Environmental classification of mangrove wetlands of India

V. Selvam

Macro-level environmental factors that determine the area, species diversity and biomass of the mangrove wetlands of India are analysed. On the basis of the spatial and temporal variations in these factors, major mangrove wetlands of India are classified. The Sunderbans and Mahanadi mangroves can be classified as tide-dominated, whereas Godavari, Krishna, Pichavaram and Muthupet mangrove wetlands can be grouped as river-dominated. The mangrove wetlands of Gujarat fall under the category of drowned-river valley type. Changes in some of the environmental factors, particularly changes in the periodicity and quantity of freshwater that flows into mangrove wetlands are examined, which indicates that reduction in freshwater flow would lead to reduction in the diversity of exclusive mangrove plant species. The current classification system can be utilized to develop strategies for long-term conservation of mangrove wetlands.

THE coastal zone of the mainland of India and Andaman and Nicobar islands is endowed with the presence of extensive and diverse mangrove wetlands. These mangrove wetlands act as a barrier against cyclones, avoid coastal erosion and provide nursery grounds for a number of commercially-important fish, prawns and crabs. Some of these mangrove wetlands play an important role in enhancing the fishery production of the adjacent neritic waters by exporting organic and inorganic nutrients[1]. The environmental setting of this multiple-use ecosystem is governed by physical forces such as geomorphology of the coast, climate, tidal amplitude and duration, and quantity of freshwater inflow[2–4]. These macro-level environmental factors of mangrove wetlands undergo changes both in time and space, and these changes are reflected in the mangrove forest composition and structure[5,6]. Understanding the development of mangrove forest communities through time, with reference to changing environmental condition, is a basic requirement to develop and implement mangrove conservation and management plans. In this article the environmental setting of the mangrove wetlands of India are described and a classification system is provided. Changes in the floristic and forest structure of these mangrove wetlands due to changes in some of the macro-level environmental factors are also discussed.

Geomorphic settings of the mangrove wetlands

On the macro scale, geomorphic settings of the mangrove wetlands of the east coast of India are different from those of the west coast[7]. The costal zone of the west coast is narrow and steep in slope due to the presence of the Western Ghats. Secondly, there is no major west-flowing river. As a result, mangrove wetlands of the west coast of India are small in size, less in diversity and less complicated in terms of tidal creek network. On the other hand, mangrove wetlands of the east coast are larger, high in diversity, and water-bodies associated with mangroves are characterized by the presence of larger brackish water-bodies and a complex network of tidal creeks and canals. This is mainly due to larger delta created by east-flowing rivers and gentle slope of the coast. According to Forest Survey of India (FSI)[8], out of 4,87,100 ha of mangrove wetlands in India, nearly 56.7% (2,75,800 ha) is present along the east coast, and 23.5% (1,14,700 ha) along the west coast, and the remaining 19.8% (96,600 ha) is found in the Andaman and Nicobar islands (Table 1).

Environmental setting of mangrove wetlands of the east coast

Along the east coast of India, environmental setting of the mangrove wetlands differs widely from north to south.

Sunderbans

Sunderbans is the largest mangrove wetland in the world. It covers an area of about 1 mha, of which 60% is located in Bangladesh and the remaining western portion, comprising 40%, lies in India[9]. The Indian part of the Sunderbans is located in the western part of the Ganges–Brahmaputra delta. Ganges and Brahmaputra rivers are

V. Selvam is in the M. S. Swaminathan Research Foundation, Taramani Institutional Area, Taramani, Chennai 600 113, India
e-mail: vselvam45@hotmail.com

Table 1. Mangrove wetlands of India

State	Mangrove wetland	Total area of the wetland (ha)*	Actual forest cover (ha)
East coast			
West Bengal	Sunderbans	4,26,000	2,12,500
Orissa	Mahanadi	67,000	21,500
Andhra Pradesh	Godavari	33,250	24,100
	Krishna	25,000	15,600
Tamil Nadu	Pichavaram	1,300	900
	Muthupet	13,000	1,200
West coast			
Gujarat	Gulf of Kutch	58,200	85,400
	Gulf of Khambat	53,123	17,700
Other mangroves	–	–	11,600
Andaman and Nicobar islands	Andaman islands		92,900
	Nicobar islands	–	3,700
Total			4,87,100

*Records of the State Forest Department.

snow-fed and have a number of large distributaries and rivulets through which freshwater is supplied to the Sunderbans mangroves throughout the year. Because of this, salinity of the water both within the mangrove forest as well as near the sea is lower than that of the sea water even during summer months[10]. The Sunderbans region has a warm humid climate with an annual rainfall of about 1600 to 1800 mm. It receives rainfall during the southwest monsoon season, which starts in June and continues until October, with occasional rainfall throughout the year. The degree of aridity calculated on the basis of the ratio P/Etp (ref. 3), where P is the mean annual rainfall and Etp is the potential evapotranspiration, is > 0.75.

