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Overview Article

Biodiversity and its conservation in the Sundarban Mangrove Ecosystem

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Abstract. The Sundarban, covering about one million ha in the delta of the rivers Ganga, Brahmaputra and Meghna is shared between Bangladesh (~60 %) and India (~40 %), and is the world's largest coastal wetland. The area experiences a subtropical monsoonal climate with an annual rainfall of 1,600–1,800 mm and severe cyclonic storms. Enormous amounts of sediments carried by the rivers contribute to its expansion and dynamics. Salinity gradients change over a wide range of spatial and temporal scales. The biodiversity includes about 350 species of vascular plants, 250 fishes and 300 birds, besides numerous species of phytoplankton, fungi, bacteria, zooplankton, benthic invertebrates, molluscs, reptiles, amphibians and mammals. Species composition and community structure vary east to west, and along the hydrological and salinity gradients. Sundarban is the habitat of many rare and endangered animals (*Batagur baska, Pelochelys bibroni*, *Chelonia mydas*), especially the Royal Bengal tiger (*Panthera tigris*). Javan rhino, wild buffalo, hog deer, and barking deer are now extinct from the area. Large areas of the Sundarban mangroves have been converted into paddy fields over the past two centuries, and more recently into shrimp farms. The Sundarban has been extensively exploited for timber, fish, prawns and fodder. The regulation of river flows by a series of dams, barrages and embankments for diverting water upstream for various human needs and for flood control has caused large reduction in freshwater inflow and seriously affected the biodiversity because of an increase in salinity and changes in sedimentation. *Heritiera fomes* (locally called Sundari, from which Sundarban derives its name), *Nypa fruticans* and *Phoenix paludosa* are declining rapidly. During the past three decades, large parts of the remaining Sundarban have been protected for wildlife, particularly tiger, through the creation of several sanctuaries and a biosphere reserve. Parts of the Sundarban in both India and Bangladesh have been declared World Heritage sites. However, its biodiversity continues to be threatened by a growing human population that not only places pressure on its biological resources, but also impacts on the freshwater inflows from upstream areas. Oil exploration in coastal areas is also emerging as a new threat. Further threats arise from global climate change, especially sea level rise. The future of the Sundarban will depend upon the management of freshwater resources as much as on the conservation of its biological resources.

Key words. Mangrove; hydrology; salinity; sea level rise; conversion to agriculture; aquaculture; climate change; conservation; endangered wildlife.

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Introduction

Mangroves[1] are intertidal forested wetlands confined to the tropical and subtropical regions (Tomlinson, 1986). The total global area of the mangroves is estimated at only 18.1 million ha (Spalding et al., 1997), against over 570 million ha of freshwater wetlands including peatlands globally (but excluding paddy fields; Spiers, 1999). Although mangroves have been exploited for many centuries, our scientific understanding of these wetland forests remained poor until the 1970s (Lugo and Snedaker, 1974; Blasco, 1975; Chapman, 1976). During the past three decades or so, these wetland forests have received increasingly greater attention which is reflected in an exponential increase in the number of publications (Ellison, 2002). Several recent publications have examined issues concerning ecology, management and conservation of mangroves (Robertson and Alongi, 1992; Ricklefs and Latham, 1993; Ellison et al., 1999; Kathiresan and Bingham, 2001; Macintosh and Ashton, 2002; Ellison, 2002; Linneweber and de Lacerda, 2002; Vannucci, 2003; Saenger, 2003).

The biodiversity of mangroves has also been of increasingly greater interest, firstly because of the Convention on Biological Diversity, and secondly, because the mangrove ecosystems are among the most threatened by the global climate changes, particularly the sea level rise (Macintosh and Ashton, 2002, 2004). Mangroves are relatively well known for their floral diversity which is comprised of only 65–69 species of vascular plants which have several specific adaptations to the dynamic coastal environment (see Kathiresan and Bingham, 2001) and among the fauna, their fisheries (both fishes and crustaceans) resources are better understood. The global patterns of biodiversity in mangroves also present an interesting picture. Whereas the latitudinal pattern of mangrove flora is normal in as much as the highest species richness of plants occurs around the Equator and declines at higher latitudes – both north and south (Duke et al., 1998; Ellison et al., 1999), the longitudinal distribution is quite 'anomalous' with high concentrations in the Eastern Hemisphere between 90º E and 135º E (Ricklefs and Latham, 1993; Ellison and Farnsworth, 2001). Interestingly, the mangrove-inhabiting molluscs follow a similar pattern (Ellison et al., 1999).

More than 41 % of the world's mangroves occur in South and Southeast Asia of which Indonesia alone accounts for 23 %. A further 20 % of the total mangrove area lies in Brazil, Australia and Nigeria (Spalding et al., 1997). While practically all mangroves occur in small patches that develop in deltaic habitats, the mangroves in the Ganga-Brahmaputra-Meghna Delta, shared between India and Bangladesh, are the only contiguous and largest coastal wetland system in the world. Popularly known as Sundarban[2], they currently cover about one million ha area, greater than the combined area of Wadden Sea wetlands that are shared between Denmark, Germany and the Netherlands.

Exploration of the Sundarban mangroves dates back to the 16th century (Rollet, 1981). A large bulk of published literature exists on the Sundarbans of both India (Naskar and Guha Bakshi, 1987; Chaudhuri and Choudhury, 1994; Guha Bakshi et al., 1999) and Bangladesh (Seidensticker et al., 1991; Hussain and Acharya, 1994; IUCN-BD 2002, Islam and Wahab, 2005) covering many aspects of their habitat characteristics, flora, fauna (particularly fisheries), utilization and management, yet very little is known about the functional aspects of this ecosystem. In this review, we examine the current state of our knowledge of Sundarban's biodiversity, various factors threatening it, and the recent conservation measures. This is preceded by a brief overview of the geology, climate, soils and hydrology which are the major driving variables of mangrove biodiversity in this region. It may be noted here that since 1947 the Sundarban mangroves are divided between India and Bangladesh (formerly East Pakistan), and the two parts differ considerably in the nature and extent of investigations, conservation and management. They also differ substantially in the level of human exploitation over more than a century. This makes it difficult to integrate the information of the entire Sundarban. Therefore, we frequently refer to the Indian and Bangladesh parts of the Sundarban separately.

The Sundarban mangroves

The Sundarban (21º 30′ to 22º 40′ N, 88º 05′ to 89º 55′ E) comprises essentially of numerous islands formed by the sediments deposited by three major rivers, the Ganga, Brahmaputra and the Meghna, and a dense network of smaller rivers, channels and creeks. The maximum elevation within the Sundarban is only 10 m above the mean sea level. The western and eastern limits of the Sundarban are defined by the course of the River Hooghly (a distributary of River Ganga) and River Baleshwar respectively (Fig. 1). The River Harinbhanga (known as Ichamati or Raimongal in Bangladesh) demarcates the

[1] The term 'mangrove' is used variously referring to plants (Macnae, 1968; Unesco, 1973), their communities (Blasco, 1975; Hamilton and Snedaker, 1984) and the whole ecosystem. Macnae (1968) reserved the term 'mangal' to describe the mangrove plant communities. In this paper, we follow Arroyo (1979, 1997) who used the term mangrove for the entire ecosystem, its plant communities as well as the plants inhabiting them.

[2] Often referred to in plural as 'Sundarbans' because the forest comprises of hundreds of islands separated by rivers and creeks, or to mean both the Indian and Bangladesh parts together.

border between India and Bangladesh. About 60 % of the mangrove forests lie in the Khulna District of Bangladesh and the rest in the 24-Paragnas District of West Bengal (India). The estimates of the total area of Sundarban in the two countries often differ considerably. According to recent estimates, the area of the Sundarban in Bangladesh is 599,330 ha (1978 Landsat data; Rahman et al., 1979) and in India it is 426,300 ha (Sanyal, 1983).

