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Landscape Narrative of the Sundarban:

Towards Collaborative Management by Bangladesh and India

inspiring change

Document Information

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LIST OF ACRONYMS

ADB	Asian Development Bank
BBS	Bangladesh Bureau of Statistics
BFRI	Bangladesh Fisheries Research Institute
BFRI	Bangladesh Forest Research Institute
BWDB	Bangladesh Water Development Board
CEGIS	Center for Geographic and Information Services
CISS	Centre for Integrated Studies on Sundarban
DAE	Department of Agricultural Extension
DoE	Department of Environment
DoF	Department of Fisheries
DPHE	Department of Public Health Engineering
ECA	Ecological Critical Areas
FAP	Flood Action Plan
FD	Forest Department
FGD	Focus Group Discussion
GOB	Government of Bangladesh
NFiPo	National Fish Policy
NFoP	National Forest Policy
RIMS	Resources Information Management System
SBCP	Sundarbans Biodiversity Conservation Project
SIZ	Sundarban Impact Zone
SLR	Sea Level Rise
SRF	Sundarbans Reserve Forest
UNDP	United Nations Development Programme

GLOSSARY OF TERMS

Bagdis	Bagdis are indigenous people descended from people with Dravidian links, a hunter-gatherer tribe majorly living over the Raarh Bengal and the plateau of Chhotonagpur. In Sundarban, they emerged as one of the largest fisher communities.
Bagda	Tiger shrimp or Asian tiger shrimp.
Bengal tiger	The Bengal tiger (*Panthera tigris tigris*) often called the Royal Bengal Tiger is the most numerous tiger subspecies present in South Asia. The Bengal tigers in the Sundarban in India and Bangladesh are the only tigers in the world inhabiting mangrove forests. Latest camera trap report showed an average of 106 tiger's presence in Sundarban area in Bangladesh (The guardian, 2015). In Indian side of Sundarban an average of 86 tiger presents (The Indian Express, 2016).
Buffer zone	A part of the Sundarban Biosphere Reserve in west Bengal, India is known as Buffer Zone. This zone is around 1180 km² and includes reserved forest adjoined surrounding areas of the core zone, a portion of the Sundarban tiger reserve, Sajnakhali Wild Life Sanctuary and compact Reserve Forest blocks lying between Malta and Thakuran rivers under 24-Parganas (South) Forest Division .
Dampier–Hodges Line	This line was drawn to demarcate *khas mahal* (government's own estate) in 1829-1830 (World Bank, 2014, Danda et al 2011), because the *zamindars* (landlords), to avoid paying legitimate revenue, started large-scale encroachment of forest adjacent to their estates. Dampier was the then Commissioner of Sundarbans and Lt. Hodges was the Surveyor. They drew a line from Kulpi on the river Hugli to Basirhat on the river Khhamati that has since been known as the Dampier-Hodges line, south of which lies the Indian Sundarbans Delta.
District	Type of administrative division in India and Bangladesh managed by local government.
Dacca	Dhaka is the capital city of Bangladesh. It was known as Dacca before 1982.
Eocene	A major division of the geologic timescale which lasted from 56 to 33.9 million years.
Eurasian Plate	The tectonic plate which includes most of the continent of Eurasia.
ECA	In 1995 with the enactment of the Bangladesh Environment Conservation Act, the Government is empowered to declare an area which is enriched with unique biodiversity and environmentally significant and shall need protection or conservation from destructive activities as ecologically critical area (ECA). Under the Environmental Conservation Act of 1995 the government of Bangladesh had declared a 10-km wide area surrounding the northern and eastern boundaries of the Sundarban Reserve Forest with an approximate area of 17.5 km^2 as an Ecologically Critical Area (ECA).
Ganga/Ganges	One of the most iconic rivers of South Asia, the Ganga or Ganges is called Ganga in India. In Bangladesh the official name is the Ganges.
Hyper synchronous channels	It's a funnel-shaped estuarine channel where convergence exceeds friction. In these type of channels tidal currents increases up until the tidal river zone. The rising tide occupies a shorter time cycle, inducing faster landward velocity