The mean sea level in the Sunderbans is about 3.30 m and the mean highest high water level (MHHW) and mean lowest high water level (MLHW) are 5.94 and 0.94 m respectively[11]. Due to gentle slope of the coast and large tidal amplitude, tidal water penetrates at an average distance of 110 km inland from the shoreline and in some areas, the effect of the tides is felt over 300 km inland[9]. The geomorphology of this mangrove estuary is funnel-shaped with numerous linear, tidal mud flats and a network of tidal channels. These mud flats lie more or less perpendicular to the shoreline and parallel to the direction of tidal flow. Presence of large tidal flats is a common feature in tide-dominated mangrove estuaries, where strong tidal currents work and rework the sediments to create such tidal flats[4]. In the Sunderbans, during the monsoon rains, the estuarine regime is influenced by the interaction of the headwater discharge and the tides, which together influence the seaward drift of the sediment. During reduced inflow of freshwater, strong tidal currents govern the estuary and influence the upstream sediment movement. The tidal mud flats provide suitable microenvironment for colonization of the mangrove plants, which grow into dense and tall mangrove plant communities. The total area of the Indian part of the Sunderban mangrove wetland is about 4,10,000 ha, of which 2,12,500 ha is occupied by mangrove forest[8] and 1,78,100 ha is water body[9].

Mahanadi mangrove

Mahanadi mangrove is present in the mid-region of the Orissa coast, about 250 km south of the Sunderbans mangrove. It is located in the combined delta of the rivers Mahanadi, the Brahmini and Baitarani, which are interconnected. Distributaries of the Mahanadi and Brahmini join together near the coast and have a common estuarine region. Similarly, Baitarani at its lower reaches drains into the river Brahmini and these two rivers have a common mouth near a place called Dhamra[12]. Bhitarkanika mangrove wetland, which is one of the important mangrove genetic resources of the world[13], is located in the estuarine environment created by Brahmini and Baitarani. Since the mangrove forest of the Mahanadi delta receives freshwater from three rivers, they are rich in species diversity and dense and tall like the Sunderbans. The annual rainfall is about 1600 mm. Nearly 70% of the rainfall occurs during June to October (southwest monsoon) and 30% is experienced during November to January due to winter rainfall. The region has sub-humid climate (indicating that the winter rainfall is deficient) and P/Etp varies between 0.5 and 0.75. The tide is semi-diurnal in type and tidal amplitude of about 4.5 m was recorded in the mouth region of the estuary and 2.8 m inside the estuarine region. However, Untawale[11] indicated that the MHHW and MLHW in the Mahanadi mangrove are about 2.58 and 0.71 m respectively. The mean sea level in the region is about 1.66 m. Because of the influence of the high-tidal amplitude on the ecology of

Mahanadi estuary, Upadhyay[14] classified it as tide-dominated coastal plain estuary. Due to variation in freshwater flow and tidal water penetration, water salinity within the mangrove wetland varies from 2 to 6 parts per thousand (ppt) during peak monsoon season, 18 to 30 ppt during winter season and 25 to 32 ppt during summer months[14].

Godavari mangrove

Godavari mangrove wetland is located in Andhra Pradesh (AP), in the delta created by the river Godavari. The Coringa mangrove wetland, the largest mangrove in AP, occupies the northern portion of the Godavari delta. The river Godavari branches into Vasishta and Gautami near Dowleswaram, which is considered as the head of the delta. Two distributaries, namely Coringa and Gaderu branching-off from the northern bank of the rivers Gautami-Godavari, supply freshwater to the Coringa mangroves. Freshwater flows into the mangrove wetlands of the Godavari delta for a period of six months and peak flow normally occurs during July to September, coinciding with the southwest monsoon season. During this period the entire delta, including the mangrove wetland is submerged under freshwater, since penetration of sea water is completely blocked by the large amount of incoming freshwater[15]. Brackish water condition prevails from October to February and sea water dominates the entire mangrove wetland from March to May due to absence of freshwater discharge. It has been recorded that the river Godavari has changed its course towards south in recent years and as a result, the amount of freshwater reaching the Coringa mangroves is reduced, affecting the growth and distribution of less saline-tolerant mangrove species[16]. The drainage basin of the river Godavari occupies an area of 3.1×10^5 km^2 and the mean annual discharge is 1.05×10^{14} l.

The climate in this region is sub-humid and mean annual rainfall varies between 1200 and 1300 mm. The dry season extends for about six months, from December to May (if the rainfall during a month is equal to or less than twice the mean atmospheric temperature, then that month is called a dry month)[3]. The mean sea level in Godavari mangrove wetland is about 0.87 m and the MHHW is 1.54 m and MLHW is 0.20 m (ref. 14). A large bay called Kakinada Bay is associated with the northern part of the Godavari estuary. It has a long sand spit in the eastern side, which separates Kakinada Bay from the Bay of Bengal. This bay is shallow, about 2 m in depth and during low tide many of the areas of this bay are exposed. By measuring the growth of the sand spit with the available map prepared in 1789, it has been estimated that previously the mangrove was at about 6 km inside the present shoreline. This is an indication for expansion of the mangrove into the sea, a characteristic feature of the river-dominated mangrove wetland[4].