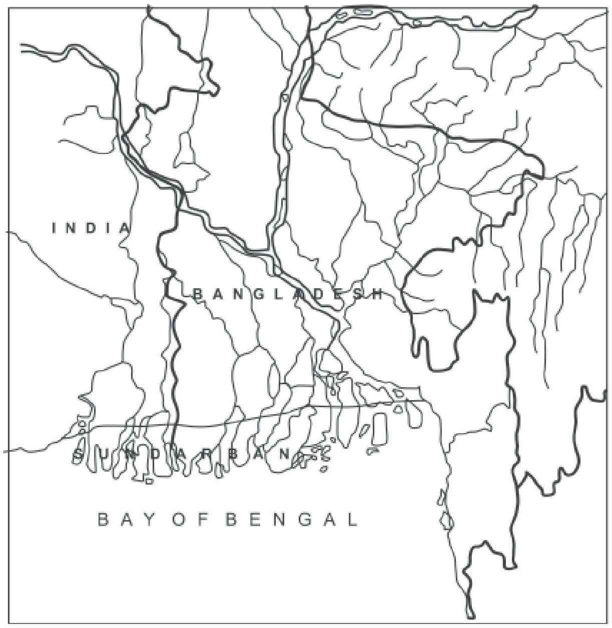

Figure 1a. Location of the Sundarban in the Ganga Brahmaputra Delta.

Geology

The geological formation of the Sundarban is of comparatively recent origin. Several geomorphological changes since the Tertiary period that included tectonic movements in northwestern Punjab and the southeastern flow of the River Ganga, resulted in the deposition of sediments in the Bengal Basin and development of the Sundarban Delta (Wadia, 1961). It is noteworthy that the Ganga and Brahmaputra together carry the world's largest sediment load to the oceans (Coleman, 1969; Milliman and Meade, 1983; Milliman et al., 1995). Neotectonic movements in the Bengal Basin between the 12th and 15th century AD further resulted in an easterly tilt (Morgan and McIntire, 1959). During the 16th century, the R. Ganga changed its course to shift eastwards and join the Brahmaputra (Deb, 1956; Blasco, 1975; Snedaker, 1991). Later, in the mid 18th century, the combined Ganga (now called Padma) and Brahmaputra again tilted eastwards to empty into the R. Meghna (Williams, 1919; Snedaker, 1991). This continuing tectonic activity greatly influenced the hydrology of the deltaic region because of changes in the sedimentation patterns and the reduction

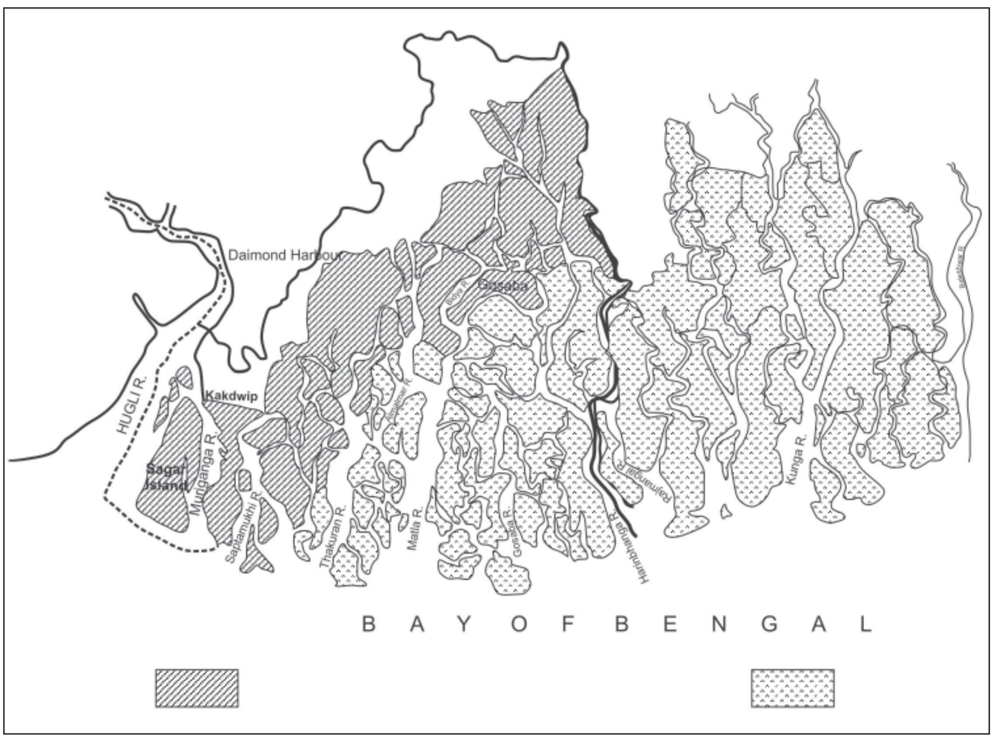

Figure 1b. The Sundarban mangroves are shared between India and Bangladesh. Mangroves once extended up to the Dampier-Hodges line – the inward limit of tidal influence. Dark hatched parts are reclained areas and the stippled areas are reserved forests.

in freshwater inflows. Most rivers (distributaries) other than the Hooghly, that contributed to the formation of the Ganga Delta (from west to east: Muriganga, Saptamukhi, Thakuran, Matla, Gosaba and Bidya), have lost their original connections with the Ganga because of siltation (Fig. 1b), and their estuarine character is now maintained by the monsoonal runoff alone (Cole and Vaidyaraman, 1966). Thus the delta-building process has nearly ceased in the west, but has accelerated in the eastern part. The high rate of sediment deposition in the Sundarban may be understood from the estimated increase in the land area by more than 800 km^2 in 80 years between 1793 and 1870 (Richards, 1990). Recent studies by Chakrabarti (1995), however, show that the mangroves are the dominant geomorphic agent in the evolution of tidal shoals and their accretion to the main landmass.

Soils

The land is moulded predominantly by tidal action. An intricate network of waterways, of which the larger channels (often 1.5 to 2.0 km wide), run in a generally north-south direction, intersect the whole area. Innumerable small khals (= creeks) drain the land at each ebb tide. Rivers tend to be long and straight, a consequence of the strong tidal forces and the clay and silt deposits which resist erosion. Easily eroded sands collect at the river mouths and form banks and chars, which are blown into dunes above the high-water mark by the strong southwest monsoon. Finer silts are washed out into the Bay of Bengal, but mud flats are formed on the leeward side of the dunes where they are protected from wave action. These mudflats become overlain with sand from the dunes, and develop into grassy meadows. This process of island-building continues for as long as the area on the windward side is exposed to wave action. With the formation of the next island further out, silt begins to accumulate along the shore of the island and sand is blown or washed away (Seidensticker and Hai, 1983).

Most of the soils derived from alluvial deposits are azonal with little or no profile development (Chaudhuri and Choudhury, 1994; Sarkar et al., 1999). Clay loam is the predominating soil type in the Sundarban, though silty and sandy loams also occur in many areas. Clays with or without muck occur in swamps and alluvial lakes. Alluvial soils along the coast, and especially in the Sundarban area, show a white efflorescence of sodium chloride, as they are impregnated with salts by tidal estuaries. These soils have been formed from deposits brought by tidal currents. Numerous tidal flats have been formed after the headwater flow through the deltaic distributaries of the R. Ganga were silted up. The parent deposits are either rich in calcium or magnesium, or consist of half-decomposed organic matter. The coastal soils are usually classified as saline, non-saline and alkali soils. Pure sands, which form sand dunes, occur mainly along the coast.