	of the tidal current that turns the estuaries into sediment sinks.
Halophyte	Halophytes are the major flora in Sundarban mangrove forest which occupies the largest share of the true mangrove species. The habitats of halophytes are frequently inundated with tidal sea water grows in waters of high salinity.
Holocene	A major division of the geological present timescale approximately 11,700 years of time period.
James Rennell	Major James Rennell was an English geographer, historian and a pioneer in oceanography. He is also known as Father of Indian Geography.
Jean-Baptiste Tassin	Pioneering Lithographer in India established the Oriental Lithographic Press in Calcutta in 1830.
Khas land	Government owned fallow land, where nobody has property rights.
Khas Mahal	It known as Governments own estate. In 19th Century threatening of possible loss of revenue British set out to demarcate the non-leased forest area as khas Mahal in the area of sundarban.
Panchayat	The cornerstone of a local self-government organization in India of the panchayati raj system at the village or small town level.
Prawn/shrimp	According FAO, in terms of aquaculture and farming, shrimp are marine creatures, while prawns live strictly in fresh water.
Ramsar	International treaty for the conservation and sustainable use of wetlands also known as the Convention on Wetlands. It is named after the city of Ramsar in Iran, where the Convention was signed in 1971.
Radcliffe Line	Radcliffe Line was published on 17 August 1947 as a boundary demarcation line between India and Pakistan upon the Partition of India. It was named after its architect, Sir Cyril Radcliffe, who was the chairman of the Border Commissions.
Sundarban /Sundarbans	The narrative has used the name Sundarban in order to align with the local language of the Sundarban region that is Bangla. While there has been no official declaration, many recently published documents including the MoU between the two countries has discarded the anglicised form 'Sundarbans' and have been using the name Sundarban .
Sundari	It is the dominant mangrove tree species of the Sundarban also known as *Heritiera fomes*. This species is found in the upstream estuarine zone in the high inter tidal region. It prefers freshwater and is fast-growing in low-saline environments (IUCN Red List).
SBR	In 1989, the Ministry of Environment & Forests, Govt. of India adopted the National Man & Biosphere Programme (MAB) and in 1989 declared the entire 9,630 sq.km. of Sundarban in Indian side as Sundarban Biosphere Reserve(SBR). The Sundarban Biosphere Reserve(SBR) includes 1600 sq km of south 24 Parganas reserved Forest and 2600 sq km of Sundarban Tiger Reserve.
SRF	The Sundarban Reserve Forest (SRF), located in the southwest of Bangladesh between the river Baleshwar in the East and the Harinbanga in the West, adjoining to the Bay of Bengal, is the largest contiguous mangrove forest in the world.
SIZ	The area within a 20 km wide radius surrounding the periphery of the Sundarban is often termed as Sundarban Impact Zone or SIZ. The population residing within this area are directly dependant on the Sundarban. Five

	districts of Bangladesh named Bagerhat, Satkhira, Khulna, Barguna and Pirojpur fall within the SIZ.
Upazila	Upazila is an administrative unit in Bangladesh. They function as sub-units of districts. Total 491 Upazila currently present in Bangladesh.
UNESCO World Heritage Site	Unique landmark of geographically and historically identifiable piece of special cultural or physical significance recognized by the United Nations. In India, 169,0226 Hector (Approx.) and In Bangladesh, 139,700 Hector areas of Sundarban have been enlisted as UNESCO World Heritage Site in 1987 and 1997 respectively.

SCIENTIFIC NAMES

Plants	
Amur	*Amoora cucullata*
Beain	*Avicennia officinalis*
Chanda lota	*Dalbergia spinosa*
Dhundal	*Xylocarpus mekongensis*
Dhanshi	*Myriostachya wightiana*
Keora	*Sonneratia apetala*
Passur	*Xylocarpus mekhongensis*
Gewa	*Excoecaria agallocha*
Goran	*Ceriops decandra*
Golpata	*Nypa fruticans*
Hargoza	*Acanthus ilicifolius*
kewa katta	*Pandonus foetides*
Keora	*Sonneratia apetala*
Nol-khagra	*Phragmties karka*
Sundari	*Heritiera fomes*
Animals	
Black-capped kingfisher	*Halcyon pileata*
Brahminy kite or Sonkha cheel	*Haliaster Indus*
Bengal Tiger	*Panthera tigris tigris*
Common dolphin	*Dolphinus delphis*
Crocodiles	*Crocodylus porosus*
Capped langur	*Semnopithecus pileatus*
Gangetic dolphin	*Platanista gangetica*
Irrawaddy dolphin	*Orcaella brevirostris*
kakra	*Bruguiera gymnorrhiza*
Rhesus macaque or banor	*Macaca mulata*
Spotted deer or chitra horin	*Axis axis*

smooth-coated otter	*Lutrogale perspicillata*
small-clawed otter	*Aonyx cinerea*
The great Indian civet	*Viverra zibetha*
White-bellied Sea Eagle	*Haliaeetus leucogaster*

1. Introduction and context

Covering more than 10,000 km^2 of deltaic floodplains across Bangladesh and India, the Sundarban Region contains arguably the largest continuous block of mangrove ecosystem remaining in the world. The unique ecosystem is a delicate balance between the freshwater flows of the tributaries and distributaries of Ganges-Brahmaputra riverine system and saline waters of the Bay of Bengal. The Sundarban is internationally recognized for its high biodiversity of mangrove flora and fauna supported by terrestrial and aquatic (freshwater and marine) environment. The saline intertidal hydrological system supports diverse plant and wildlife assemblages, and economically significant fisheries. While the Sundarban landscape is celebrated for its ecological attributes, nearly 0.1[1] percent of the global population, amongst the poorest in the region, is directly dependant on the Sundarban for their livelihood. When an ecosystem spans a border, political and administrative boundaries create uncoordinated management and impinge on the effectiveness of having an integrated approach. In both countries there are numerous agencies present with mandates and activities concerning matters ranging from conservation to coastal issues to centralized schemes for socioeconomic development. Without a doubt, Sundarban represents one of the most complex ecological and socio-political landscapes of this region.