Krishna mangrove

The Krishna delta is the seaward-extended land mass created by alluvial deposit of the river Krishna. Geomorphologically, the Krishna delta comprises bays, tidal creeks, extensive tidal mudflats, spits and sand bars[17]. The seaward growth of the delta resulted in the formation of extensive Nizampatnam Bay in the south and Masulipatnam Bay in the north. The Krishna delta starts near Vijayawada and its first distributary, namely Hamsaladevi branches-off 60 km downstream from Vijayawada. This distributary runs northward and meets the sea near Machillipatinam. Two distributaries, namely Gollamattapaya and Nadimeru branch out 30 km downstream from Hamsaladevi distributary. The main Krishna river flows southward to the above two distributaries and joins the sea near a point called False Divi Point[18]. Mangroves are abundant in three islands located between Gollamattapaya and Nadimeru distributaries and Krishna river. The total area of the drainage basin of the river Krishna is about of 2.6×10^5 km^2 and the mean annual discharge is 6.0×10^{13} l (ref. 19).

As in the case of river Godavari mangroves, the mangrove wetland of Krishna delta also receives freshwater for about six months. The salinity level in the Krishna mangroves is always high, since evaporation in the Krishna river is 15% more than that in the Godavari[19]. The tidal amplitude in the Krishna mangroves is only 90 cm, the MHHW is 1.10 m and MLHW is 0.20 m. The mean sea level is 1.1 m.

Pichavaram and Muthupet mangroves

Pichavaram and Muthupet mangrove wetlands are located in the northernmost and southernmost ends respectively, of a large delta called the Cauvery delta and the distance between the two mangrove wetlands is about 180 km. Unlike the other mangrove wetlands of the east coast, both the Pichavaram and Muthupet mangroves receive freshwater mostly during the northeast monsoon season from October to November. Thus, in these two mangrove areas dry season is long, extending from February to September and corresponding to it, the average salinity of the mangrove water is also high during the dry season, ranging from 35 to 45 ppt. In some of the pockets of the Muthupet mangrove wetlands, water salinity as high as 75 ppt has been recorded[20]. The climate is subhumid and P/Etp ranges between 0.5 and 0.75. Compared to other mangrove wetlands of the east coast of India, the tidal amplitude of the Pichavaram and Muthupet mangroves is very low, MSL is about 0.34 m, MHHW is about 0.67 m, and MLHW is about 0.03 m. Like any other delta, the Cauvery delta also has a number of distributaries and one among them is river Coleroon. The Pichavaram mangrove is located in the redundant delta of this river and mangrove vegetation is absent in the active delta of the river Coleroon. The presence of mangroves in either redundant or abundant delta and its absence in the active delta is another characteristic feature of river-dominated mangrove wetlands[4]. In the case of Muthupet mangrove wetlands, six distributaries of the Cauvery delta discharge their water into it and form a large lagoon before reaching the sea.

Thus, area of the mangrove wetlands, amount and periodicity of freshwater flow and tidal amplitude progressively decrease along the east coast from the northernmost mangroves (Sunderbans) to the southern most mangroves (Muthupet). On the other hand, the number of dry months is high in the southern mangroves than in the northern mangrove wetlands. Such variations in environmental setting have their own influence on the flora, fauna and fisheries of these mangrove wetlands.

Environmental setting of mangrove wetland of the west coast

In the west coast of India, major wetland is present in Gujarat. Nearly 77% of the Gujarat mangroves are confined to the Gulf of Kutch and the remaining are found in the Gulf of Khambat region[21]. The mangroves in this region are developed under extremely arid climate (P/Etp = 0.3 to 0.5). The bioclimate is hot, with a rather cold season, subdesertic, with very strong average annual thermal amplitude of about 12°C. The average rainfall in the Gulf of Kutch is about 470 mm and the dry season continuous from October to June. In the Gulf of Khambat, annual rainfall is slightly higher, 900 mm, but the dry period is for eight months[2]. Freshwater discharge from any perennial river does not take place in this mangrove wetland. It has been described by the Space Applications Centre[17] that in the Gulf of Kutch, marine processes are dominant throughout the year due to negligible freshwater discharge, whereas the Gulf of Khambat is nothing but an ‘extension of the sea on the land’. The total area of the mangrove wetlands of Gujarat is about 1,05,100 ha of which dense mangrove vegetation is present only in about 21,500 ha (20% of the total area) and remaining area is constituted by degraded mangroves and saline-encrusted mudflats[17]. Analysis of the sediment sample taken 2 km from the shoreline of the Gujarat coast shows that sea level stood about 20 m below the present sea level about 8000 to 9000 years ago[22]. This clearly indicates that the present mangrove areas of Gujarat were inundated due to rise in sea level and thus can be classified as drowned-valley type mangroves.