Similarly in the Bangladesh Sundarban, the soil is a silty clay loam with alternate layers of clay, silt and sand. The surface is clay except on the seaward side of islands along the coast , where sandy beaches occur. In the eastern part, the surface soil is soft and fertile whereas it is harder and less suitable for tree growth in the west (Choudhury, 1968). The soil pH averages 8.0 (Christensen, 1984).

Climate

The climate of the area is characterized by relatively high temperature and humidity (>80 %) throughout the year, and well distributed rainfall during the monsoon season. Temperatures rise from a daily minima of 2–4 °C in winter to a maximum of about 43 °C in March and may exceed 32 °C during the monsoon. Recent reports suggest that the air temperature over the Sundarban and adjacent parts of the Bay of Bengal are gradually increasing (Huq et al., 1999; Agrawala et al., 2003). The cold season lasts from about the middle of November to the end of February and is followed by the summer from March to May. There is a six-month dry season during which evapotranspiration exceeds precipitation.

The rainfall over the Ganga-Brahmaputra deltaic region decreases from east to west and from south to the north. In the Bangladesh region, mean annual rainfall varies from about 1,800 mm in Khulna, north of the Sundarban, to 2,790 mm on the coast. The average annual rainfall in the Indian region is only 1,661.6 mm. It decreases from 1,805 mm in the south on Sagar Island towards Kolkata in the north. Most of the rainfall (about 74 % of the total) occurs during the southwest monsoon period (June–September). Some precipitation is received in the latter half of the hot season and in October.

There is relatively little variation in the rainfall between years. During the first half of the 20th century, the highest and lowest annual rainfalls were only 142 % (in 1933) and 62 % (in 1935) of the normal respectively. Only rarely have two or three consecutive years experienced below normal (<80 % of average) rainfall. On an average there are 80 rainy days (>2.5 mm rainfall) in a year.

Winds are generally light to moderate with a slight increase in force during the summer and monsoons, but in the southern Sundarban area, particularly near the coast, winds are stronger. Winds blow mostly from directions between the south-east and south-west during May to September. In October, winds vary in direction. During the winter, winds blow mainly from the north-west. In March and April they blow from the south and south-west.

Thunderstorms are common during summer afternoons. These may be in association with severe squalls and occasional hail. These are commonly known as nor'westers (because the associated squalls usually come from the north-west) or Kalbaisakhi (the disastrous winds of Baisakh, the first month of the Bengali calendar). Storms result in heavy rain and a sharp drop in temperature.

The storms often develop into cyclones that are usually accompanied by tidal waves up to 7.5 m high (Seidensticker and Hai, 1983). Available long-term records show that cyclones over the Bay of Bengal adjoining the Sundarban are increasing in their intensity, but decreasing in their frequency of occurrence. This correlates with the rising trend in temperatures mentioned earlier and has a significant bearing on the extent of coastal flooding, erosion and saline water intrusion due to storm surges (Huq et al., 1999; Agrawala et al., 2003).

Hydrology and salinity regimes

The hydrology of the Sundarban is dominated by the freshwater flows from Rivers Ganga, Brahmaputra and Meghna, which exhibit very high seasonal variation in their discharge, and the tides which range in height from 2 to 5.94 m. Tidal influence extends to more than 50 km inland from the shoreline and surges increase considerably during the cyclonic storms.

The freshwater flows from the rivers and the tidal ingress result in a gradient of salinity that varies both spatially and temporally. In general, the salinity is higher nearer the coast and the water is nearly fresh on the inland side limit of the Sundarban. Similarly, the salinity decreases from west to east. The eastern part of the Sundarban in Bangladesh is oligohaline (<5‰ salinity) whereas most of the Indian Sundarban is polyhaline (Fig. 2).

During the past few decades, however, the sources of all rivers in the western part of the Indian Sundarban have progressively silted up, disconnecting the inflow of fresh water into the mangrove delta. Freshwater flows are much larger from Brahmaputra and Meghna rivers on the Bangladesh side particularly in the Baleshwar River on the eastern side of the Sunarban (Seidensticker and Hai, 1983). The reduced freshwater flows in western parts of the Sundarban have resulted in increased salinity of the river waters, and has made the rivers shallower over the years. At the same time, during ebb tides, the receding water level causes scouring of top soil and creates an innumerable number of small creeks, which normally originate from the centre of the islands. The ebb tide eroding action is stronger in some islands than others within the Sundarban. The receding water carries large volumes of silt which is deposited along the banks of rivers and creeks during high tides. This results in increasing the height of the banks as compared to the interiors of the islands. Over time, such eroded channels extend further inwards into the islands and form muddy blanks which may check the penetration of high tides to the interior of the islands. Irregular flooding of these blanks by high tides, coupled with the capillary action of the clayey soil and excessive heat during dry periods, results in the deposition of a salt crust on the soil surface, converting them into saline blanks. Lands on the sea faces are continually denuded by tidal waves. Towards the west, new land formation occurs because of heavy silt deposition from the Hooghly River and its distributary, the Muriganga at their confluence with the Bay of Bengal. Thus, the habitat is characterized by a continuing erosion of banks, the formation of new islands, and ever-changing soil texture and salinity of water under the influence of tides.

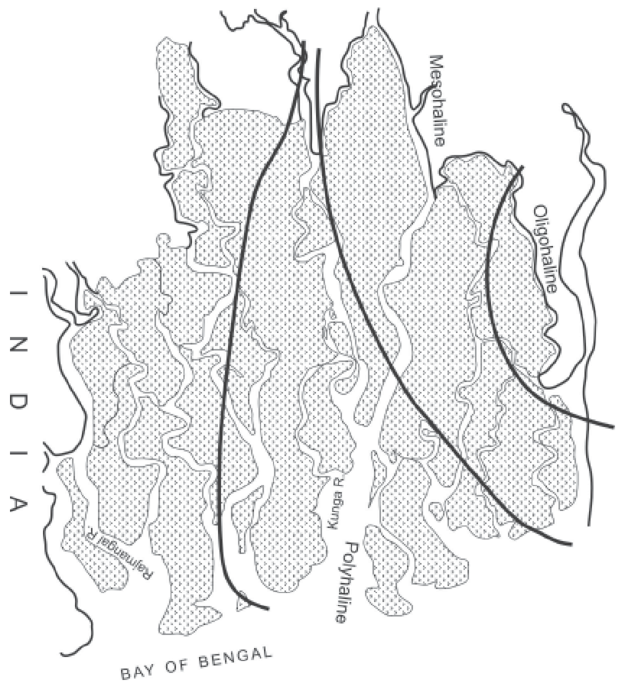

Figure 2. Salinity zones in the Bangladesh Sundarban.

In recent years, the Farakka Barrage, built in 1974 on the River Ganga within India, has also affected freshwater flows into the Bangladesh part of the Sundarban. Similarly, the construction of several dams and barrages in the Damodar River catchment area and on the Ganga have resulted in a decreased silt load and less deposition of detritus in the estuaries downstream.

Biodiversity

The large spatial and temporal variability in hydrological regimes (both freshwater inflows and the tides), topography and texture of the substratum, the salinity, and their interactions, result in very high habitat heterogeneity in the mangrove ecosystems, and thereby ensure an equally diverse biodiversity. There has been some discussion about the characteristic mangrove plants and a distinction is usually made between the "true mangrove" and "mangrove associate" species. However, following the definition of wetland species by Gopal and Junk (2000, 2001), here we consider all those species which depend directly or indirectly upon the mangrove habitats, or on any other organism living in the mangrove as mangrove organisms.