Divided by the international border, the mangrove forest, the rivers and canals and the entire ecosystem of the Sundarban has often been seen as not one, but two separate ecosystems. Yet, the shared Sundarban region signifies a strong opportunity for strategic cooperation and coordinated or joint actions between Bangladesh and India, resulting in simultaneous poverty reduction and sustainable ecosystem management. Given that each country's portion of the Sundarban is essentially part of the same ecosystem, the region would benefit from coordinated and collective policy development between Bangladesh and India on conservation strategies that could be implemented jointly or by each country individually.

1.1. The Sundarban Region

An integrated approach is needed to reconcile increased conservation value and habitat connectivity, with livelihood improvement and poverty alleviation, this approach needs to be embedded in a holistic understanding of the ecosystem and the dynamics between the ecological (physical and biological) and adjacent socio-cultural systems (Reed et al, 2014; Sayer et al 2012; Frost et al, 2006). This is the reason in this study, the Sundarban region has been defined as the Sundarban Reserve Forests (SRF) and Ecologically Critical Area adjacent to the Sundarban (ECA) in Bangladesh and Sundarban Biosphere Reserve (SBR) in West Bengal, India (shown in Figure 1.1). The Sundarban region, thus defined not only represents the uninhabited mangrove forests but also adjacent inhabited areas that were historically

[1] Nearly 5 million in West Bengal, India live in the buffer zone of Sundarban Biosphere Reserve. According to IUCN (2014) the populations living within a 20 km wide radius surrounding the periphery are directly dependent on the Sundarban. This population is about 2.5 million (BBS, 2011).

forested and currently the populations living in the populated areas are directly dependant on the forest for their lives and livelihood.

Geographically the undivided Sundarban tract extends approximately 260 km west-east along the Bay of Bengal from the Hugli River estuary in India to the western segment of the Meghna River estuary in Bangladesh and reaches inland for about 80 km at its broadest point. The total area of the Sundarban, including both land and water, is roughly 10,200 sq. km, about 60 percent of which is in Bangladesh (around 6,017 sq. km) and rest (4200 sq. km) in India (World Bank, 2014). In Bangladesh, this 6,017 sq. km area is protected as a reserve forest (this was declared during the British period in 1875). In 1999 the Ministry of Environment and Forest of Bangladesh, under the Environmental Conservation Act (ECA) of 1995 had declared the 10-km wide buffer zone surrounding the northern and eastern boundaries of the SRF with an approximate area of 1750 hectares as an Ecologically Critical Area (ECA) (IUCN, 2014). As mentioned earlier this area that is, SRF and Sundarban ECA form the eastern side of the Sundarban region. Analysis from different studies (IUCN 2014, CEGIS, 2013), however, show that the population which according to BBS (2011) is 2.5 million, residing in a 20 km wide radius surrounding the periphery are directly dependant on the Sundarban in Bangladesh, this 20 km area is often called the Sundarban Impact Zone (SIZ) (IUCN, 2014). Taking this information into account, the socio-cultural description of the narrative also includes the population of this corresponding area.

The Sundarban Biosphere Reserve forms the western part of the Sundarban region. In 1970, the Ministry of Environment and Forests, Government of India (GoI) adopted the UNESCO (United Nations Educational, Scientific and Cultural Organization) Man and Biosphere programme and declared 9630 sq. km. of the Ganga delta in West Bengal as the Sundarban Biosphere Reserve in 1989. The northern territory of the SBR is demarcated by the Dampier Hodges line[2] of 1829-1830 (World Bank, 2014, Danda et al 2011). This includes approximately 4,260 sq. km of reserve forests, of which around 40 percent has been declared protected areas, including about 1,330 sq. km as a national park, and around 406 sq. km as wildlife sanctuaries. The SBR also includes a buffer zone that includes parts of the tiger reserve[3] and Sajnakhali Wild Life Sanctuary; and the transition zone with mostly non-forest areas and historically reclaimed areas for agriculture. (http://www.sundarbanbiosphere.org/).

[2] This line was drawn to demarcate khas mahal (government's own estate) in the early 19th century. Threatened with possible loss of revenue, the British set out to demarcate the non-leased forest area as khas mahal. Dampier was the then Commissioner of Sundarbans and Lt. Hodges was the Surveyor.

[3] The Sunderban Tiger Reserve, governed by Project Tiger which is administered by the National Tiger Conservation Authority (NTCA) and has a total geographical area of 2585 km^2 with 1437.4 km^2 consisting of populated areas and forest covering 1474 km^2.