Environmental setting of mangrove wetland of the Andaman and Nicobar islands

The Andaman and Nicobar island region is an important archipelago of the Indian territory, situated about 1150 km east of the southeast of India, near Burma and Sumatra. This archipelago comprises two groups of islands (i) the Andaman, the biggest group with 204 islands distributed over an area of 6400 km^2. The total area of the mangrove wetland in this group of islands is about 1,15,000 ha; (ii) the Nicobar group is smaller than the Andaman group, but it is less explored. Out of the 22 islands, 12 remain practically uninhabited. The geology of the Andaman–Nicobar archipelago is complex. There is a great diversity of sedimentary rocks dominated by sandstone. Locally, conglomerates or calcareous rocks are found to form the cliffs of the islands. One important phenomenon of this region is the numerous recent volcanic activities in the southern part of the Andaman. Some of the islands of the Andaman group are volcanic in origin[23]. The climate is humid and annual rainfall in the Andaman and Nicobar group of islands is about 2750 mm and 3080 mm respectively. In the Andaman group, there is a marked dry season, extending from January to March, whereas in Nicobar island there are no dry months since monthly rainfall even during January to March exceeds 150 mm. The tidal amplitude in the Andaman and Nicobar islands is about 1.90 m. The mangroves of Andaman and Nicobar islands are gregarious, dense and diverse in nature and found along the tidal creeks, bays and lagoons. The tidal creeks often form outlets to the rain-fed streams that flow from the interior and carry silt to the shore to form muddy plains facilitating the spread and regeneration of mangroves[24]. Chatterjee[25] showed that in both the Andaman and Nicobar islands, there are remains of raised coral beaches and wave-cut cliffs on both the sides of the coast, indicating the carbonaceous nature of the soil.

Classification of Indian mangrove wetlands

Currently, two major classification systems developed by Lugo and Snedaker[26] and Thom[4] respectively, are commonly followed to classify mangrove wetlands. The classification system developed by Thom[4] can be used to group mangrove wetlands on a regional scale. It is based on three groups of dynamic factors, namely (i) geophysical (changes in sea-level, climatic conditions and tidal properties of a region), (ii) geomorphic (character of sedimentation, dominance of particular processes–wave or river, tidal or river, etc. and micro-topography of the wetland), and (iii) biological. On the basis of these characters, Thom[4] identified five environment settings for mangrove wetlands that occur on coasts dominated by terrigenous sediments, and three settings for carbonate platforms. On the basis of this system, environmental settings of the Indian mangroves can be classified as given in Table 2, and some of the tide and river-dominated mangrove wetlands of the east coast of India are shown in Figure 1.

Table 2. Environmental setting of mangrove wetlands of India

Mangrove	Setting	Dominant features
Sunderbans and Mahanadi mangroves	Tide-dominated allochthonus type of mangroves	High tidal range with strong bi-directional current; main river channels funnel-shaped with extensive tidal-flat, colonized by mangroves.
Krishna and Godavari mangroves of Andhra Pradesh, and Muthupet and Pichavaram mangroves of Tamil Nadu	River-dominated allochthonus type of mangroves	Rapid deposition of terrigenous material; delta expand seward; mangroves dominate in the region of abundant delta; active delta found nearby without mangrove vegetation.
Gulf of Kutch and Gulf of Khambat mangroves of Gujarat	Drowned bedrock valley type of mangroves	Bedrock valley drowned by rising sea-level; relatively small river delta could be seen at the head of the valley; tidal delta may occur in the mouth of the estuary.
Andaman and Nicobar Island mangroves	Carbonate platform on low energy coasts type of mangroves	Platform slowly accreting due to the accumulation of marl (calcareous) and peat; coral reef or sand barrier mitigate wave energy and allow fringe mangrove to grow extensively in shallow water area.

Table 3. Environmental characters and floristic of major mangrove wetlands of India

Mangrove	Source of freshwater	Annual average discharge (m^2/s)	Total rainfall (mm)	Dry months	Tidal amplitude (m)	Number of species	Dominant species
East coast of India							
Sunderbans	Ganges and Brahmaputra	1,13,776*	1600 to 1800	4	4.8	26	*Excoecaria agallacha*, *Ceriops decandra* and *Sonneratia apetala*
Mahanadi	Mahanadi, Brahmani	32,956**	1600	4	4.5	26	*E. agallocha* *C. decandra* and *S. apetala*
Godavari	Godavari	29,207	1100	6	1.34	17	*E. agallocha*, *Avicennia officinalis* and *S. apetala*
Krishna	Krishna	14,775	1200	8	0.90	12	*Avicennia marina*
Pichavaram and Muthupet	Cauvery	2,641	1300	8	0.64	11	*A. marina*
West coast of India							
Gulf of India	No major river	–	470	8	2.2	8	*A. marina*
Gulf of Khambat	No major river	–	900	8	–	8	*A. marina*
Andaman and Nicobar islands	No major river	–	2750 to 3080	3	1.90	24	*Rhizophora apiculata* and *R. mucronata* *Ceriops tagal*

*Most of the water flows only into the eastern part of mangrove wetland of the Sunderbans which lies in Bangladesh.
**Does not include annual mean flow of the Baitarani river which also contributes to the mangrove wetlands of Mahanadi delta.

