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11. Impact of Climate Change on Mangrove Forests along the South West Coast: A Case Study from Kasargod, Kerala, India

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Abstract

Mangrove habitats are an important constituent of coastal wetlands. They are unique and located between sea and land, influenced by tidal and fresh water regimes, and hence are fragile in nature. The impact of sea level rise on mangrove community has been reported to be a serious issue in some of the Southeast Asian countries (Aksorakaoe and Paphavasit, 1993). Considering constant increase in global warming, the mangroves from Kasargod taluka (Kerala), were evaluated for their structure, composition and likely impacts of predicted climate variation.

The mangrove cover in Kerala, though sparse, is relatively better represented in the Kasargod taluka. Patchy and fringing type of vegetation could be attributed to the microtidal nature, relatively steep topography of the coast. About ~ 0.45 km^2 of mangrove area was estimated from the study region. The flora was represented by seven spp and dominated by Avicennia officinalis. The stand density varied from 276-583 nos. ha^{-1} with relatively high (720 nos.ha^{-1}) towards the upstream regions of kayals and backwaters. Substratum mainly composed of sand (37.7-95.9 %) with rich (0.41-2.48 %) organic carbon. Benthic faunal density ranged from 130-396 nos 10 cm^{-2} and was dominated by polychaetes and nematodes. The mangroves exist ~ < 1 m above present low water level. Increased sea level may drastically impact mangrove habitats by altering the hydrological features and related processes. The vertical rise in the water column due to sea level rise and the limitations of landward margins may result in water logging, ultimately killing mangroves and associate fauna. The present observations and discussion below would help in the long term monitoring of the impact of climate change on mangrove habitats of India.

Key Words: Global warming, sea level rise, mangroves, vulnerability, monitoring.

Introduction

Wetlands are vital to the health of environment due to their immense ecological and socioeconomic value. India has ~ 7.6 × 10^4 km^2 of wetland area of which ~ 4.0 × 10^4 km^2 is contributed by coastal wetlands (Garg *et al.*, 1998) comprising of estuaries, bays, lagoons, brackish waters, lakes and salt pans. The various tidal zones, with characteristic substratum, sustain a variety of specialised habitats of productive and complex nature. Mangroves, influenced by marine as well as fresh water are the most predominant and ecologically fragile habitats of coastal wetlands. About 8 % of India's coastline admeasuring ~ 3760 km^2 area has been occupied by mangroves. These habitats have been reported (Jagtap *et al.*, 2002) to harbour varieties of biota of ecological and commercial importance. However, being easily accessible, mangrove ecosystems from the country have been over-exploited in the recent past leaving them in the most degraded stage.

Mangroves are largely restricted to intertidal areas in deltas, around the islands and along the shores of estuaries, bays and lagoons. These habitats are the first to be directly affected from global climate change because of their location at the interface of sea (Ellison and Stoddart, 1991). The most plausible scenario (UNEP, 1992) indicates increase in the CO_2 concentration in the atmosphere, to a level of 840 ppm by the year 2100 increasing the global temperature and sea level at the rates of 0.3 °C and 6 mm 10 yr^{-1}, respectively. This scenario could be of use in projecting trends in the impact of climate change on mangrove ecosystem. The potential impact of sea level rise on the mangrove community is a serious issue in some of the Southeast Asian countries. (Aksorakaoe and Paphavasit, 1993). Considering the ecological and socio-economic significance of mangrove habitats and increasing threat from global warming, mangrove inventories from selected localities in Kasargod taluka of Kerala (south west coast) were carried out during present investigations. The observations discussed below would be of help in the long term monitoring of climate change on mangrove communities. The present piece of work forms a part of India's NATCOM projects aimed to identify regions of higher vulnerability to climate change in the country.

Description of the Study Site

Kerala (8°81'– 12°48' N and 74°52'-77°22' E), has area of ~ 38,864 km^2, of which the coastal wetlands constitutes ~ 937.3 km^2 (Nair and Sarkar, 2002). The coast is characterised by asymmetrical topography dominated by undulating, subdued hills and steepy scarp slopes, and altitude ranges from below mean sea level (MSL) to 2,694 m above MSL. The lowlands occupy about 10 % of the total landforms consisting of beach ridges, beaches with swamps and lagoons, backwaters and coconut and rice plantations. The midland region (altitude 7.5–75 m above MSL) consists of valleys and accounts for ~ 42 % of the landmass. The terrain is undulating with numerous rivers, small hills and valleys. The highland regions (75-750 m above MSL) constitute about 43 % of the total landform and covered with forests and drained by numerous streams.

Kerala experiences typical tropical warm and humid climate (Anon, 1999) with average monthly humidity varying from 85-95 %, maximum during June to September and minimum during January. It receives average total rainfall of 2900 mm yr^{-1}, (Fig. 11.1a), ~ 85 % of which is received from southwest monsoon (June to September). During October-November it receives rain from northeast monsoon. The mean annual number of rainy days is 126 with range of 46-172 days. The average annual temperature varies from 21.7 °C to 32.4 °C with the minimum during January and maximum during May (Fig. 11.1b). Wind speed in the coastal stretches varies from 6.7-10.9 km hr^{-1}, and it remains the maximum during the months of May-June. Tidal height increases from south to north and ranges from an average minimum of 0.3-1.04 m at Kochi (Fig. 11.1c, Anon, 1999).

Kerala has undergone major changes in its land-use pattern. The transformation of shrinking land into agricultural land and reclamation of tidal influenced regions and deforestation forms major causes for change in land use. The land area used for rice cultivation declined by 4450 km^2 between 1975-1996. Vegetation cover too has been reported to decline from 44.4 % in 1905 to 14.7 % during 1983. It has been stated that the conversion of forest land to agricultural land was encouraged by state government policies (George and Chattopadhyay, 2001).

Kasargod taluka of Kerala lies between 12°30'- 12°39' N and 72°56'- 74°59' E, ~ 50 km south of Mangalore, (Karnataka). The physical, geomorphological and climatological data described earlier (Fig. 11.1a-c) is also applicable to the study region. The Kayals (estuaries) and brackish water regions are subjected to microtides and are mostly shallow (<5 m deep). The coast is indented with 10 major kayals, however, all of them except Mogral, Kumbla and Pallam backwaters, (Plate I, a & b) were almost totally devoid of mangroves. These three water systems had connections with Arabian Sea during the time of samplings. The landward margins and banks of Kayals are either at elevated land or limited by constructions of dykes, roads and urban and agricultural developments. The backwaters are commonly used for fishing (Plate I d) while downstream region towards the mouth is intensively exploited for sand extraction.