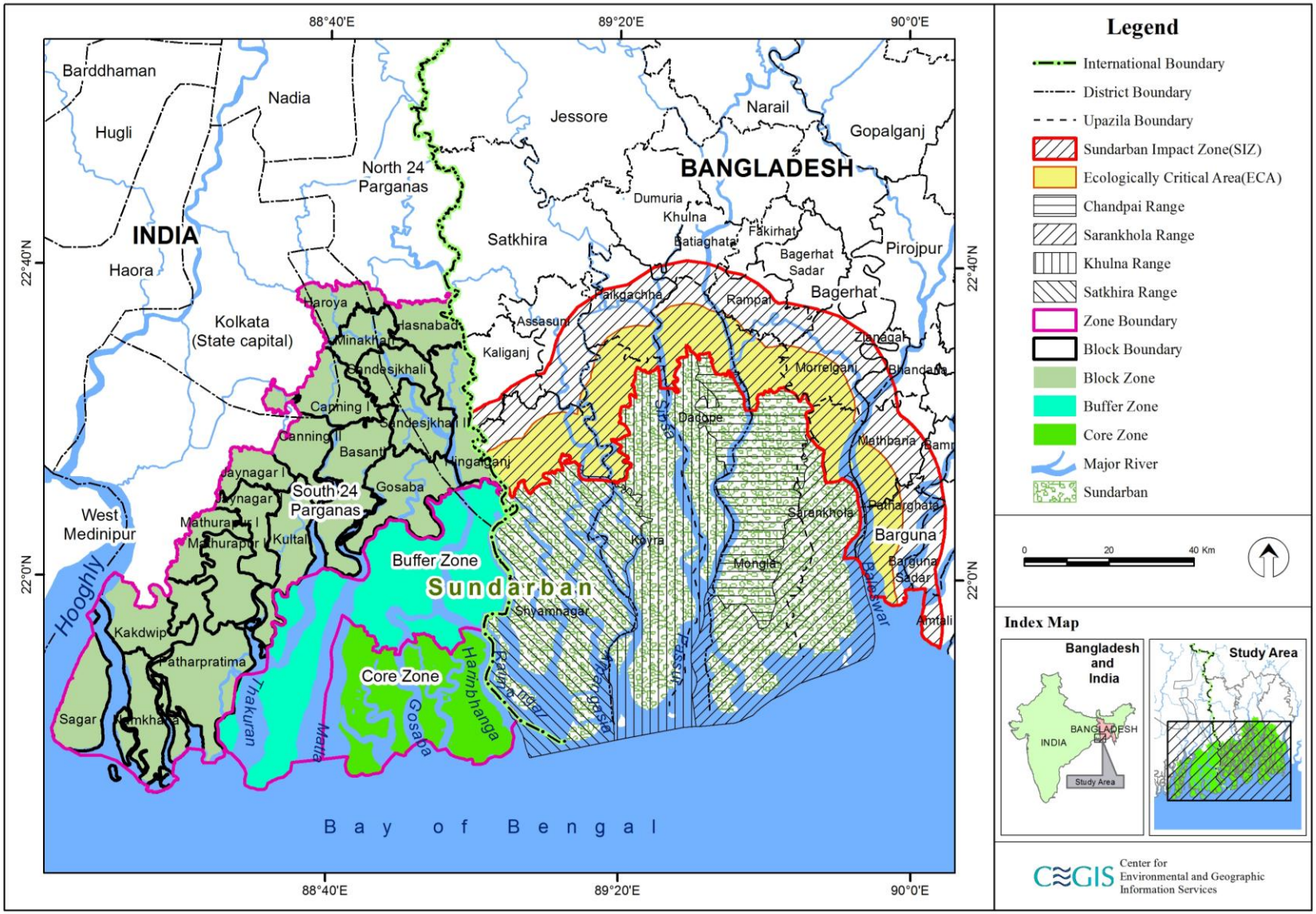


Figure 1.1: The Sundarban Region

Outstanding the Universal Value of Mangroves

The shared Sundarban Region is considered to be one of the seven most globally important wetlands of the world (WWF, 2015). Recognizing the importance and uniqueness of the Sundarban, UNESCO declared the Sundarban National Park, forming the core area of SBR as World Heritage Site by UNESCO in 1987 of the forest a World Heritage Site[4] in 1987. Three wildlife sanctuaries with about 32,400 hectares of the SRF in Bangladesh forms the core breeding area of a number of species of endangered wildlife and has been declared UNESCO World Heritage Site in 1997. According to UNESCO, 'One of the largest remaining areas of mangroves in the world, the Sundarbans supports an exceptional level of biodiversity in both the terrestrial and aquatic (freshwater and marine) environments'. The Bangladeshi portion has also been recognized as a Wetland of International Importance under Ramsar[5] listing. Recently, the West Bengal portion has been nominated by GOI for recognition as Ramsar Site.