The system developed by Lugo and Snedaker[26] provides scope to divide a mangrove wetland into smaller units based on micro-topographical features with respect to mean sea-level, frequency of tidal inundation into the areas and appearance of forests. According to this system six community types could be identified, each has its own set of environmental variables such as soil type and depth, soil salinity, tidal flushing rates. Each of these community types also has its own range of primary production, litter decomposition and carbon export along with differences in nutrient cycling rates, and factors that determine the role of mangroves on the bioproduction of adjacent water bodies. Application of this system in classifying each mangrove wetland into different community

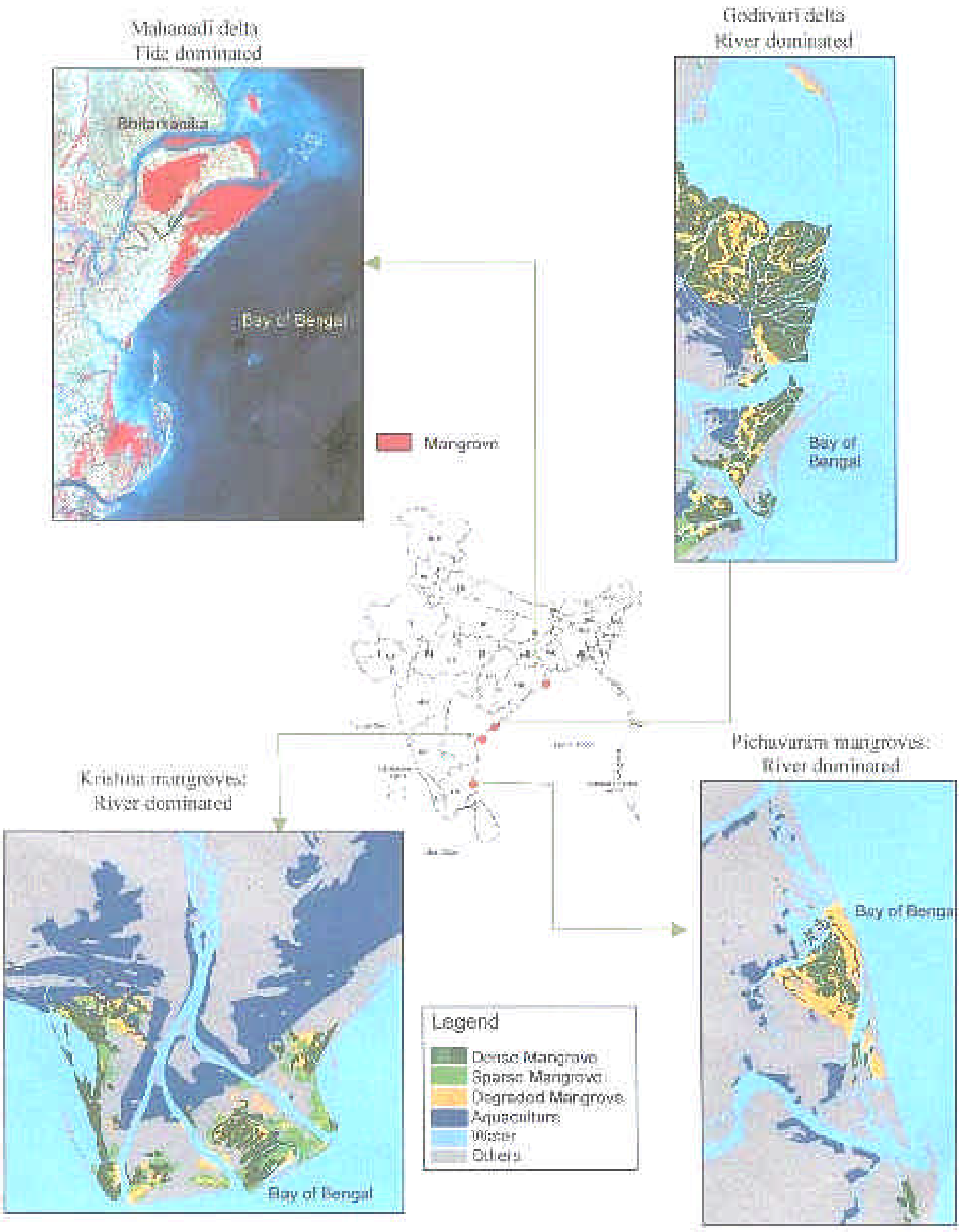

Figure 1. Some tide- and river-dominated mangrove wetlands of east coast of India.

types requires intensive field studies. Only limited attention is paid to this aspect.