Justification for Selection of Study Site and Locations

The selection for study site and location (Kerala coast) was based on the following criteria

- Existing literature revealed that Kerala state has the most degraded mangroves
- The existing mangroves are under constant threat from evergrowing population and socio-economic pressures
- Inspite of extensive reclamation and intensive anthropogenic pressures, mangroves exist at several locations
- There is no scope for landward extension of mangroves as the dikes are constructed along the banks/shores of Kayals as well as backwaters, restricting the landward spread of waters during high tide
- The land slope relative to sea level at Kochi is recorded (Emery and Aubrey, 1989) to be –2.05 mm yr^{-1}, which is relatively much higher compared to the same from other tide gauge stations along the different coastal states of India
- The entire coast is highly dynamic and severe erosion has occurred at many locations. The hydrography of the region is complex due to strong littoral currents. The submergence nature of the coast make it further vulnerable to sea level rise.

Methodologies

The most vulnerable areas along the Indian coast were determined from the risk assessment by integration of physiographic evaluation, site specific sea level changes, tidal environment and hydrographic feature (Chauhan et al., Unpublished data).

The existing information relevant to mangrove ecosystem was obtained from various published literature (Ramchandran *et al.*, 1986; Anon, 1998; Jagtap *et al.*, 2002). Data pertinent to the various wetland categories and their extent were sought from the existing CRZ maps and other relevant documents (Anon, 1992; 1998a). The physical data for backwaters were also estimated by reproducing existing CRZ maps (Anon, 1998a). The mangrove area along the water bodies was roughly estimated by considering the approximate average width and length of various fringes and patches of mangrove stands.

The rapid survey of the entire coast was conducted during August 2002, to understand the status of mangrove habitats such as major formations, species composition and various anthropogenic pressures on them. Based on the nature, extent, composition and intensity of human pressures, four locations namely Vypin Island (Kochi), Mogral Puthur, Kumbla Kayals and Pallam backwaters (Kasargod taluka) were identified for the proposed mangrove inventories. However, considering intense anthropogenic pressures particularly from urbanisation, aquaculture and agriculture on the mangrove regions of Vypin Islands (Plate I, d), observations were concentrated on the mangroves from Kasargod region for the following reasons:

- Relatively better formations and less anthropogenic pressures on mangroves compared to other areas in Kerala
- No industrial pollution
- No the scope for mangroves for new formations as well as further landward extension, as landward margins are limited by the construction of dikes, roads and urban and agriculture developments
- Major mangrove formations are restricted to the islands in the Kayal systems (Plate I a-b) except Pallam backwaters which are ~ < 1 m above low tide mark
- Mangrove region sustains small fisheries

Data on distribution, composition and quantum of mangroves was collected by standard belt transect and quadrant methods (Jagtap, 1986; Anon, 1998 b). Two transects each of 100 m width, were laid down perpendicular to the shore from low tide to the high tide marks, in the major mangrove regions from Pallam backwaters (Branch of Chandragiri estuary). The length of the transect varied from 100-150 m, depending upon the intertidal expanse of the mangrove region. However, in the Kayals (Mogral Puttur and Kumbla), the belt transects of the same width were laid down in the upstream (T IV and T V), midstream (T III) and downstream (T I and T II) zones (Fig. 11.2a-c) and across the estuaries up to the high tide marks along both the banks. The stations sampled against each transect were named from M1 – M5 for Mogral estuary while the same were denoted by K1 – K5 in case of Kumbla estuary (Fig. 11.2a-c). Sampling zones were denoted by DS (downstream), MS (midstream) and US (upstream) along with stations for expressing results. The reference stations for benthic fauna in Mogral and Kumbla estuaries were referred as R1 and R2 respectively (Figs. 11.2 b-c). The transect length varied from ~100-900 m depending upon the width of estuaries. The cross transects were taken because mangrove formations were confined to island regions in the Kayal systems and the intertidal flats in the midstream and upstream regions along the banks were very narrow (~ 3-10 m).

The quantification of mangrove within the belt transects was done by selecting random quadrants of 100 m^2 each in the mangrove stands confined to islands. In each transect 20-25 quadrants were observed for species composition, stand density and Diameter at Breast Height (DBH) of major species as described earlier (Jagtap, 1986 and Anon 2000). From each transect 30-50 number of plants of major species were measured for their DBH (> 2.5 cm diameter) to estimate the average DBH. The major associated species were also recorded from the mangrove stands. The quantitative data for mangroves was expressed on an average for individual study location, by pooling and averaging data from each zone.

Sediments from the vicinity of mangroves within the transect at different stations of different zones and reference station (Fig. 2a-c) were also collected for studying benthic faunal (meio as well as macro) composition and quantum, organic carbon contents and granulometry. The benthos samples were collected and analysed using standard methods (Anon, 1998 b). The organic carbon from the sediments was analysed using method of Wakeel and Riley (1957) while granulometry was done as described by Folk (1968). The water samples influencing mangroves from each zone were also analysed for salinity using the method of Strickland and Parson (1968). The results have been expressed on an average basis.

Results

Kerala coast is dotted with 48 water inlets of which 28 are temporary and the rest are permanent. The major estuaries or water bodies are represented by Vembanad lake (190 km^2) and Ashtamudi estuary (40 km^2). In general, the mangroves along the Kerala coast could be described as very sparse and thin. Inspite of intense anthropogenic pressures, particularly from urbanisation and agricultural activities, several localities such as Veli, Ashtamudi, Kumaragon, Vypin island, Chembu, Vallarpadam, Cheltuva, Nadakavu, Pappinisseri, Kunjimangalam, Dharmadan, Sheriya, Kumbala, Mogral Puttur, Pallam etc. have sustained small to large patches of mangroves. Though past records (Ramchandran et al., 1986) have indicated 15 species (Table 11.1) in the present studies only 12 spp of mangroves were observed. The mangroves like *Avicennia officinalis*, *Acanthus illicifolius* and *Rhizophora mucronata* form the dominant species (Table 11.2).