The estuarine wetlands of the Sundarban are constantly fed by nutrients brought in by freshwater of the Ganga/Ganges river system and flushed by the ebb and flow of the tides, their inticrate three-dimensional landscapes promote richly complex interdependencies and thus support a diverse population of plant and animal species, both terrestrial and aquatic. These wetlands also sustain billions of worms, protozoa, barnacles (*Balanus spp.*), oysters (*Crassostrea spp.*), lichen and other invertebrates. These organisms in turn feed juvenile fish, crabs, prawns, shrimp, and mollusks, which seek refuge in the shallow inter-tidal reaches that characterize the mangrove wetlands; these in turn support wading migratory and local birds, pelicans, and the endangered Crocodile. Prain (1903) recorded 334 species of plants belonging to 245 genera from Sundarban mangrove forest and adjoining areas. Henning (1892) reported 70 species from 34 families for the entire Sundarban Region. As many as 447 species of vertebrate wildlife (amphibians, reptiles, birds and mammals) including the iconic Bengal Tiger, Gangetic and Irrawaddy dolphins and the olive ridley turtles have been reported from Sundarban Heining, R. L. (1892).

Mangroves are immensely productive ecosystems on earth resulting in a a large number of benefits (shown in Figure 1.2) such as employment, income and food security (fuel, fisheries, honey), tourism, scientific research and mineral extraction; they also provide indirect benefits, such as climate regulation and transportation, combating cyclones and tidal bore; and through their intrinsic value, such as the conservation of biodiversity and social identities continue to support and increase adaptive capacities of coastal populations and their future generations (Salem and Mercer, 2012; Nellemann et al, 2009; Mitsch and Gosselink, 2000). Mangrove extracts can be the potential sources of chemicals and medicines containing anti-cancer and anti-diabetic compounds, insecticides and piscicides. Extracts and chemicals from mangroves have been used mainly in folkloric medicine, the extraction of novel natural chemical compounds from mangroves is in its infancy and needs to be explored further (Saranraj and Sujitha, 2015). The Sundarban is no exception, and provides innumerable ecological, environmental and socio-economic benefits. As mentioned before a large population depends directly on the Sundarban

[4] A World Heritage Site is a place that is listed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as of special cultural or physical significance.

5 The Ramsar List of Wetlands of International Importance, according to Article 2 of the treaty text, is the keystone of the Ramsar Convention which is the intergovernmental treaty that provides the framework for the conservation and wise use of wetlands and their resources.

for their livelihood as abundant fish and biomass resources (namely, fuelwood, pulpwood, leaves, shells, crabs, honey, fish, prawn seed and shrimp fry) are harvested by local communities. The scenic beauty and rich biodiversity of the forest attract many tourists also benefit the local population from creation of work opportunities, better infrastructure, and improvements in health and safety standards. Nearly 30 million people living in areas surrounding the protected areas of the Sundarban, as well as urban areas such as Kolkata and Khulna are dependent on the well-being of the Sundarban in a variety of ways. The wetland is remarkable for protection from the tidal surge and strong winds generated from the cyclonic depression in the Bay of Bengal. Since the 2004 Indian Ocean Tsunami, there has been considerable global interest in the role of mangroves as natural barriers that protect the lives and properties of coastal communities from periodic storm events and flooding (Barbier et al, 2011). Mangroves help stabilize sediment and retain soil in their root structure reduces shoreline erosion and deterioration. Mangroves also serve as barriers in the other direction; their water purification functions protect coral reefs, seagrass beds, and important navigation waters against siltation and pollution (Wolanski 2007). Moreover, the capacity of mangroves, sea grasses, and salt marshes to sequester carbon dioxide from the atmosphere, which is also known more specifically as 'blue carbon', is becoming increasingly recognized. In recent decades, research and carbon inventories have shown that mangrove ecosystems store large quantities of carbon in their biomass and soil; up to five times more and more effectively, up to 100 times faster, than terrestrial forests (Hossain and Chowdhury 2015; Howard et al, 2014; UNEP, 2014; Nellemann et al, 2009). The net biosphere-atmosphere exchange of carbon in the Sundarban has been estimated at 2.79 tonnes per hectare per annum (Verma et al 2015). The Sundarban thus offers a unique and highly efficient approach to climate change mitigation and adaptation.