Mangrove floristic

The total number of exclusive or true mangrove plant species in the world is 68, and they belong to 27 genera[6]. Out of the 68 species, 51 are present in the South Asian mangrove wetlands and 33 are recorded in the mangrove wetlands of India[9,16,27–30]. Table 3 shows the number and dominant species of mangrove wetlands of India with reference to various physical factors. As indicated in Table 3, number of species and biomass is high in the mangrove wetlands, which receive more freshwater through river discharge and where rainfall is high and number of dry month is less. In these mangrove wetlands, low saline-tolerant species are dominant. On the other hand, in the mangrove wetlands where salinity is high due to low rainfall and less freshwater run-off and high number of dry months, species diversity is low and a few species like *Avicennia marina*, which is considered as the most saline-tolerant mangrove species, dominate[2]. Regarding biomass, available literature indicates that it is high in the Sunderbans, Andaman and Nicobar island mangroves and low in Tamil Nadu and Gujarat mangroves[9].

Changes in mangrove floristic

In most of the mangrove wetlands the floristic has changed dramatically. In the Sunderbans, *Heriteria fomes* was the most abundant species and attained more than 30 m in height in the past. Now it has completely disappeared from the Indian part of the Sunderbans and only limited population is present in the Bangladesh Sunderbans. Similarly, in the Pichavaram mangrove wetlands *Xylocarpus granatum*, *Sonneratia apetala*, *Kandelia candel* and *Bruguiera gymnorhiza* were present till recently[31,32], but now, no individual of these species is present. Palynological studies carried out in Muthupet mangrove wetland indicate that true mangrove species belonging to Rhizophoraceae were the dominant species about 150 years ago, but now they are locally extinct[32]. According to Mathuda[33], dense and tall trees of *Avicennia officinalis*, *Excoecaria agallocha* and *Luminitzera reacemosa* constituted nearly 90% of the population of the Godavari mangrove wetlands in 1950s, but now they constitute only 37% of the population. On the other hand, bushes of *Suaeda maritime* and *S. monica* constitute nearly 40% of the population[29]. These two species are halophytes but not true mangrove species and they can tolerate salinity as high as 100 ppt. In general, current status indicates that except in Andaman and Nicobar islands, in all other mangrove wetlands of India, low saline-tolerant species are gradually disappearing and species like *A. marina* which can tolerate a high and broad range of salinity are becoming dominant.

The main reason for such changes is reduction in the periodicity and quantity of freshwater reaching the mangrove environment. The floral components, forest structure and biomass of the mangrove wetlands are determined at the micro level by soil and pore-water salinity (salinity of the water that is present in the pores of the soil[34–37]). The relationship between soil and pore-water salinity and macro-physical forces are shown in Figure 2. Among the factors that control soil and pore-water salinity, climate, tidal amplitude and mineral con-

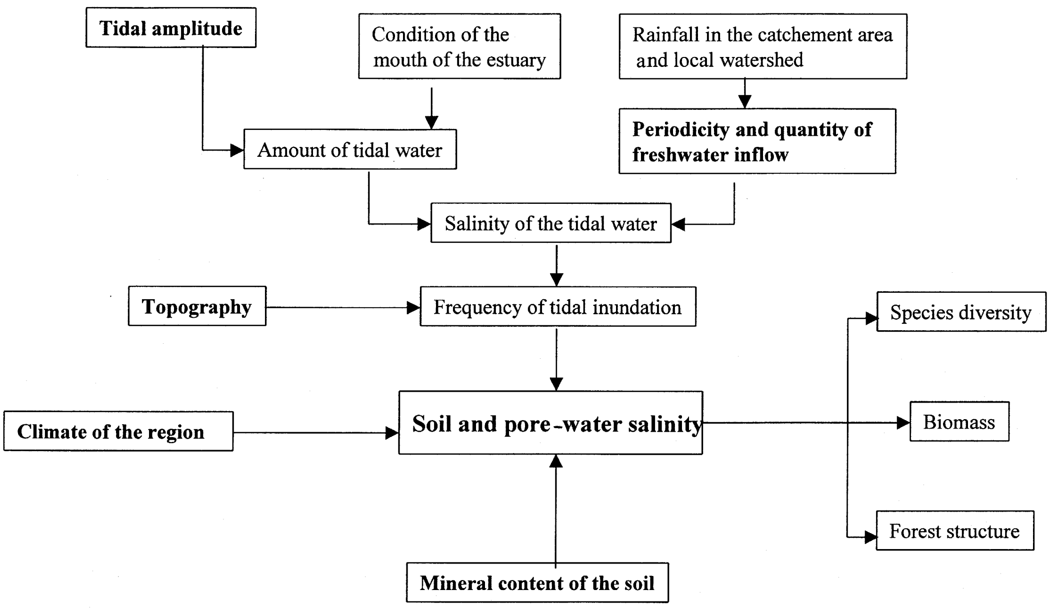

Figure 2. Macro-level environmental factors affecting soil and pore-water salinity of mangrove wetland and its biological characters.

tent of the soil could not be changed in a short duration by human activities. On the other hand, construction of dams in the upstream areas can change inflow of freshwater effectively in a short duration. In many of the Indian mangrove wetlands, freshwater reaching the mangroves considerably reduced from late 19th centaury due to diversion of freshwater in the upstream area[38,39]. For example, the amount of freshwater reaching the Pichavaram mangroves through river Coleroon has reduced from 73 TMC (thousand million cubic feet) in 1920s to 31 TMC in 1980s, to 3–5 TMC in 1990s[30] due to construction of large and small dams since 1924.