The present survey indicated that the northern coast of Kerala, particularly Kasargod taluka (Fig. 11.2a-c) has better mangrove formations and presented by eight species (Tables 11.2-11.3). The total mangrove cover along Kerala was estimated to be ~1.71 km^2 of which the maximum area (~ 0.45 km^2) occurs from Kasargod and nearby regions (Table 11.4), and mostly confined to the upstream regions of Kayals of Kumbala, Mogral Puttur and backwaters at Pallam. Mangroves occur as narrow fringes along the banks to large patches as observed along Pallam backwater and along the southern bank of Kumbla in the downstream zone. The stands were mainly confined to the islands in the upstream regions of Kumbla and Mogral Puttur. The landward margins of Kayals and backwater are limited by anthropogenic development resulting in the narrow intertidal zone along the banks or shores. Tree species like *A. officinalis* was observed to be dominant (% FO = 47-100), with height and DBH values ranging from 3-15 m and 5-17.4 cm, respectively (Table 11.3). The density of mangroves varied from 133-720 number of plants ha^{-1}, of which *A. officinalis* were ranging from 97-627 nos ha^{-1} (Table 11.3). *Acanthus illicifolius* formed the most dominant under canopy stands. The other prominent forms observed were *R. mucronata*, *K. candei* and *Bruguiera gymnorrhiza*. Occasional patches of *Aegiceras corniculatum* were noticed from the midstream regions of Mogral Puttur towards high tide mark. The mangrove stands might be < 1 m above present low water level. The associated flora was commonly represented by *Cyperus javanicus*, *C. pangorei*, *Baringtonia racemosa*, *Scaveola serica*, *Dolichandrone spathaceae*, *Cerbera odollam*, *Derris heterophylla*, *Thespesia populanea* and *Scirpus littoralis* (Table 11.1).

The salinity values in the upstream regions varied from 3.4 to 10.73 % while in the midstream and downstream regions these values were observed in the range of 6.74 to 15.74 % and 12.53 to 16.15 %, respectively (Table 11.5). The sediments from all the stations of study area was predominantly sand varying from ~ 37.7 to 95.9 % (Table 11.5). The organic carbon in the sediments from mangrove habitats varied from 0.41 to 2.48 % (Table 11.5). Macrobenthic fauna was dominated by polychaetes (Table 11.5). This was followed by crustaceans in particular brchyuran crabs, isopods, amphipods and tanaidaceans. Among other taxa sea anemone, sipunculida and nemertea were recorded. There were gastropods but no record of bivalves. Some of these gastropods were associated with mangrove trees. The fauna was rich and the density recorded varied between 96 and 396 nos. m^{-2} (Table 11.5). The meiofaunal components of the two estuaries were similar and comprised of Nematoda, Polychaeta, Oligochaeta, Turbellaria and Harpacticoida. Nematodes were the most dominant group numerically ranging between 74-85 % at Mogral river and 66-78 % at Kumbla river. Next in the order of abundance were Harpacticoid, Copepod and Turbellaria (Table 11.5). Total meiofaunal density ranged from 253-368 nos.10 cm^{-2} in Mogral and 130-339 nos. 10 cm^{-2} in Kumbla estuary. The faunal density was relatively high at reference stations compared to the same in the regions influenced by the mangroves.

Discussion

Mangroves though confined to the regions between 32° N-38° S latitudes, the maximum extent and species diversity exists in the tropical belt (Bacon, 1970). These habitats all over the world are considered to be of a great significance due to their productive nature, and ecological role, as nutrient sinks and for substrate stabilisation. Being repository nature of habitats, mangroves are known as basic land builders and keep pace with rising sea level (Ellison and Stoddart, 1991; Ellison, 1989). However, these ecologically important habitats from the tropics, particularly from the Indian subcontinent are under severe stress from ever-growing anthropogenic pressures, reducing resilience in the face of sea level rise.

Composition and extent of mangroves are generally governed by the nature of climate, topography, tidal and physico-chemical characteristics of ambient waters. The total mangrove cover in India has been recorded to be ~ 3760 km^2 of which ~ 2490 km^2 and 1270 km^2, exist along the east and west coast, respectively (Jagtap, *et al.*, 2002). Almost 80 % of the mangrove cover along the entire west coast occurs in the Gulf of Kachchh, which could be attributed to extensive mudflats and greater tidal amplitude. However, along the central and southwest, the intertidal expanse is limited to very narrow belts due to rising coast as well as narrow tidal amplitudes. The Kerala coast has been observed to have very limited mangrove cover compared to other coastal states along the west coast (Jagtap *et al.*, 2002). However, species like *H. littoralis* and *Excoecaria indica* have been reported (Ramchandran *et al.*, 1986) only in Kerala along the west coast. The mangroves occur in narrow fringes or small to large patches along the banks or on the islands of estuaries and backwaters. The fringing and patchy distribution of mangroves in Kerala could be attributed to the micro-tidal nature of estuaries and limited intertidal mudflats along the banks. Lately, mangrove area of ~ 1.71 km^2 has been delineated from Kerala (Anon, 1998). Inspite of extensive reclamation during the recent past, Kerala coast was observed to have good mangrove cover at several locations. The estimates from CRZ maps (Anon, 1998) showed very poor mangrove cover of 0.017 km^2 and open tidal flats amounting to ~0.56 km^2 from Kasargod district. Mangrove habitats from Kerala coast have suffered a great damage in the past due to reclamation, mainly for urbanisation and agriculture. The existing mangroves too are under severe and constant threat from anthropogenic activities. The Kerala coast occupied ~70 km^2 of mangrove in the recent past (Ramchandran et al., 1986), which is presently reduced to a few hundred hectares with ~0.45 km^2 cover in the Kasargod district (Table 4). The low estimate (0.017 km^2) of mangrove cover from the Kasargod taluka from CRZ maps might be due to the limitation of satellite data used. Approximately 30 % decline in state forest cover during last eight decades (George and Chattopadhyay, 2001) could largely be attributed to deforestation of coastal vegetation, including mangroves.

About 37 % and 35 % of Kerala coast has been estimated to be under erosive and dynamic processes, respectively (Chauhan *et al.*, unpublished). The highly erosive and dynamic nature as well as sea level variations indicate high vulnerability of the Kerala coast to sea level rise. Keeping in view the intensity of sea level changes along the Kerala Coast (Emery and Aubrey, 1989) and importance of mangroves in keeping with sea level rise, it is very necessary and urgent to conserve existing mangroves along the Kerala coast. Kasargod taluka represents relatively better mangrove formations and subjected to less anthropogenic influences, hence could form an ideal location for the long term monitoring the impacts of climate change.