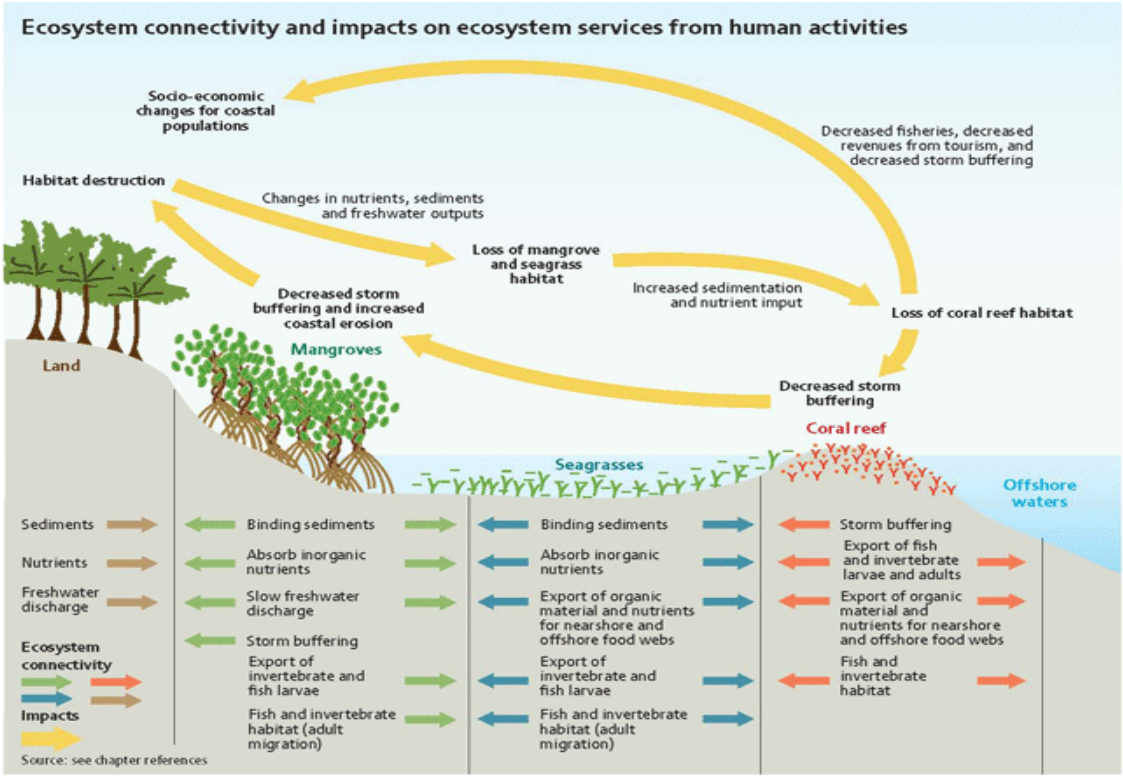


Figure 1.2: Benefits of mangrove ecosystem

While it is difficult to put a value on the benefits of a mangrove forest such as the Sundarban, valuation of ecosystem services can play an important role in policy formulation for protection and management of mangroves. Experts estimate, mangroves of the Sundarban generate services worth between $456.32 to $1,191.84 per ha per year in Bangladesh (Haque and Aich, 2014) and the Sundarban Tiger Reserve in India provides flow benefits worth $732 per ha per year (Verma et al 2015). These figures can be further revisited with increased access to reliable data and information, emergence of robust valuation methodologies and better understanding of the benefits of mangroves.

Yet, mangroves are a relatively rare forest type and constitute less than one percent of all tropical forests and cover an estimated area of 152,000 sq km land surface in 118 countries. Estimates show coastal mangroves remain one of the most threatened ecosystems on the planet, being lost at a rate greater than coral reefs and tropical rainforests (UNEP, 2014). In the 1970s, mangroves may have covered as much as 200 000 sq. km , or 75% of the world's coastlines (Spalding et al. 1997). But since then, at least 35% of global mangrove area has been lost, and mangroves are currently disappearing at the rate of 1–2% annually (Valiela et al. 2001, Alongi 2002, FAO 2007). Already 16% of mangrove floral species, are critically endangered, endangered or vulnerable and 10% are near-threatened. More than 40% of the vertebrates found in the mangrove habitats are now also at risk of extinction due to habitat loss (Sarker et al, 2016). Integrated management and conservation of mangroves is not only critical for biodiversity, coastal protection, and the livelihoods and wellbeing of adjacent populations but also has the potential to support the climate adaptation and mitigation efforts of the larger region as well as the world. The Sundarban constitutes the world's largest contiguous mangrove ecosystem; the second largest is only about one-tenth in size. As one of the largest block of mangroves remaining in the world, the conservation of the Sundarban has become a matter of immediate urgency at the local as well as the regional and global level.

1.2. About the Narrative

Any strategic mechanism for supporting collaborative approaches to managing shared ecosystems requires appropriate knowledge and comprehensive understanding of the ecosystem in its entirety. This joint landscape narrative integrates a mosaic of information linked together to support the development of an action plan for the Sundarban that addresses poverty, livelihoods, biodiversity conservation as well as climate change adaptation. Most importantly the narrative creates a multilayered and holistic understanding of the Sundarban to establish planning boundaries that transcends political boundaries, narrow perspectives and multiple scales.

In both countries the Sundarban has been of great interest to researchers, scholars, wildlife biologists, botanists, hydrologists, morphologists, economists, environmentalists as well as writers, journalists, artists, litterateurs and enthusiasts from the region and abroad. Thus literature on the Sundarban is abundant, as much as 20,000 books, reports, essays and documents can be catalogued covering various aspects including biodiversity, hydro-morphology of the region, cultural history, social development, livelihood, resource utilization and management. Yet there is very little attempt to understand the Sundarban in its entirety, as one ecosystem, as one landscape or one region (Dipu and Ahmed, 2013;

Gopal and Chauhan, 2005; Sarker 2010). For example, the most recent survey of forest resources of Sundarban as one ecosystem was carried out in the 1930s; the successive inventories and assessments have been at country level. In 2011, a Vision document, Indian Sundarbans Delta: A Vision (Danda et al, 2011), was prepared for the Sundarban Biosphere Reserve in India and in 2014, a similar document was established for Bangladesh, Bangladesh Sundarban Delta Vision: 2050; a common vision of sustainable development and mangrove conservation does not yet exist. So the information of the forest as one ecosystem is not up-to-date and current literature also remains divided by the boundary, focusing on only one part of the Sundarban.