Another important example is the changes that have taken place in the floristic of the Indian part of the Sunderbans due to reduction freshwater. Due to neo-tectonic movement, the Bengal Basin is slowly tilting towards the east. The raising of the western region of the Sunderbans separated the ancient branches of the river Ganges from the area which today comprises the Indian part of the Sunderbans[40,41]. Now the main deltaic region and highest level of freshwater run-off are restricted to Bangladesh Sunderbans. As a result, the salinity of Bangladesh Sunderbans is much lower than that of the Indian Sunderbans. Because of this, the Bangladesh Sunderbans is characterized by the presence of large population of less saline-tolerant or freshwater-loving species such as *Heritiera fomes* and *Nypa fruticans*, whereas in the Indian part of the Sunderbans, low stands of *E. agallocha*, *Agiceras corniculatum* and *Ceriops decandra* are common. Even after shifting of the Ganges and Brahmaputra towards the east, the amount of freshwater reaching the Indian part of the Sunderbans makes its salinity lower than that of the other mangrove wetlands of India. Experimental evidences indicate that at high salinity, mangrove plants spend more energy to maintain water balance and ion concentration rather than for net primary production and growth[36,42,43]. Hence, increase in salinity due to reduction in freshwater flow would lead to disappearance of the low salinity tolerant species through gradual decline of the population[41].

Conclusion

The ecology of the mangrove wetlands is influenced by a number of macro-level physical forces. Among them, the quantity and periodicity of freshwater flow plays a significant role in determining the species diversity, biomass and forest structure. This is especially important for river-dominated mangrove wetlands since the flora of these mangrove wetlands is more susceptible to reduction in freshwater flow than tide-dominated mangrove wetlands. Secondly, species selection for plantation or restoration of degraded mangroves needs to be based on the currently available species. Any attempt to reintroduce the low-saline species that were lost from a mangrove wetland might not succeed without increasing the freshwater flow. For example, attempts to reintroduce *Sonneratia apetala*, *Xylocarpus granatum* and *Bruguiera gymnorhiza* in the Pichavaram and Muthupet mangrove wetlands failed because of high soil salinity. Thirdly, river-dominated mangroves characterized by high nutrient influx and strong out-welling from mangrove forests, play a significant role in maintaining the fishery production of the adjacent coastal waters[4]. Hence, reduction in freshwater flow would affect the amount of nutrient exported to coastal environment and thereby affect fishery production. Thus, in order to save the current floral diversity and biomass of the mangrove wetlands as well as fishery production of the adjacent coastal waters, prevention of further reduction in freshwater inflow into the mangrove wetlands should be one of the main objectives of mangrove conservation and management plans.

1. Alongi, D. M., Boto, K. G. and Robertson, A. I., in *Tropical Mangrove Ecosystem* (eds Alongi, D. M. and Robertson, A. I.), American Geophysical Union, Washington DC, 1992, pp. 251–292.
2. Blasco, F., in *The Mangroves of India*, French Institute of Pondicherry, Pondicherry, 1975.
3. Blasco, F., in *Mangrove Ecosystem: Research Methods* (eds Snedaker, S. C. and Snedaker, J. G.), UNESCO, Paris, 1984, pp. 18–35.
4. Thom, B. G., in *Mangrove Ecosystem: Research Methods* (eds Snedaker, S. C. and Snedaker, J. G.), UNESCO, Paris, 1984, pp. 3–17.
5. Woodruff, C., *Tropical Mangrove Ecosystem* (eds Alongi, D. M. and Robertson, A. I.), American Geophysical Union, Washington DC, 1992, pp. 7–42.
6. Duke, N. C., *Tropical Mangrove Ecosystem* (eds Alongi, D. M. and Robertson, A. I.), American Geophysical Union, Washington DC, 1992, pp. 63–100.
7. Ahmad, E., in *Coastal Geomorphology of India*, Hindustan Publishing Corporation, New Delhi, 1972.
8. State of Forest Report, Forest Survey of India, Dehra Dun, 1999.
9. Choudhuri, A. B. and Choudhury, A., in *Mangroves of the Sunderbans: Volume 1 India*, IUCN, Bangkok, 1994.
10. Baidya, A. and Choudhury, A., in *The Mangroves* (ed. Bhosale, L. J.), Shivaji University, Kholapur, 1986.
11. Untawale, A. G., in *Mangroves of Asia and the Pacific: Status and Management* (ed. Umali, R. M.), UNESCO Regional Office, New Delhi, 1986, pp. 51–88.
12. Sinha, B. N., in *Geography of Orissa*, National Book Trust, New Delhi, 1999.
13. Swaminathan, M. S., in *Conservation of Mangrove Genetic Resources*, M.S. Swaminathan Research Foundation, Chennai, 1994, pp. 87–95.
14. Upadhyay, S., *Indian J. Mar. Sci*., 1988, **17**, 19–23.
15. Ganapathi, P. N. and Rama Sarma, D. V., *Curr. Sci*., 1965, **34**, 631–682.
16. Rao, U. M. and Rao, G. M. N., *Indian J. Mar. Sci*., 1988, **17**, 326–329.
17. Space Application Centre, in *Coastal Environment*, Indian Space Research Organization, Ahmedabad, 1992.
18. Varadarajulu, R., Harikrishna, M., Chitti Babu, P. and Chakaravarthy, P., *Mahasagar*, 1985, **18**, 265–272.
19. Sarin, M. M., Rao, K. S., Bhattacharya, S. K., Ramesh, R. and Somayajulu, B. L. K., *Mahasag*ar, 1985, **18**, 129–143.