An assessment of the total biodiversity in Indian Sundarban is given in Table 1. Overall, there are relatively small differences between the species composition of the Indian and Bangladesh parts, largely because the development of the mangrove system has been dictated by similar processes. However, the overarching gradients of salinity and freshwater that occur across the Sundarban from west to the east, are clearly reflected in the distribution of biota. The Sundarban in the two countries differs also in the extent of management interventions. It must also be emphasised that the Sundarban mangrove in India has been explored frequently and in greater detail, particularly floristically, whereas the mangroves within Bangladesh were poorly investigated until recently (Chaffey et al., 1985). Recent surveys provide considerable information on several groups of plants, fishes, reptiles, amphibians and birds (Ismail, 1990; Hussain and Acharya, 1994; Seidensticker, 1991; IUCN-BD, 2002a, b, c). Differences in the nomenclature followed in the two countries also sometimes make comparisons difficult. The following account is based largely on the Indian part of the Sundarban, with frequent comparisons with the information available from Bangladesh.

Table 1. Total biodiversity recorded to date from the Indian Sundarban mangroves.

Group of Organisms	No. of species	Reference
Flowering Plants	105	Naskar and Mandal (1999)
Pteridophytes (Ferns & Fern allies)		
Algae	150	Sen et al. (2000)
Lichens	32	Santra (1999)
Vertebrates	445	Das and Nandi (1999)
Chondrichthyes	22	
Osteichthyes (Fishes)	154	
Amphibians	8	
Reptiles	58	
Birds	163	
Mammals	40	
Phylum-		Das and Nandi (1999)
Sarcomastigophora	45	
Aplicom plexa	24	
Myxozoa	4	
Ciliophora	31	
Invertebrates		
Porifera	1	Mukherjee (1975)
Cnidaria	33	Mandal and Nandi (1969)
Ctenophora	2	Nandi et al. (1993)
Platyhelminthes	41	Chaudhuri and Chaudhury (1994)
Turbellaria	1	Anon (1995)
Monogenera	21	
Trematoda	13	
Cestoda	6	
Nemathelminthes	68	
Acanthocephala	3	
Nemertinea	2	
Rotifera	4	
Mollusca	143	
Sipuncula	2	
Echiura	3	
Annelida	78	
Polychaeta	69	
Oligochaeta	6	
Hirudinea	3	
Arthropoda	476	
Crustacea	240	
Insecta	201	
Arachnida	33	
Merostomata	2	
Entoprocta	1	
Bryozoa	3	
Brachiopoda	1	
Chaetognatha	4	
Echinodermata	20	
Hemichordata	1	

Species diversity

Floristic diversity. Mangrove plants are usually divided into 'true mangrove' and 'mangrove associate' species. Globally, Duke (1992) recognised 69 species (belonging to 26 genera and 20 families) of true mangroves (major and minor, sensu Tomlinson, 1986) though recently Kathiresan and Bingham (2001) recognized only 65 species (22 genera and 16 families). Of these, at least 30 true mangroves occur in the Indian Sundarban. Debnath and Naskar (1999) identified 36 species as true mangroves. The Bangladesh part of the Sundarban differs mainly in the relative abundance of various species. Whereas members of the Rhizophoraceae and Avicenniaceae generally dominate most other mangrove areas, the Bangladesh part of the Sundarban has the greatest abundance of Sterculiaceae (*Heritiera*) and Euphorbiaceae (*Excoecaria*). Rhizophoraceae is the largest family with 11 species; four genera (*Rhizophora, Bruguiera, Avicennia* and *Sonneratia*) are represented by four species each and 5 genera (*Xylocarpus, Excoecaria, Thespesia, Derris* and *Tamarix*) have three species each. In Bangladesh there is only one species of *Bruguiera* (*B. parviflora*), whereas *Lumnitzera racemosa* and *Barringtonia* sp. are quite restricted in occurrence. Interestingly, the Sundarban supports fewer species than other mangrove areas in India and Southeast Asia. For example, there are 45 mangrove species recorded from the Andaman and Nicobar Islands in the Bay of Bengal (Deshmukh et al., 1991a) and 55 species from Bhitarkanika in the delta of the Brahmani and Baitarni rivers in Orissa on the east coast of India (WWF-I, 2001).

The total flora of the Sundarban has also been estimated differently in India and Bangladesh. In India, the total vascular flora (including mangrove associates) is estimated at 100 species representing 34 families and 57 genera. comprises of 30 species of trees, 32 shrubs, and the rest are herbs, grasses, sedges and two ferns. Many terrestrial upland plants within the Sundarban area have apparently not been included because Seidensticker and Hai (1983) recorded 334 plant species representing 245 genera from the Bangladesh Sundarban. This record lists numerous epiphytes and climbers, which include 13 orchids and several ferns. Several species in the Indian Sundarban do not occur in Bangladesh part, whereas many other species have been reported from Bangladesh alone (Choudhury, 1968; Ismail, 1990). Interestingly, some species listed earlier from Bangladesh by Prain (1903) and Choudhury (1968), such as *Bruguiera sexangula, Rhizophora apiculata* and *Sonneratia alba*, were not recorded by Chaffey et al. (1985) and it is feared that these species may have disappeared from the eastern part of the Sundarban. *Heritiera fomes* (locally known as Sundari, the most important timber species from which Sundarban derives its name),which is abundant on the Bangladesh side, is not common on the Indian side where it is considered endangered. *Nypa fruticans* also has a limited occurrence within the Indian Sundarban; it is rapidly disappearing because of extensive exploitation. Based on their present status, *Aegiceras corniculatum, Kandelia candel, Rhizophora* sp., *Sonneratia acida, Sonneratia apetala* and *Sonneratia caseolaris* also require conservation measures (Table 2).

Table 2. Rare, threatened and endangered flora of the Indian Sundarbans.

Family	Species	Status
Rhizophoraceae	1. *Rhizophora apiculata*	Occasional
	2. *Bruguiera parviflora*	Occasional
	3. *Ceriops decandra*	Occasional
	4. *Kandelia candel*	Occasional
Meliaceae	5. *Aglaia cucullata*	Rare
	6. *Xylocarpus mekongensis*	Threatened
	7. *Xylocarpus granatum*	Threatened
Sterculiaceae	8. *Heritiera fomes*	Threatened
Rubiaceae	9. *Scyphiphora hydrphyllacea*	Very Rare
	10. *Hydrophyllax maritime*	Very Rare
Tiliaceae	11. *Brownlowia lanceolata*	Occasional
Arecaceae	12. *Nypa fruticans*	Occasional
Acanthaceae	13. *Acanthus volubilis*	Very Rare
Papilionaceae	14. *Cynometra ramiflora*	Rare
	15. *Dalbergia spinosa*	Rare
Sapotaceae	16. *Manilkara hexandra*	Rare
Rutaceae	17. *Atalantia correa*	Very Rare

Algae. The algal flora of the Sundarban is very poorly known, but the available information suggests that the Sundarban has a highly diverse algal flora comprised of both benthic and planktonic forms ranging from the freshwater to marine environments. In the only study in Bangladesh, Islam (1973) reported 34 species of planktonic and benthic algae. Various published reports on the algal flora provide only a patchy picture as they are based on short-term surveys of small isolated areas (see Pal et al., 1988; Santra et al., 1988, 1991). Sen et al. (1999) recorded 80 species of algae (32 Cyanophyceae and 27 Chlorophyceae) from different parts of the Indian Sundarban. These included only 7 species of diatoms, whereas Banerjee and Santra (1999) listed 48 species of diatoms from the Hooghly-Matla estuary alone. In a recent report, Naskar et al. (2004), however, list 150 species including 15 species of Rhodophyceae and 2 species of Phaeophyceae. Another study recorded 12 genera and 16 species of benthic algae belonging to the Cyanophyceae, Chlorophyceae, Chrysophyceae and Rhodophyceae. Species of *Botrychia, Catenella* and *Caloglossa* form a turfy covering on mangrove tree trunks and pneumatophores. At a lower level on the same trees, species of *Caloglossa* occur along with *Chaetomorpha* and *Rhizoclonium*. Species of *Lyngbya, Oscillatoria* and *Microcoleus* are common on pneumatophores and on the mud (Mandal and Naskar, 1994).