Moreover, the extent of investigation, conservation strategy and focus of management and subsequently, type of data and information is considerably different in the two countries. For example, the vision documents prepared for both sides of the Sundarban and the strategies set out in both the documents vary considerably. The primary focus of the Indian vision is community well being, ecosystem conservation and phased out-migration. The Bangladesh vision emphasises on the management and conservation of the delta (IUCN, 2014). On the other hand, analysis of 60 online documents show that substantial data and information on salinity of Bangladeshi Sundarban is available and publicly accessible information dates back to 1962, whereas in India the salinity related reports are much less and oldest information found dates back to 1995.

This work is an attempt to combine the learnings, knowledge, data and information and to identify gaps in learning from both sides. There is a growing recognition that sectoral approaches to land management are not sufficient or effective to meet multiple challenges of poverty alleviation, biodiversity conservation, and food production. Integrated approaches are needed address complex issues to facilitate the simultaneous framing of development and conservation goals (Reed et al, 2014; Sayer et al 2012; Frost et al, 2006). Key issues and themes in the landscape narrative include ecological flows in landscape mosaics, land use and land cover change, scaling, relating landscape pattern analysis with ecological processes, and landscape conservation and sustainability. There is also a need to understand the role of human activities and development processes on the ecosystem, the coupling between biophysical and socioeconomic sciences is required (WCED (1987); UN, 1992, Angelstam et al. 2013a; Angelstam et al. 2013a). Therefore it is important to take a broader look at the natural resource base and consider the full range of ecosystem processes that provide and sustain those resources. This more holistic, expanded view of ecosystem management often requires more coordination between different agencies, stakeholders or governments who must work across jurisdictional boundaries making natural resources management more politically, legally and ecologically complex.

The Joint Sundarban Landscape Narrative thus aligns the different literature, data and information focussing on physical (land and water), biological (flora and fauna) and socio-economic and cultural variables to analyse change dynamics and facilitate increased and effective cooperative management in the Sundarban Region. Figure 1.3 shows the different components of the Sundarban Landscape Narrative.

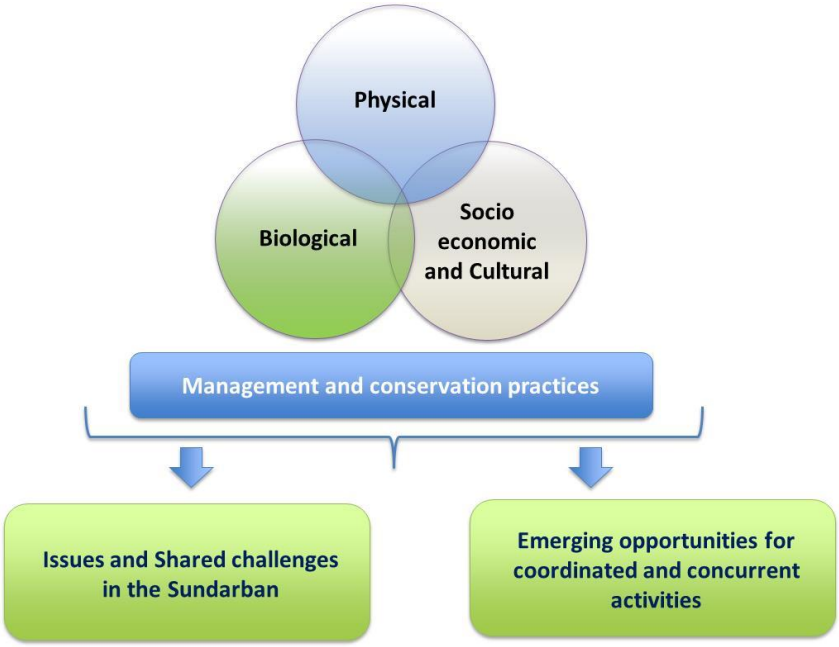


Figure 1.3: The different components of the Sundarban Landscape Narrative

Narratives can especially support in building partnerships and trust and help in translating quantative knowledge and information into socially acceptable plans and practices (Silbernagel, 2000). Taking this into considerations, the objectives of this Narrative are to:

- Create a multilayered and holistic understanding of the Sundarban to establish planning boundaries that transcends political boundaries and multiple scales;
- Align and analyse information of ecological, socio-economic and cultural variables of Sundarban from different sources and records to support joint understanding of the Sundarban;
- Synthesize current literature to identify effective management approaches and practices of the past;
- Identify gaps in the learnings, knowledge, data and information on the Sundarban.