20. Selvam, V., Ph D thesis, University of Madras, Chennai, 1992.
21. Singh, H. S., in *Mangroves of Gujarat*, Gujarat Ecological Education and Research Foundation, Gandhinagar, 2000.
22. Srivastava, P. C., Verma, K. K. and Mathur, U. B., in Proceedings of the Seminar on Quaternary Environment (ed. Merh, S. S.), Hindustan Publishing Corporation, New Delhi, 1982, pp. 415–421.
23. Thothathri, K., *Bull. Bot. Surv. India*, 1962, **14**, 281–296.
24. Rao, T. A. and Chakraborti, S., *Curr. Sci*., 1987, **56**, 1045–1051.
25. Chatterjee, S. P., in *Fluctuations of Sea Level Around the Coast of India during the Quaternary Period* (ed. Dikshit, K. R.), Geological Survey of India, 1983, pp. 269–277.
26. Lugo, A. E. and Snedaker, S. C., *Annu. Rev. Ecol. Syst*., 1974, **5**, 39–64.
27. Banarjee, L. K., *Trop. Ecol*., 1987, **28**, 117–125.
28. Kathiresan, K. and Ravikumar, S., *Indian For.*, 1993, **119**, 773–775.
29. Azariah, J., Selvam, V. and Gunasekaran, S., *Hydrobiologia*, 1992, **247**, 253–260.
30. Selvam, V., Navamuniyammal, M., Gnanappazham, L. and Ramakrishna, D., in *Atlas of Mangrove Wetlands of India–Part 1 Tamil Nadu*, M.S. Swaminathan Research Foundation, Chennai, 2000.
31. Kannupandi, T. and Kannan, R., in *Anthology of Indian Mangroves*, ENVIS Centre, Annamalai University, Chidambram, 1998, pp. 25–29.
32. Caratini, C., Blasco, F. and Thanikaimoni, G., *Pollen Spores*, 1973, **15**, 281–292.
33. Mathuda, G. S., in Proceedings of the Mangrove Symposium, Ministry of Food and Agriculture, Kolkata, 1959, pp. 66–68.
34. Wells, A. G., in *Mangrove Ecosystems in Australia: Structure, Function and Management* (ed. Clough, B. F.), Australian National University Press, Canberra, 1982, pp. 57–78.
35. Bunt, J. S., Williams, W. T. and Duke, N. C., *Aust. J. Bot*., 1982, **30**, 401–404.
36. Clough, B. F., in *Tropical Mangrove Ecosystem* (eds Alongi, D. M. and Robertson, A. I.), American Geophysical Union, Washington DC, 1992, pp. 225–250.
37. Smith III, T. J., in *Tropical Mangrove Ecosystem* (eds Alongi, D. M. and Robertson, A. I.), American Geophysical Union, Washington DC, 1992, pp. 101–136.
38. Ramanathan, R. and Varadarajulu, R., in *Recent Researches in Estuarine Biology* (ed. Natarajan, R.), Hindustan Publishing Corporation, New Delhi, 1973, pp. 151–164.
39. Banerjee, L. K. and Gosh, D., in *Anthology of Indian Mangroves*, ENVIS Centre, Annamalai University, Chidambaram, 1998, pp. 20–24.
40. Morgan, J. P. and McIntire, N. C., *Bull. Geol. Soc. Am*., 1959, **70**, 319–342.
41. Spalding, M., Blasco, F. and Field, C., in *World Mangrove Atlas*, The International Society for Mangrove Ecosystems, Okinawa, Japan, 1997.
42. Clough, B. F., *Aust. J. Plant Physiol*., 1984, **11**, 419–430.
43. Smith, J. A. C. *et al.*, *New Phytol.*, 1989, **111**, 293–307.

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