidal swamps for seedling transplantation, d- View of transplanted seedlings).

Table 1: Physical data relevant to mangrove habitat

Parameter	Country			
	India	Pakistan	Bangladesh	Sri Lanka
Mean monthly temperature °C	19-27	18-31	19-27	26-30
Mean annual rainfall (mm)	1967.5	220	2831	2002
Spring tide amplitude (m)	1.5-5	2-3	03-6	<1
Area of mangroves (km ²)	3760	1760	4050	120
Number of true mangrove species	73	4	22(?)	35
Number of protected areas	21	2	4	8

Source: 3,5,6,15,30,47,48

Table 2: Mangrove associated flora and fauna from India

Biotic group	No of species
Flora	
Bacteria	50
Fungi	184
Manglicolous fungi	76
Bryophytes / Ferns	35
Lichens	32
Algae	48
Seagrasses	2
Associated angiosperms	165
Subaerial angiosperms	676
Fauna	
Crustaceans	229
Molluscs	212
Wood borers	24
Fishes	185
Reptiles	39
Birds	117
Mammals	36

Source: 3, 30, 47, 49

Table 3 : Estimates of sea level rise (SLR) based on the analysis of Tide Gauge data from Indian subcontinent

Country	Locality	SLR (mm yr ⁻¹)
India	Visakhapattanam	0.76
	Chennai	-0.65
	Kochi	1.14
	Mumbai	0.78
	Islands Laccadive Archipelago	8
Pakistan	Karachi	1.1
	Hiror point	4
	Chor chango	6
Bangladesh	Cox's Bazar	7.8
Sri Lanka		0.5

Source:

14,10,50,51

Fig. 1

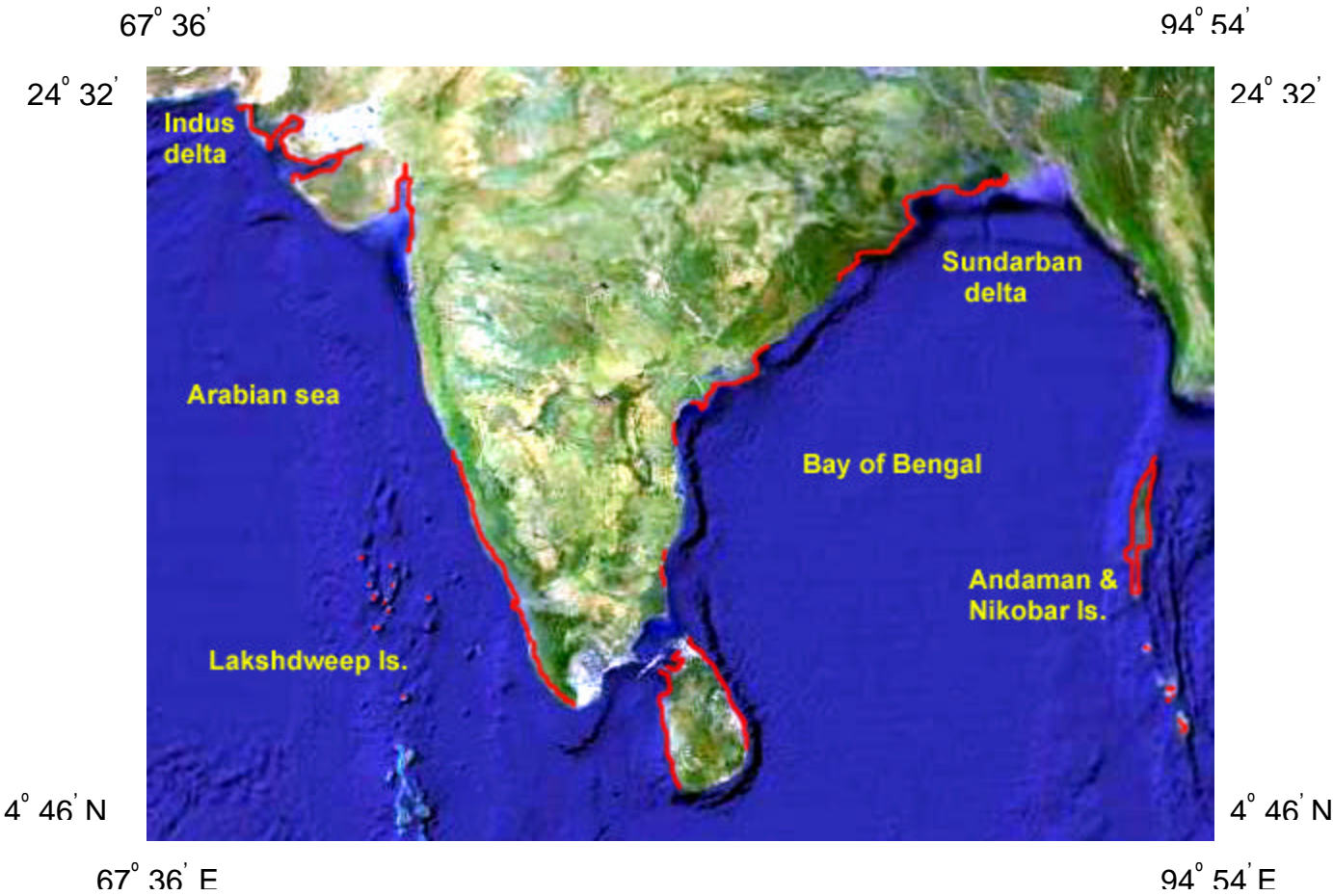
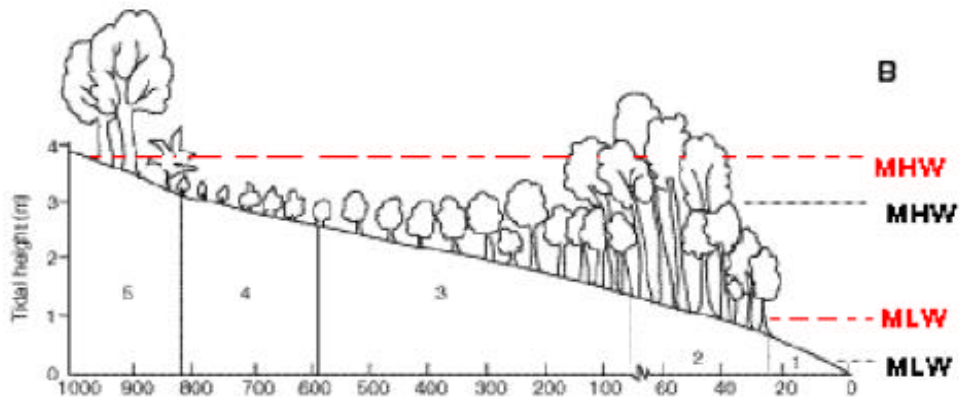


Fig. 2



- 1- Open Mud Flat
 - 2- Tall Mangroves (*Avicennia marina*) Zone
 - 3- Dwarf Mangroves (*Avicennia marina*)
 - 4- Obligate halophytic zone
 - 5- Terrestrial vegetation
- MHW- Mean High Water
MLW- Mean Low Water