Micro-organisms. The diversity of bacteria and fungi in the Sundarban has not been examined in detail, although some reports mention various microorganisms in the soils and on decomposing litter, besides pathogens infesting mangrove leaves (Pal and Purkayastha, 1992), fish, prawns and mammals (Das, 1999). Bacteria play a significant role in the mangrove environments and the Sundarban is expected to harbour a diverse bacterial community which is yet to be explored, unlike other Indian mangroves that are better known (Balasubramanian and Ajmal Khan, 2002). Furthermore, 32 species of lichens have also been recorded from the Indian Sundarban (Santra, 1998).

Faunal diversity. The fauna of the Sundarban has attracted much attention because of the huge economic importance of many species. Crustaceans account for the largest proportion of animal biomass, with an estimated annual harvest of 40 million kilograms of fiddler crabs and 100 million kilograms of mud crabs (Hendrichs, 1975), besides a considerable harvest of shrimps, prawns and lobsters. The Sundarban supports very rich estuarine and coastal marine fisheries. Among the diversity of insects, honeybees hold an important position for the production of large quantities of honey and beeswax. Also, the Sundarban is the only mangrove forest with a species of the tiger – the Royal Bengal Tiger (*Panthera tigris*). The total faunal diversity of the Sundarban in listed in Table 1.

Fish. The fish fauna of the Bangladesh Sundarban includes 53 pelagic and 124 demersal species (Sarker, 1989; Rainboth, 1991). Of these, over 120 species have been recorded in commercial catches (Seidensticker and Hai, 1983). The Indian Sundarban supports a similar number of species (165 species; Sanyal, 1999). The fish diversity is directly related to the salinity gradients in different parts of the Sundarban. Whereas Mukherjee (1975a) considered only brackish water and marine species of fish in the Indian Sundarban, Sanyal (1999) expanded the list by including 31 freshwater species. Recently, Islam and Haque (2004), in their detailed review of the fisheries resources of Bangladesh Sundarban, have described the distribution of fish species along the salinity gradients. Fishes such as *Harpodon nehereus, Trichiurus savala, Setipinna* sp., *Pampus* sp., *Sardinella* sp. and *Salar* sp. occur in areas with salinity, whereas *Pangasius pangasius* and *Lates calcarifer* occur in freshwater areas or those with very low salinity. The dominant fishes in brackish water zones (moderate salinity) are *Hilsa (Tenualosa) ilisha, Pomadasys hasta, Polynemus* sp. and *Coilia* sp. Several marine fishes also often occur within the mangroves.

Reptiles and amphibia. The species richness of both reptiles and amphibia is also similar in the Sundarbans of the two countries: 8 and 7 amphibians and 53 and 59 reptiles in Bangladesh and India, respectively (Hussain and Acharya, 1994; Sanyal, 1999; Naskar et al., 2004). Among snakes, the Family Boidae is the largest with 13 species, followed by Hydrophidae (7 species), Elapidae (4 species) and Typhlopidae and Viperidae (2 species each). Noteworthy species are the king cobra (*Ophiophagus Hannah),* Indian spectacled cobra (*Naja naja)* and Indian python (*Python molurus).* Among 14 turtles and tortoises, six species are nearly extinct or threatened (Table 3). Of the four marine turtles, the olive ridley turtle (*Lepidochelys olivacea*), though endangered, is the most abundant. The green turtle (*Chelonia mydas*) is rare due to excessive fishing, while the loggerhead (*Caretta caretta*) and hawksbill (*Eretmochelys imbricata*) are not common (Hussain and Acharya, 1994). The river terrapin (*Batagur baska*) and three of the 14 species of lizards and monitors are also endangered (Table 3).

Birds. The avifauna of the Sundarban is highly varied and very rich in species. In Bangladesh, 315 species have been recorded (Sarker and Sarker, 1986; Hussain and Acharya, 1994). These include about 95 species of waterfowl (Scott, 1989) and 38 species of raptors (Sarker, 1985a,b). Several species of kingfishers (including brown-winged and stork-billed kingfishers, *Pelargopsis amauropterus* and *P. capensis*, respectively) and the magnificent white-bellied sea-eagle (*Haliaeetus leucogaster*) are quite common, as are many herons, egrets, storks, sandpipers, whimbrels, curlews and other waders. There are also many species of gulls and terns, especially along the coast and the larger waterways. The grey-headed fish eagle (*Ichthyophaga ichthyaetus*) and Pallas's fish-eagle (*Haliaeetus leucoryphus*) are quite rare. Apart from the species particularly associated with the sea and wetlands, there is also a considerable variety of forest birds, such as woodpeckers, barbets, shrikes, drongos, mynahs, minivets, babblers and many others (Salter, 1984).

The Indian side of the Sundarban has a similar avian diversity (Law, 1953, 1954, 1956, 1959; Mukherjee, 1972, 1975b; Naskar and Mandal, 1999). Though only about 150 species were listed by Naskar (1999), Chaudhuri and Choudhury (1994) report more than 300 species of which about 100 are migratory. The list includes a large number of species that remain in the reclaimed areas adjoining the mangroves.

Mammals. Of significant interest is the fact that the mammalian diversity exhibits significant differences between the Indian and Bangladesh sides of the Sundarban: the former has only 31 species of mammals (Chaudhuri and Choudhury, 1994, Sanyal, 1999) against 49 species in Bangladesh (Hussain and Acharya, 1994).

Table 3. Threatened fauna of Sundarbans

Scientific Name	Common Name
Mammalia	
Muntjanus muntjack	Barking Deer
Panthera tigris tigris	Royal Bengal Tiger
Felis bengalensis	Leopard Cat
Felis viverrina	Fishing Cat
Platinista gangetica	Gangetic Dolphin
Orcaela brevirostris	Irrawady Dolphin
Neophocaena phocaenoides	Little Indian Porpoise
Manis pentadactyla	Chinese Pangolin
Reptilia	
Crocodylus porosus	Estuarine Crocodile
Lepidochelys olivacea	Olive Ridley Turtle
Batagur baska	Batagur Turtle
Lissemys punctata	Indian Flapshelled Turtle
Trionyx gangeticus	Indian Softshelled Turtle
Kachuga tecta	Indian Tent Turtle
Varanus bengalensis	Common Indian Monitor
Varanus flavescens	Yellow Monitor
Varanus salvator	Water Monitor
Python morulus	Indian Rock Python
Aves	
Ardea goliath	Great Goliath Heron
Pelecanus phillippensis	Dalmatian Pelican
Leptotilos duius	Lesser Adjutant Stork

At least five species, namely the Javan rhinoceros (*Rhinoceros sondaicus*), water buffalo (*Bubalus bubalis*), swamp deer (*Cervus duvauceli*), gaur (*Bos frontalis*) and probably the hog deer (*Axis porcinus*) have disappeared locally during the past century (Seidensticker and Hai, 1983). The one-horned rhino (*Rhinoceros unicornis*), Indian bison (*Bos gaurus*) and Sambhar (*Cervus unicolor*), which were once common here, are also now locally extinct. The only primate is the rhesus macaque (*Macaca mulatta*) which still occurs in good numbers, but its population is declining gradually (Blower, 1985; Gittins, 1981). The Sundarbans of Bangladesh and India support one of the largest populations of tiger, *Panthera tigris* (estimated 350-400). Spotted deer (*Cervus axis)* and wild boar (*Sus scrofa*) occur in large numbers and form the principal prey of the tiger. Besides three species of otters, there are wild cats (*Felis bengalensis*, *F. chaus* and *F. viverrina)* and the Ganges River Dolphin (*Platanista gangetica*).