Global warming due to emission of green house gases is expected to result in a sea level rise. Mangrove habitats are subjected to immediate threat due to sea level rise because of close proximity with the sea. However, climate change and subsequent rise in the sea level are very slow processes. Various factors in addition to the sea level rise contribute towards the abilities of mangroves and salt marsh vegetations to adapt to the rising sea level (Thom, 1982, Woodroffe, 1987). Moreover, mangroves exhibit high fidelity to particular habitats because of their physiological, anatomical and morphological adaptations to a stressful environment.

Adequate supply of allochthonous sediments would be predominant factors in determining the persistence of mangroves during relative sea level rise. The estuarine and backwater regions are under constant threat from reclamation, particularly for urbanisation, agriculture and industrialisation (Plate I, c) About 7.23 % of estuarine area was reduced during 1967-1973 for various anthropogenic developments (Anon, 1992). Similarly, most of the backwater bodies are silting due to massive deforestation activities causing severe erosion (Nair *et al.*, 1987). Our observations also suggest heavy siltaton particularly in the upper reaches of the backwaters/estuaries (Table 11.5). Mangroves could keep pace with sea level rise of 8-9 cm 100 yr^{-1} but remain under stress at rates between 9-12 cm 100 yr^{-1} (Ellison and Stoddart, 1991). They would neither grow nor form peat at rates of sea level rise of 12 cm 100 yr^{-1}. It is therefore, projected that sea level rise of 50-350 cm during the next 100 years (Hoffman, 1984; Houghton *et al.*, 1990 and Jagar and Ferguson, 1991) will have devastating impact on the low lying mangrove areas such as along the Kerala coast. The present day mangroves occur between 0.4-0.9 m above MSL. (Ellison, 1989). Moreover, autochthonous organic production, accumulation and export of the same may further increase as a result of global warming and rise in sea level.

Carbon dioxide concentration in the atmosphere is projected to be in the range of 540-970 ppm in the year 2100 compared to 360 ppm during the year 2000. It would increase global temperature by 1.4 °C to 5.8 °C over the period 1990-2100, leading to a sea level rise. The change in atmospheric temperature may greatly influence precipitation and evaporation, ultimately affecting the salinity from marine habitats. Individual mangrove species have particular salinity tolerance. Species like *Avicennia marina* and obligate marine halophytes in the supralittoral regions are adapted to high salinity in the ambient environment. However, species like *K. candel, Sonneratia caseolaris* and *S. apetala* are adapted to lower salinity along the west coast (Jagtap, 1986). Species of *Rhizophora, A. officinalis* are confined to polyhaline (salinity 18-30 ‰). The mangrove seedlings of all species require very low salinity for their early growth. Therefore, the change in temperature may further increase or decrease (in case excess) precipitation causing salinity stress, and affecting productivity, growth and survival of individual mangrove species. Similarly, every plant yield higher at particular optimum temperature and hence mangrove productivity may also get affected if ambient temperature exceeds the 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. Increased canopy respiration may greatly reduce photosynthetic rate falling close to zero at leaf temperature >40 °C. Increased respiration would cause rise in humidity, intensifying infestation of mangroves by insects and pests.

Ongoing rise in the atmospheric CO_2 concentration stimulates the productivity of both habitat and food in the natural environment. Higher CO_2 concentration may cause reduction in stomata conductance to check transpiration, improving growth and productivity rates, due to an improved budget. Mangroves are highly efficient in converting atmospheric carbon into autochthonous organic carbon sustaining the productivity in near shore waters (Lugo and Snedaker, 1974; Clough and Attiwil, 1982; Woodroffe, 1987; Boto and Bunt, 1981). However, there has to be an optimum limit by individual plant to react positively to CO_2 concentration in the surroundings. It has been found that mangrove species exhibited net increase in productivity to an atmospheric concentration of 700 ppm of CO_2 at a salinity of 25 ppt but not at higher salinities (Ball *et al.*, 1997). Therefore, increased temperature, CO_2 concentration in the atmosphere and salinity concentrations in the ambient environment would obviously increase stress on mangroves.

The mangrove habitats proper and associated environments such as estuaries, backwaters and coastal waters influenced by them, being rich in detritus serve as good nursery and fishing grounds. Therefore, the various kinds of biota in association with mangroves contribute towards local as well as national economy to certain extent. Some of the organisms like fish, molluscs and crustaceans are known to adjust rapidly to the changing temperature. However, soft bodied animals and bivalves from the mangrove habitats are highly sensitive to temperature rise. Temperature rise resulting in extreme salinity regimes may adversely affect snail and crab population as well as juvenile forms of commercially important shell fish and fish. The intertidal zonation of benthos can be used as indicator of different environment features. Many mangrove dependant benthic faunal 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.

Rise in MSL will have immediate and direct effect on the intertidal habitats, including mangroves, due to increased influence of marine processes and declined influence of terrestrial processes. The biota in mangrove ecosystem with specific tolerances within the tidal spectrum will migrate further landward as their former habitat become increasingly marine. The mangrove ecosystem, such as that from study regions, where land margins of estuarine and backwater systems are limited by various developments, will have no scope for further expanse. The mangroves from such regions may totally disappear as a result of permanent submergence of roots and pneumatophores (Fig. 11.3 a-b), if mangroves do not maintain optimum sedimentation rate (8 to 9 cm 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. Rapid changes in salinity in the environment may cause disappearance of existing biota and formation of totally new assemblage. High-energy waves resulting from increased sea level may accelerate erosion in the regions devoid of mangroves, ultimately causing damage to the landward properties (Brunn, 1962; Schwartz, 1967). Mangrove ecosystems being complex in nature, multi-dimensional long-term approach for monitoring impact of climate variation is pre-requisite.