Fig. 3

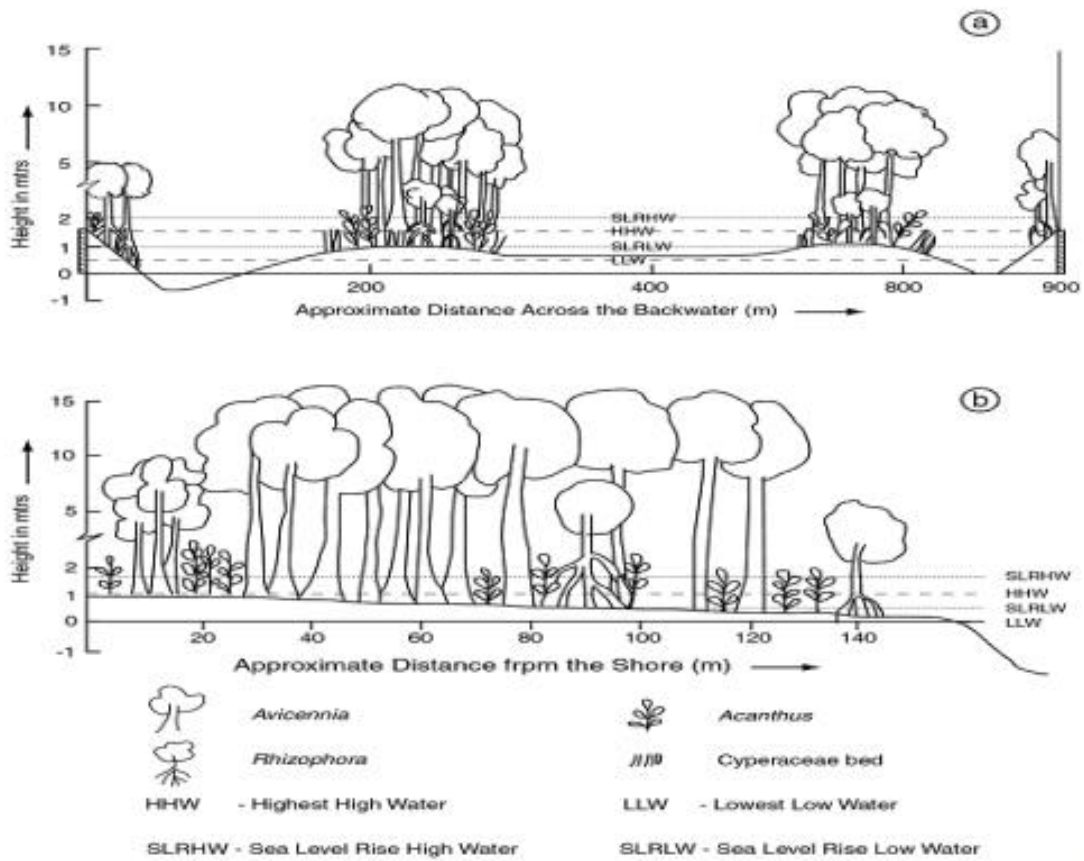


Plate I

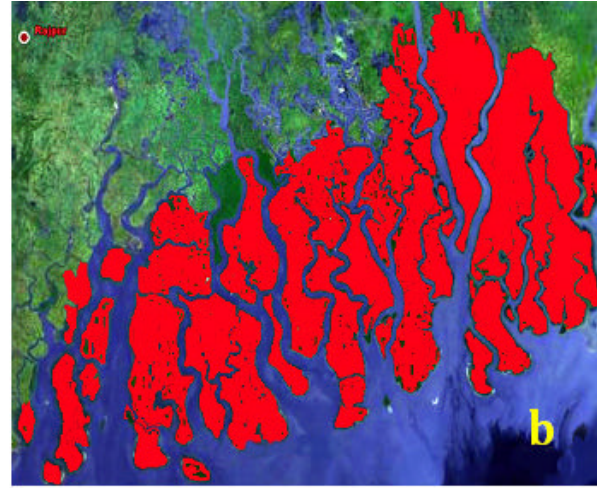
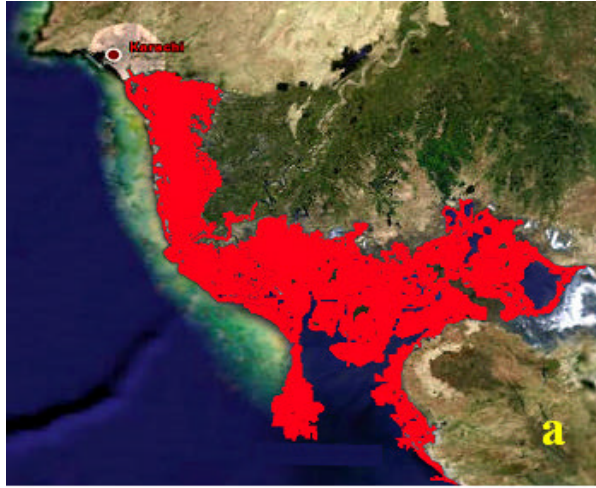


Plate II



Plate III



Plate IV