Here, the notoriety of the Sundarban for its man-eating tigers must be mentioned. Every year a significant number of people (an average of 23 annually) are killed by tigers, particularly in the southern and western parts of the Sundarban. Hendrichs (1975) hypothesised that such killings were linked with the high salinity levels and the absence of freshwater for drinking purposes. However, recent analyses suggest that the killing of humans is at least partly related to the frequency of tiger-human interaction which makes humans available as easy prey (Salter, 1984; Siddiqi and Choudhury, 1987).

Invertebrates. In the Indian Sundarban, arthropods are the most abundant invertebrates (476 species) comprised almost entirely of crustaceans (240) and insects (201 species). Molluscs (143 aspecies), annelids (78 species) and nematodes (68 species) are the next most common groups of invertebrates, other than the protopzoans (104 species) (Chaudhuri and Choudhury, 1994). As mentioned earlier,the crustaceans are of great economic importance and a large number of species of prawns and shrimps are exploited commercially. A substantial proportion of species are planktonic. Among insects, odonates and dipterans have the largest representation. At least 15 other phyla are represented in the invertebrate fauna of the Sundarban. Unfortunately a similar inventory is not available for the Bangladesh Sundarban. Available reports suggest the occurrence of at least 24 species of shrimp, 7 species of crabs, 8 species of lobsters and 8 species of molluscs that are commercially exploitable.

Zonation and community diversity

The hydrological (depth and frequency of flooding) and salinity gradients that develop in a geo-morphologically dynamic environment influenced by both depositional and erosional processes, create a large diversity of habitats which are occupied by different plant communities. The distribution of different communities along the flooding gradient is often interpreted in terms of a zonation or successional sequence (Untawale 1987; Naskar and Guhabakshi, 1987). *Heritiera* species require more freshwater and occur together with *Phoenix paludosa* and *Nypa fruticans,* generally above the tide level. These species may occur separately, or in association with each other, or with *Excoecaria agallocha* or *Ceriops decandra*. The latter species join *Rhizophora* and *Bruguiera* in relatively saline and frequently inundated intertidal habitats, whereas *Sonneratia* and *Avicennia* species occur below the mean tide level. Recent studies on mangroves (Bunt, 1999), including those in the Bangladesh Sundarban (Ellison et al., 2000), based on large scale sampling and detailed multivariate analysis, have however failed to detect any zonation pattern with respect to edaphic variables that co-vary with elevation. Champion (1936) recognized the Sundarban as a seral moist tropical forest, comprised of a mosaic of beach forest and tidal forests. The latter were divided into four types: low mangrove forests, tree mangrove forests, salt-water *Heritiera* forests and freshwater *Heritiera* forests. Later Champion and Seth (1968) classified the wetland forests into littoral forests (freshwater) and tidal swamp forests (mangroves). Mandal (2003) distinguished further between the vegetation of the active delta (southern part of the Sundarban with dense swamp forest), and freshwater areas (rivers, creeks, ponds) and agricultural fields of the mature delta.

The Indian part of the Sundarban with higher salinity supports sparse *Excoecaria agallocha*, a dense understory of *Ceriops*, and dense patches of the hantal palm (*Phoenix paludosa*) on drier soils. *Xylocarpus* sp. and *Bruguiera* sp. occur sporadically throughout the area. *Oryza coarctata*, *Nypa fruticans* and *Imperata cylindrica* are prevalent on mud flats (Khan, 1986). Large stands of *Sonneratia apetala* occur on newly accreted mud banks. Sand dunes bordering the sea are primarily colonized by grasses such as *Paspalum vaginatum, Panicum repens, Aeluropus lagopoides* and *Phragmites karka*, which are followed by *Sesuvium portulacastrum* and *Ipomoea pes-caprae* (= *I. biloba*) which constitute the climax dune vegetation. *Salicornia brachiata, Hygrophyllus asiatica* and *Scirpus fruticans* occur occasionally. Within Bangladesh, the salinity of the Sundarban decreases eastwards and, accordingly, a polyhaline, a mesohaline and an oligohaline zone are recognized. Within each of these zones, vegetation associations change with elevation above sea level and the distance from the seashore (Hussain and Acharya, 1994).

The successional sequence of mangrove communities follows a similar pattern throughout the Sundarban. Small variations occur according to the salinity regimes (Karim, 1988). Grasses such as *Leersia, Porteresia* and

Phragmites and trees such as the species of *Avicennia* and *Sonneratia* are the pioneers on newly accreted land. With an increase in elevation of the land mass relative to the tidal height, the succession proceeds to a stage where *Heritiera fomes, Ceriops decandra* and *Excoecaria agallocha* constitute the climax community.

Threats to biodiversity

The biodiversity of wetlands is governed by a large variety of factors ranging from the evolutionary history and paleoclimate to the current biophysical and anthropogenic factors, besides the nature and intensity of interactions with adjacent systems. Furthermore, various socio-cultural, economic and political influences also affect the biodiversity directly as well as indirectly. These factors have been discussed elsewhere in the context of inland freshwater wetlands by Gopal (2005, 2006) and a conceptual framework is shown in Figure 3. The same factors influence the biodiversity of mangrove wetlands such as the Sundarban, where the interplay of hydrology, geomorphology and chemistry is most pronounced. Mangroves differ significantly from the freshwater wetlands in their hydrology as they interact daily with both the sea and inland areas.

The biodiversity of the Sundarban mangroves has, however, been affected by centuries of human exploitation of the forests, their conversion to paddy fields, and reclamation of land for various uses. Eaton (1991) describes in detail the history of human colonisation of the Sundarban from 1200 to 1750 A.D. and Richard and Flint (1991) provide details of the transformation of the Sundarban thereafter under British rule, whereas Presler (1991) discusses the management of the Sundarban until 1952. It is estimated that the Sundarban originally covered more than 40,000 km^2 in coastal Bengal. Clearing of the forest and rice agriculture was first actively promoted by the then Turk sultan rulers of Bengal. After the British colonised Bengal, the area of the Sundarban still included 14,627 km^2 of land and 4881 km^2 of waterways in 1793 (Richard, 1990). The British administration also actively promoted deliberate conversion to agriculture. Hunter (1875) describes the state of the Sundarban at the end of the 18th century when the then Governor of Bengal imposed a rule bringing the forest outside permanent settlements under Government control. The Commissioner for the Sundarban was charged with the task of "regulating and managing the waterlogged forests and swamps of the lower delta" and "to ensure that private landowners cleared, settled and reclaimed Sundarban forests and swamps for rice cultivation" (Richards, 1990). By 1870, 2,790 km^2 of mangroves had been cleared. Another 2,750 km^2 forests had been reclaimed within the next sixty years even though about 10,000 km^2 of the Sundarban mangroves were declared a protected or reserve forest. The protected forests were available for clearance on

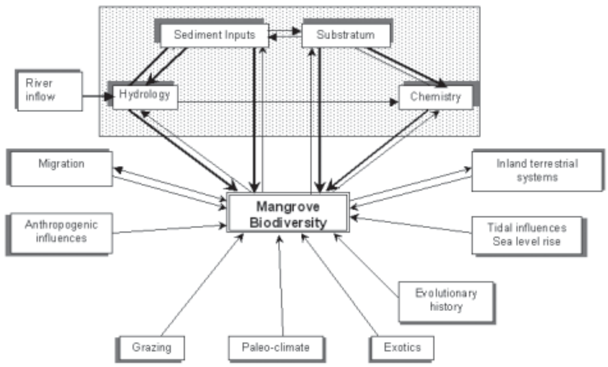

Figure 3. Factors affecting biodiversity in mangroves (adapted from Gopal, 2006).

leasing, while timber extraction was allowed in the reserve forests. It is estimated that 1,570 km^2 mangroves were reclaimed in the three decades since independence in 1947 (Richards, 1990).