Recommendations

- Mangroves in the state need to be evaluated for their reliable estimate of area coverage, using greater scale remote sensing data.
- The hotspot regions of mangroves need to be protected urgently as germplasm preservation centres.
- Climate change being slow, the impact of the same on the mangrove habitats would be visible after a long time. Therefore, long term monitoring of mangrove ecosystem from permanent plots in selected localities, is very necessary to understand the impact of climate change on it, by undertaking the following studies
  - Rate of atmospheric CO_2 conversion into biomass and impacts of temperature and saturated CO_2 levels on carbon fixation by individual mangrove species
  - Change in forest structure such as density, biomass, annual growth, litter production, phenology pattern, gene regulation and manipulation by different mangrove species as well as dependant biota, organic carbon from sediments, associated flora and fauna, hydrological characteristics, and time lapse land use pattern
- Mangrove habitats are closely linked with shallow marine ecosystems (seagrass and coral) adjacent to them. It is therefore, very necessary to formulate multi-dimensional holistic approach in understanding the impact of climate change on marine natural habitats

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Table 11.1 Relative abundance of mangrove species in Kerala (Ramchandran et al., 1986).

Species	Quilon	Kumarakm	Ernaculam	Cretwi	Calicut	Edakkad	Pappinisseri	Ezhimala	Veli	Chiteri
Mangrove Flora										
Acanthus illicifolius	C	R	C	C	C	C	C	C	C	C
Acrostichum aureum	C	C	C	C	C	C	C	C	C	C
Aegiceras corniculatum	A	A	A	C	C	C	C	C	A	C
Avicennia marina	R	A	R	O	O	O	O	C	A	C
A. officinalis	R	R	R	C	C	C	C	C	C	C
Bruguiera gymnorrhiza	R	C	R	A	A	R	C	R	R	R
B. parviflora	R	R	R	C	R	R	R	O	A	A
Excoecaria agallocha	R	R	R	C	C	C	C	C	R	C
E. indica	R	R	A	A	R	R	R	R	R	R
Heritiera littoralis	A	R	A	A	A	A	A	A	A	A
Kandelia candel	A	R	R	R	R	R	C	C	A	R
Lumnitzera racemosa	A	R	A	A	A	A	A	A	A	A
Rhizophora mucronata	A	A	C	R	A	A	R	R	A	R
R. apiculata	O	R	R	C	C	R	R	O	O	C
Sonneratia caseolaris	R	R	A	A	R	A	A	R	R	A
Associate Flora										
Ardisia littoralis	R	O	A	A	A	A	A	A	C	A
Barringtonia racemosa	C	R	C	A	R	R	R	O	C	O
Caesalpinia crista	C	C	A	A	A	A	O	C	C	A
Cerbera odollam	C	C	C	C	C	C	C	C	C	C
Clerodendrum inerme	C	R	C	C	C	C	C	C	C	C
Dolichandrone spathacea	R	R	A	A	R	A	A	A	A	A
Derris trifoliata	C	C	C	C	C	C	C	C	C	C
Hibiscus tiltaceous	C	C	C	C	C	C	C	C	C	C
Pandanus fascicularis	C	C	C	C	C	C	C	C	C	C
Phoenix humilis var. pedunculata	A	A	A	A	A	A	A	A	C	A
Stenochlaena palustre	C	C	C	C	C	C	C	C	C	C
Thespesia populnea	C	C	C	C	C	C	C	C	C	C
Viscum orientale	A	O	A	A	A	A	A	A	A	A

Legends: R = Rare, O = Occasional, C = Common, A = Absent

Table 11.2 Ecological status of mangroves based on percentage frequency occurrence (% FO) for Kasargod, Kerala.

Name of the spp.	Habitat	Kumbla Estuary	Pallam Backwaters	Mogral Estuary
Avicennia officinalis	T & S	D	D	C
Rhizophora mucronata	T & S	LC	VR	C
Kandelia candel	S	VR	—	VR
Excoecaria agallocha	S	VR	VR	VR
Bruguiera gymnorrhiza	S	VR	—	VR
Acanthus ilicifolius	S	D	D	D
Aegiceras corniculatum	T	VR	VR	VR
Lumnitzera racemosa	S	VR	VR	VR

D(Dominant)-%FO >70%; LC(Less Common)-%FO >20-39%; R(Rare)-%FO >10-19%; VR(Very Rare)-%FO >10%; — -Not observed; T-Tree; S-Shrub; %FO-% frequency occurrence

Table 11.3 The structure of mangroves from the study area, Kasargod, Kerala.

Area of Study and Geographical Co-ordinates	St.+ Z	Name of the spp.	N.P.ha^{-1}	ΣN.P.ha^{-1}	Avg. DBH(cm)	Ht. R(m)	Av. Ht.(m)	%FO	Σ(%FO)	%RF	%RD	ES
Kumbla Estuary 12°34'012"N, 74°57'724"E	K1 - K2 (DS)	*Avicennia officinalis*	350	373	17	3.0-7.0	6	33	43	77	94	LC
12°33'757"N, 74°57'516"E		*Rhizophora mucronata*	23		NA	4.0-5.0	5	10		23	6	R
12°35'674"N, 74°56'355"E	K3 (MS)	*A. officinalis*	239	339	NA	3.0-7.0	5	58	94	62	70	C
		R. mucronata	100		NA	3.0-5.0	4	36		38	30	LC
12°35'565"N, 74°56'497"E	K4 - K5 (US)	*A. officinalis*	627	720	11	3.5-7.0	6	90	127	71	87	D
		R. mucronata	93		NA	3.0-10.0	5	37		29	13	LC
Pallam Backwaters 12°29'857"N, 74°58'913"E	P1 - P2	*A. officinalis*	327	327	17.4	8.0-15.0	12	82	82	100	100	D
Mogral estuary 12°34'012"N, 74°57'724"E	M1 - M2 (DS)	*A. officinalis*	97	206	10	3.0-5.0	4	43	98	44	47	C
12°33'757"N, 74°57'516"E		*R. mucronata*	88		10	2.5-5.0	4	37		38	43	LC
		Excoecaria agallocha	9		NA	NA	NA	6		6	4	VR
		Bruguiera gymnorrhiza	6		NA	NA	NA	6		6	3	VR
		Kandelia candel	6		NA	NA	NA	6		6	3	VR
12°33"471"N, 74°57"269"E	M3 (MS)	*A. officinalis*	50	133	5	2.0-5.0	4	28	62	45	38	LC
		R. mucronata	72		8	2.5-5.0	4	28		45	54	LC
		B. gymnorrhiza	11		NA	4	4	6		10	8	VR
12°33'194"N, 74°57'296"E	M4 - M5 (US)	*A. officinalis*	85	280	8	2.5-7.0	5	40	120	33	30	C
12°33'194"N, 74°57'296"E		*R. mucronata*	160		10	3.5-7.0	9	60		50	57	C
		K. candel	10		NA	3.5	3.5	5		4	4	VR
		E. agallocha	25		6	3.5-4.0	4	15		13	9	R