Thus major threats to biodiversity have come mainly from the growing human population, and consequently, overexploitation of both timber and fauna, and conversion of the cleared land to agriculture and aquaculture. Today, the area around the Sundarban (in both India and Bangladesh) is densely populated. Approximately 2.5 million people live in hundreds of small villages very close to or within parts of the Sundarban, on which very large numbers of people depend for their livelihood at certain times of the year.

Numerous people are engaged in the commercial exploitation of sundari and other tree species, while the local people depend on the forest for firewood, timber for boats, poles for house-posts and rafters, golpatta (*Nipa fruticans*) leaf for roofing, grass for matting and fodder, reeds for fencing, and fish for their own consumption. Honey and wax are collected during the summer season (April to June) (Krishnamurty, 1990). Tens of thousand of fishermen harvest fish and shrimps for most of the year except in the monsoon season. In recent years, collection of shrimp juveniles has increased manifold, particularly for aquaculture in reclaimed areas (see, Haque, 2003, Hoq et al., 2001, 2006). It is estimated that up to 60 % of the shrimp post-larvae (PL) collected from nature die during sorting, transportation and stocking. This forces further harvests from the mangroves. Unfortunately the PL harvest of shrimp and prawns is probably the most lucrative local economic activity available to a large proportion of the Sundarban population. PL harvesting earns approximately five times more gross revenue per capita than rice farming, and probably proportionately even more on a net revenue basis as inputs other than labor are negligible compared to agriculture.

Although the ecological impacts of this activity are uncertain because of the lack of detailed information, the by-catch which is discarded and usually dies, is a substantial proportion of the Sundarban fisheries and is most likely a major negative influence on the aquatic biodiversity within the protected mangrove areas. While the reduction in shrimp juveniles directly affects the biodiversity, shrimp farming is also causing rapid deterioration in the Sundarbans similar to that in other mangrove areas (Thornton et al., 2003; Barbier and Sathirathai, 2004; Islam and Haque, 2004; Islam and Wahab, 2005).argescale collection of shrimp from estuaries directly affects the species that depend upon them for food.

Fishermen's camps are also a major source of disturbance. Illegal hunting and trapping of animals is common, not only by fishermen and woodcutters, but also occasionally by military defence personnel, e.g. in Hiron Point in the Sundarban South Wildlife Sanctuary (Blower, 1985). Habib (1989) reported that over 3,300 m of deer nets were removed between 1981 and 1987, but such poaching is now rare. Adult marine turtles and *Batagur* which get caught in fishing nets are often killed and marketed for food.

Among hydrological factors, the freshwater flows are the most significant as they influence the salinity as well as the geomorphology through the deposition of sediments. The tidal frequency is a near constant factor, but the tidal height has a significant bearing on the extent of inundation and also the erosion of freshly deposited sediments. The salinity regimes are also influenced by tidal height. Human activities, such as forest clearing and subsequent conversion to other land uses, directly influence the freshwater flow and sediment accretion. The nature of the sediments (clay to sand) also has a great bearing on the mangrove vegetation as well as the fauna. The Sundarban mangroves lie on a delta that is relatively young geologically and has been undergoing drastic changes. These changes are caused by neotectonic activity that is causing the tilting of the delta towards the east, and by the enormous amounts of sediments transported by the rivers originating in the Himalaya. The accretion of sediments in the western part and the tilting to the east causes the river to migrate eastwards. It was pointed out earlier that most of the distributaries of the River Ganga on the Indian side have silted up and do not carry freshwater. Thus, increased levels of salinity, particularly during the dry season (low flow period) affect biodiversity, with the salinity-tolerant species gradually overtaking species dependent upon regular freshwater inputs. Recent studies by Hoq et al. (2006) have clearly demonstrated the strong influence of salinity, temperature and conductivity on the seasonal abundance and distribution of shellfishes and finfishes within the Bangladesh Sundarban. The palynological evidence clearly shows that *Heritiera fomes* was very abundant in the western parts of the Sundarban 5000 years ago, and has declined relatively recently as the salinity has increased (Blasco, 1975; see also Rahman, 1990). Similarly, *Nypa fruticans* and *Phoenix paludosa* are also declining rapidly. As a long-term consequence *Heritiera* is being replaced by *Excoecaria* (Christensen, 1984). In general, the forest structure is becoming simpler and the average height of the trees is decreasing. It is estimated that in the Bangladesh part of the Sundarban, 0.4 % of the forest area is replaced by dwarf species every year. This also causes a decline in the habitat for birds, monkeys and other tree-dwelling species.

While the deterioration in vegetation is already well documented and receives continuing attention, the impacts of these changes on the fauna, particularly invertebrates, have not been investigated. Reports suggest that the changes in herbaceous vegetation are affecting the population of spotted deer which now has a much lower population in the western areas where salinity is the highest. However, an increase in *Sonneratia* sp. favours the deer because the leaves of this mangrove tree constitute its staple diet. There are several studies in other mangrove areas showing the effects of salinity levels, and their seasonal variation, on the recruitment and growth of various animals and the effect on their predators (see Hussain and Acharya, 1994).

Against this background, it is clear that human activities continue to significantly impact biodiversity in the Sundarbans. While some freshwater flows are diverted upstream for irrigation, or are regulated for flood control and hydropower, major concerns have been voiced about the effects of the diversion of water into the Hooghly River by constructing a barrage at Farakka on the Indian side of the border with Bangladesh. The water is required primarily to keep the channel open for navigation from the Bay of Bengal up to Calcutta Port. Regular dredging of the main channel is needed to maintain the depths required by large, seafaring ships. In the absence of adequate information on Sundarban biodiversity before the Farraka barrage was installed, it is not possible to assess the extent of qualitative or quantitative changes since then. However, the hilsa (*Hilsa ilisha*) fisheries have declined considerably within the Indian part of the Sundarban, largely because the barrage is a barrier to t upstream migration to the breeding sites (Sinha and Khan, 2001; Payne et al., 2004).

Whereas much emphasis has been placed on the alterations in freshwater flow regimes in recent years, the impact of embankments and polders needs to be assessed in detail. . During the past century, all streams and creeks outside the protected areas, have been extensively embanked to protect the cultivated land from inundation with saline/brackish water. About 3,700 km of embankments were constructed in Bangladesh between 1960 and 1970 (Hussain and Acharya, 1994). These embankments and polders have altered the flooding regimes, increased salinity intrusion, promoted erosion, accelerated siltation, and reduced the nutrient exchanges, and thereby affected the biodiversity (Rahman et al., 1992; Bhattacharya, 1999).

Further threats to biodiversity because of pollution have arisen on both the landward and seaward sides of the mangrove. The agrochemicals (fertilizers and pesticides) used extensively in the catchments of the Ganga and Brahmaputra rivers and their numerous tributaries, as well in the fields close to the mangroves, pollute both the waterways and the landmass, and affect the aquatic vegetation and fauna directly. Growing industrialisation of the area around Calcutta, particularly the Haldia industrial complex, and the industries situated on the western side of the Hooghly River, contribute significantly to the pollution load and hence, to the degradation of the Sundarban mangroves. From the seaward side, major pollution occurs through oil spills that cause great damage, especially to the aquatic fauna and seabirds (Blower, 1985). An oil spill from the wreckage of a Panamanian cargo ship in August 1994 near the Dangmari Forest Station, affected about 15 km^2 area including a considerable part of the Sundarban. Large scale mortality was recorded in the seedlings of *Heritiera* and *Excoecaria,* grasses, fishes, shrimps and other aquatic animals (Hussain and Acharya, 1994). Recently, the off-shore exploration for oil and gas by both Bangladesh and India has raised strong protests concerning fears about its likely impacts on the Sundarban's biota (Anonymous, 2004; Saha et al., 2005).

Conservation

Conservation of the Sundarban mangrove is supposed to have started with its declaration as a reserve forest, under the Indian Forest Act in 1878, after Schlich (1875) raised concern over its conservation (Presler, 1991). However, as described earlier, this did not help conservation *per se,* but only regulated the exploitation and conversion by the government. Soon after independence, India declared Lothian Island (3,800 ha) as a Wildlife Sanctury, and later, in 1960, another 35,240 ha were brought under the Sajnakhali Wildlife Sanctury. The hunting of tigers was banned completely in 1970, after the IUCN listed the Bengal tiger (*Panthera tigris tigris*) as an endangered species. Later, under Project Tiger, the Government of India established a Tiger Reserve in the Sundarban covering 2,585 km^2 in 1973 (Fig. 4a). Another 241 km^2 area was demarcated as a subsidiary wilderness area. The core area of 1,330 km^2 was later designated as a National Park. Another wildlife sanctuary was established in 1976 on Haliday Island (595 ha) to protect the spotted deer (*Axis axis*), wild boar (*Sus scrofa*) and rhesus macaque (*Macaca mullata*), which are dominant animals in a forest type consisting mainly of *Ceriops decandra.*

Soon thereafter, in 1977, Bangladesh created three wildlife sanctuaries: the Sundarban West (71,502 ha), Sundarban East (31,226 ha); and Sundarban South (36,970 ha), protecting about 23.5 % of the remaining Sundarban under the Bangladesh Wildlife (Preservation) (Amendment) Act, 1974. These sancturies (IUCN, 1997) lie on disjunct deltaic islands in the Sundarban Forest Division of Khulna District, close to the border with India and just west of the main outflow of the Ganges, Brahmaputra and Meghna rivers (Fig. 4b). In 1987, the Sundarban National Park in India, and in 1997, parts of the Sundarban in Bangladesh, were inscribed on the World Heritage list (IUCN, 1997).

The entire Indian Sundarban area south of the Dampier-Hodges line (that demarcates the inward limit of tidal influence), including 5,366 km^2 of reclaimed lands, has also been designated as the Sundarban Biosphere Reserve. Within the Biosphere Reserve several distinct zones have been recognised: a Core Zone comprised of the National Park and the Tiger Reserve, a Manipulation Zone (2,400 km^2 of mangrove forests), a Restoration Zone that covers 240 km^2 of degraded forest and saline mud flats, and a Development Zone which includes mostly the reclaimed areas. Only the Core Zone is under strict conservation measures. Income generating activities such as the collection of seeds of black tiger prawn (*Penaeus monodon*), the culturing of oysters and crabs, mushroom cultivation and bee-keeping for honey production are allowed in the Manipulation Zone. Efforts are being made, however, to also rehabilitate certain degraded areas through afforestation. Among faunal species, the estuarine crocodile and the Olive Ridley turtle are receiving some attention by way of captive breeding. The Sundarban Tiger Reserve in India has started a special programme for the conservation of sea turtles (http://www.wildbengal.com/sanctuaries/sunderban_main.htm).

The approaches to conservation differ considerably between the Indian and Bangladesh Sundarbans and this has been discussed at length by Seidensticker (1991). The Bangladesh Sundarban is managed as a refuge where wildlife is protected in small sanctuaries located in the larger forest tract by providing protection to the resource "hot-spots" essential to the maintenance of wildlife populations. This approach assumes that inviolate core areas surrounded by restricted-use buffer zones can ensure the survival of communities and species such as large mammals and birds which depend upon the resources such as food or nesting and roosting sites over larger areas.

In India however, the strategy for Sundarbans conservation involves the setting aside of areas where the entire life-cycle needs of a community can be met and the ecological needs of wildlife can be linked into the overall management of the system for the Sundarbans. Furthermore, in so doing, the ecological processes upon which wildlife depend become integral values in the management matrix.

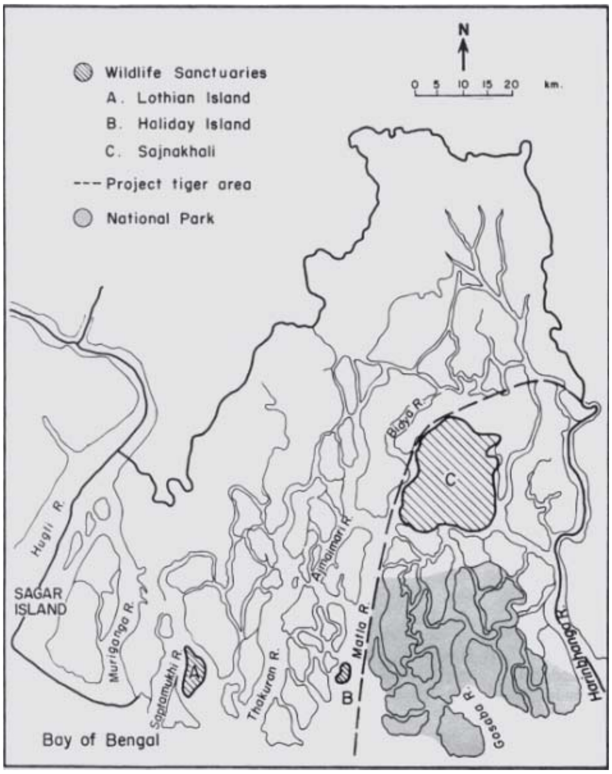

Figure 4a. Protected areas of the Indian Sundarban.

Figure 4b. Wildlife sanctuaries (dark shaded areas) in the Bangladesh Sundarban.

Future of the Sundarban

Two major factors will determine the future of the Sundarban mangroves and their biological diversity. First, the demand on freshwater resources is bound to grow as the human population in both countries continues to increase, resulting in the restriction of freshwater flows to the monsoon season when extensive floods occur in the eastern parts of India and in Bangladesh. The resultant increase in salinisation and accretion of sediments may alter vegetation composition. Impacts on animal communities may also occur due to both, the direct effects of salinity and indirectly through food chain modifications caused by the alterations in the nature and amount of detritus available in the mangrove ecosystem.

Therefore, it is the human response to the spatial and temporal variability in precipitation, and hence the freshwater availability, which will determine the water availability for sustaining the functions and values of the mangroves. The proposed plan of India for the inter-basin transfer of water through a river-linking program in India has already raised concern for the fate of the Sundarban and its rich biodiversity, as well as for the millions of people dependent upon it (Ahmed et al., 2004).

Secondly, global climate change is expected to increase the average temperature and spatio-temporal variability in precipitation, as well as cause a rise in sea level (Ellison, 1994). The increase in temperature and variability in rainfall will put further pressure on freshwater resources and hence, alter the freshwater inflows to the mangroves. If precipitation declines in the Ganga-Brahmaputra basins it may lead to a further reduction in the availability of freshwater in the deltaic region. Some models of climate change also present an increased frequency of tropical cyclones and storm surges, which may cause further changes in freshwater-seawater interactions and hence affect the mangroves (Ali, 1995, 2003; Ali et al., 1997). Substantial areas of the Sundarban along the coast are expected to be inundated by seawater in this case, and the increased landward salinity intrusion would affect the biotic composition.

Ultimately, the future of the Sundarban mangroves hinges upon the efficiency of managing the limited freshwater resources for meeting both human and environmental needs, coupled with effective adaptive responses to the added threats from climate change.

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