St.-Station; Z-Zone; US-Upstream region; MS-Midstream region; DS-Downstream region; N.P.ha^{-1}-Number of plants per hectare; S N.P.ha^{-1}-Sum of no. of plants per hectare; Av. DBH(cm)-Average diameter at breast height in centimeters; Ht.R(m)-Height Range in meters; Av.Ht(m)-Average Height in meters; % FO-Percentage frequency occurrence; S(%FO)-Sum frequency of all species; % RF-Percentage Relative frequency; % RD-Percentage Relative Density, E8-Ecological states

Table 11.4 Physical data from the water bodies from study area, Kasargod, Kerala.

Locations	W C (km)	L N B (km)	L S B(km)	AL(km)	AW(km)	L E(km)	TA(~sq km)	MA(~sq km)
Kumbla Estuary	1.2	6.4	5.8	6.1	0.48	2.9	2.93	0.15
Mogral Estuary	1.6	5.4	7.9	6.65	0.92	7.02	6.12	0.1
Pallam Backwaters(Branch of Chandragiri Estuary)	0.65	3.6	2.9	2.91	0.4	3.6	1.3	0.2

WC(km)-Width at Confluence region in kilometers; LNB(km)-Length of North bank in kilometers; Length of South bank in kilometers; AL(km)-Average Length in kilometers; AW(km)-Average width in kilometers; AW(km)-Average width in kilometers; AW(km)-Average width in kilometers; AW(km)-Average width in kilometers; LE(km)-Landward Extension in kilometers; TA (~ sq km)-approx. Total Area in square kilometers; MA(~ sq km)-approx. Mangrove Area in square kilometers.

Table 11.5 Sediment characteristics and associated benthic fauna.

	Mogral Estuary (Zones)				Kumbla Estuary (Zones)			
Sediment texture	R1 -	DS K1 & K2	MS K3	US K4 & K5	R2 -	DS M1 & M2	MS M3	US M4 & M5
Sand (%)	61.98	78.25	58.96	81.54	95.94	90.13	57.17	37.72
Silt (%)	18.14	21.26	7.46	5.37	0	0	13.64	38.79
Clay (%)	19.88	19.76	11.01	7.98	4.06	9.87	29.19	23.5
OC (%)	2.48	1.87	1.22	2.21	0.41	2.01	1.87	1.81
Salinity (‰)	-	14.65	6.74	1.8	-	16.15	15.76	10.73
Density of macrofauna (No/m^{-2})	396	96	192	272	244	288	115	140
Density of meiofauna (No/cm^{-2})	253	267	347	368	339	143	222	214

R1-Reference station 1; R2-Reference station 2; US-Upstream region; MS-Midstream region; DS-Downstream region; OC-Percentage organic carbon

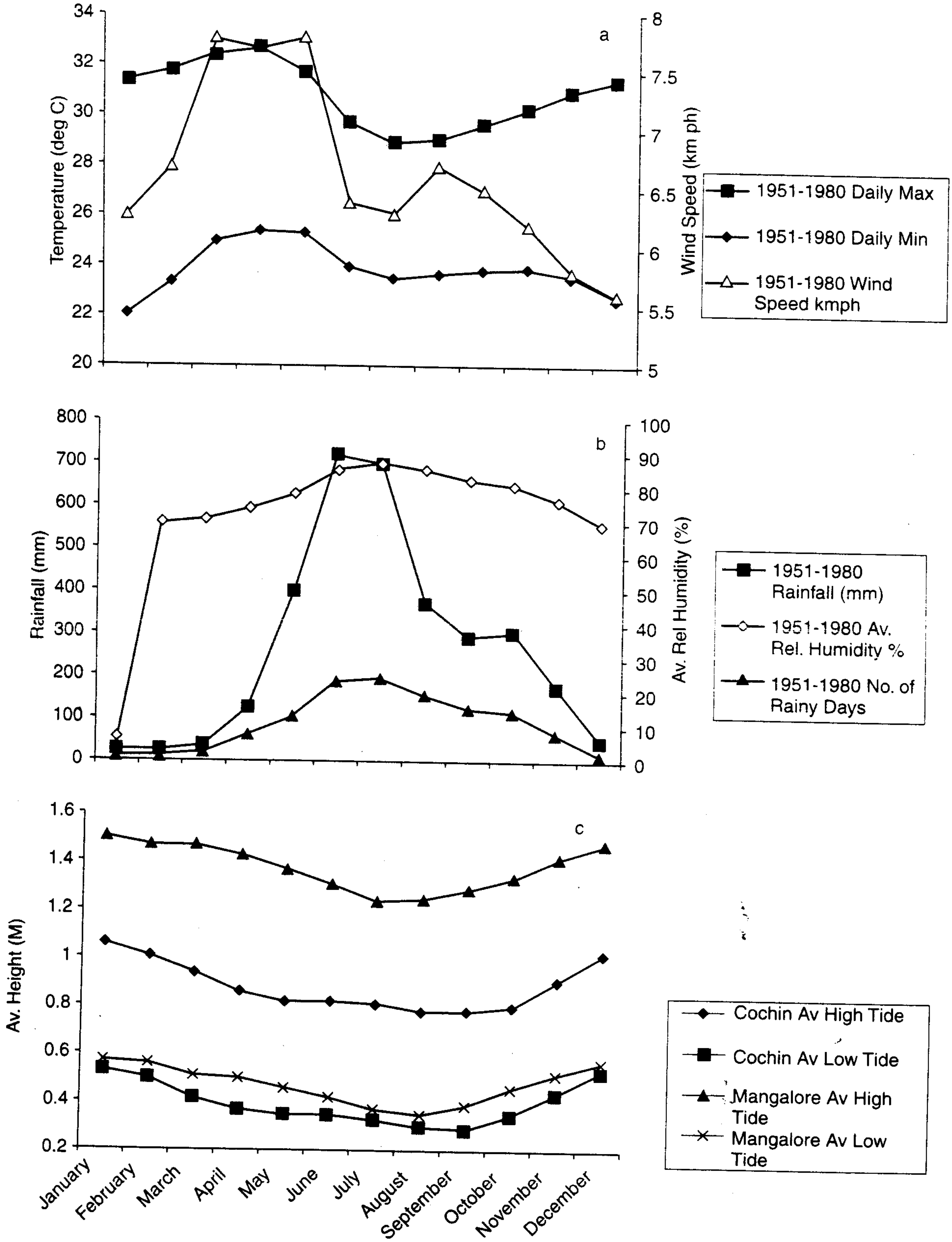

Fig. 11.1 Climatological and tidal data for Kochi (Kerala).

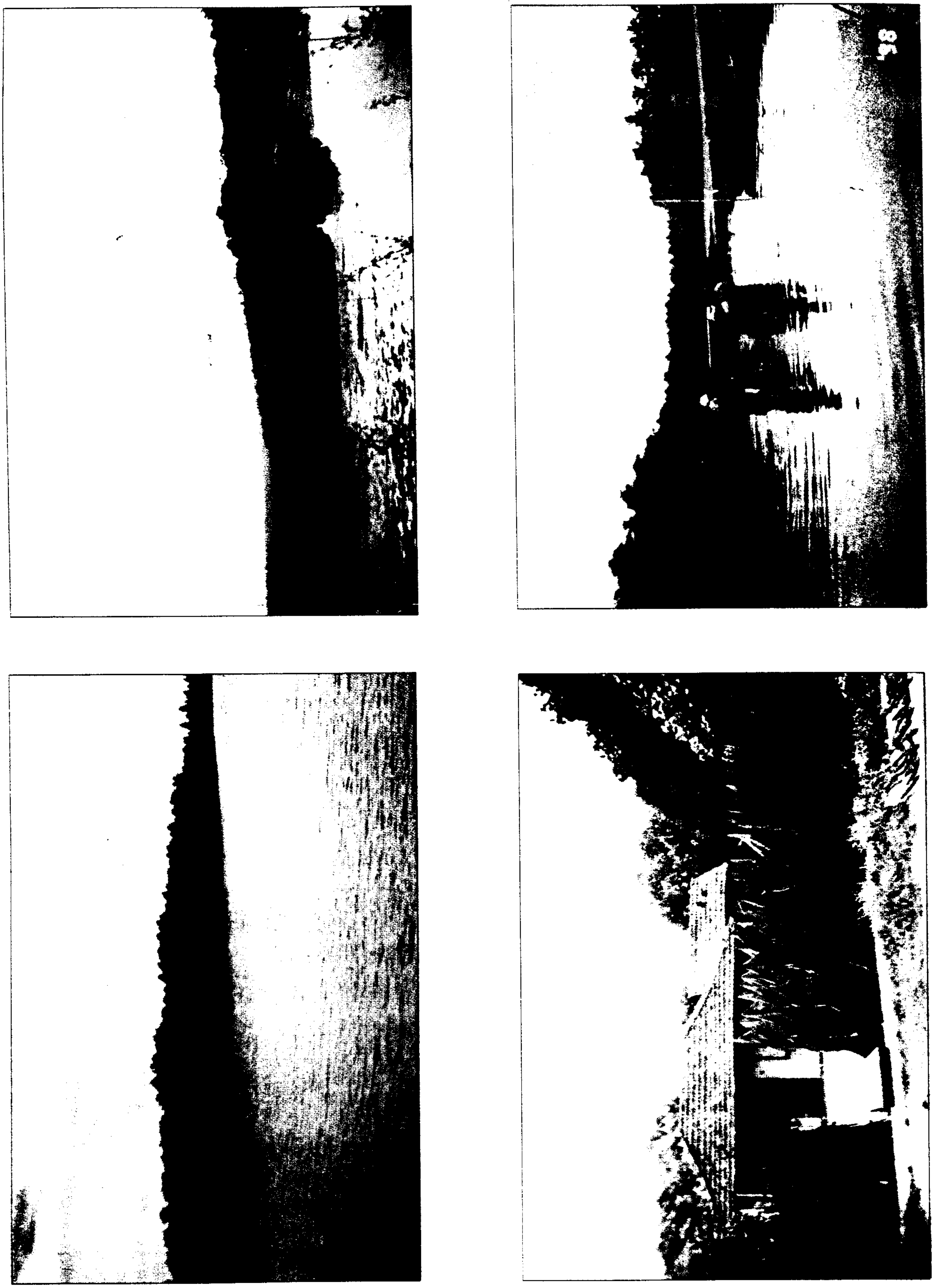

Plate I-a & b. Dense stands of mangroves from Upstream zone c- Urbanization d- Fishing activities

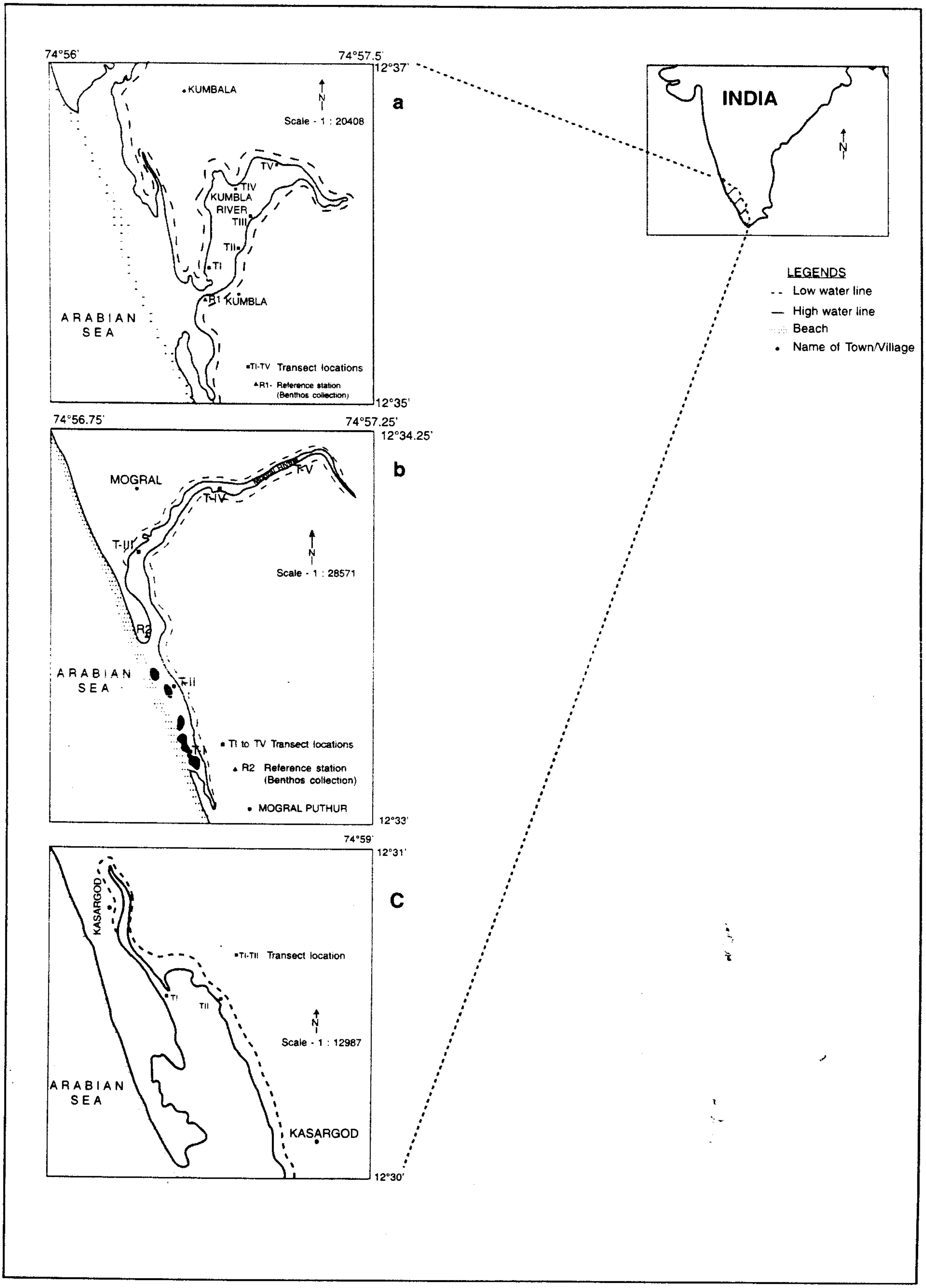

Fig. 11.2 Sampling locations in Kumbla, Mogral Puttur and Pallam.

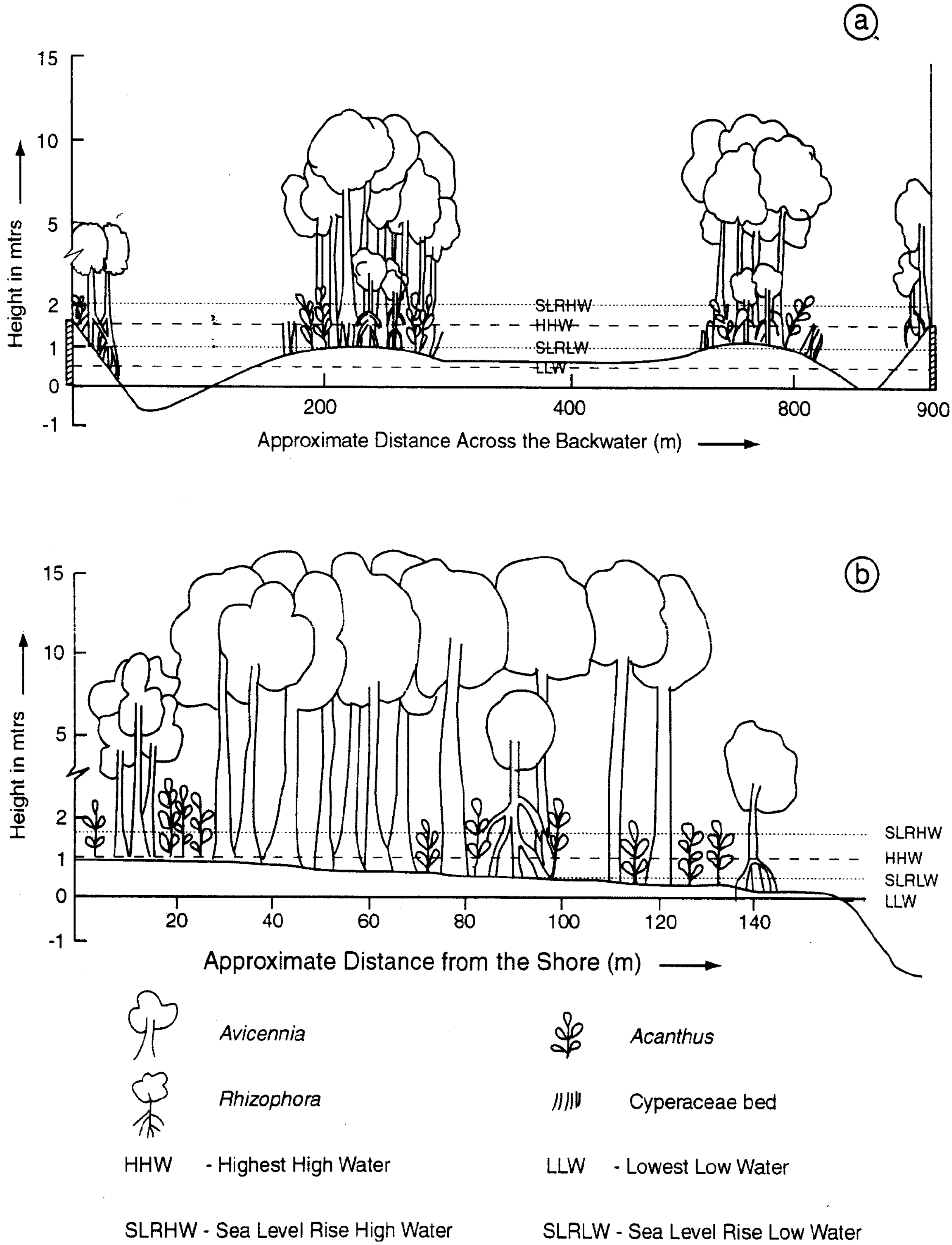

Fig. 11.3 The schematic representation showing distribution of mangroves and scenarios at present and future sea levels in estuaries of Mogral Puttur (a) and along the banks of Pallam backwater system (b).