The main source of data, information and material for the narrative has been the available literature and secondary information; interviews at the local and institutional level; and stakeholder meetings with experts and researchers. The availability, accessibility and even methodology of collection and analysis of information and data vary between the countries. Due to variances and gaps in the literature of both countries, integration of knowledge has been challenging; in many areas interpolation and scientific assumptions were used and in some cases, in the absence of adequate literature, important information on one side of the Sundarban could only be narrated. This narrative assimilates the findings in ten chapters which are briefly described here,

Chapter 1 sets the context for this narrative. A brief introduction to the Sundarban; the need for cooperation between Bangladesh and India; and the importance of such a narrative is discussed in this chapter.

Chapter 2 focuses on the history of the Sundarban looking at the settlement patterns and briefly describes the management initiatives in the Sundarban before and also after 1947.

The next three chapters create a the common understanding that form the base of the Joint Landscape Narrative by documenting features and inter linkages of the three dimensions: the physical landscape, the biological landscape and the socio-economic and cultural landscape.

Chapter 3 studies the physical landscape by integrating information on physiography (morphological, land elevation, sedimentation processes and the waterscape (rainfall, river systems, flows and water level, salinity); natural disasters and the spatial inter linkages of the different elements.

Chapter 4 explores the biological compoents of the Sundarban ecosystem and focusses on the plants and vegetation and the wildlife and fisheries of the Sundarban.

Chapter 5 describes the population dependant on the Sundarban. The socio-economic landscape of the of the surrounding population dependant on the Sundarban in Bangladesh and the Sundarban Biosphere Reserve (SBR), India. The chapter is a compilation of data and information on demographic patterns; forest dependent and peripheral livelihoods; income level and poverty; education and public services, transportation and communication; education and health; inland navigation and ecotourism. It also explores the cultural landscape of the Sundarban. The focus is on the literature, myths and beliefs, festivals and deities, films and music of the entre Sundarban.

The next three chapters synthesize current literature to identify effective management approaches, issues and shared challenges and emerging opportunities for joint and coordinated activities.

Chapter 6 describes the current management and conservation practices prevalent in both countries. The discussion identifies the synergies in the relevant laws, acts and policies and differences in the level of implementation in the two countries and how these can facilitate the development of a joint strategy for conservation of the Sundarban.

Chapter 7 highlights the issues and shared challenges in the Sundarban. Focus is on, poverty and human development, coastal erosion and flooding, climate change, environmental degradation, natural resources management, lack of data and information base, inadequate capacity of governments and communities.

Chapter 8 features the emerging opportunities for coordinated and concurrent activities for both countries by looking at disaster management; economic growth; strengthening social services; natural resources management; fisheries and aquaculture; enhancing information and understanding; adaptation and mitigation; cultural and media exchanges; and sustainable tourism.

Chapter 9 is the concluding chapter of the Joint Sundarban Landscape Narrative and based on the previous chapters presents a direction for the way forward for facilitating joint, sustainable

development of the shared Sundarban Region with stress on realizing economic growth and enhancing climate resilience.

2. A brief history of the Sundarban

The history of a landscape tells us how and why we arrived, where we are now and helps us design new management strategies to safeguard the ecosystem, support livelihoods and conserve biodiversity. Effective conservation and management activities call for careful observation of how the forest responds to natural and human disturbances and requires adjustments to future management according to those observations. This chapter presents a brief history of settlement and vegetation patterns of the Sundarban in order to develop a deeper understanding of the historic transformation of the ecological and social-cultural systems of the landscape and create a better opportunity to redefine the management options. The fertile soils of the delta have been subject to intensive human use for centuries, and the Sundarban region has been mostly converted to intensive agriculture, with just a few enclaves of forest remaining. These remaining forests are home to rich biodiversity including numerous plants and trees and provide habitat for many important animal species inclusing the endangered Bengal Tiger (*Panthera tigris*), several other threatened mammal species, such as the the capped langur (*Semnopithecus pileatus*), the smooth-coated otter (*Lutrogale perspicillata*), the oriental small-clawed otter (*Aonyx cinerea*), and the great Indian civet (*Viverra zibetha*).

Management does not necessarily mean restoring forest ecosystems to some historic benchmark or time period. That would be very difficult if not impossible. Ecological, social and economic systems are not only different today they are changing more rapidly than ever before. A historical understanding can provide perspective and better understanding of current situation.

2.1 Etymology: the mystic Sundarban

The word 'Sundarban' literally means 'beautiful forest', the Bangla word 'sundar' means beautiful and 'ban' means forest. There are a few theories on how the name of the forest came about. According to Banglapaedia (2003), the name Sundarban came from either the Sundari ban or Samudra ban. The name may have been derived from the Sundari trees (the mangrove species Heritiera fomes) that dominate the forest landscape. The name could also come from samudra (sea) as it forms the frontier to the sea. Alternately, the name could be a corrupted form of a local primitive tribe called Chandra-bandhe. Another school of thought believes that the forest is named after the pagan deity Sondor-buri (the hunting deity) of the Bagdis. The Bagdis are a cultivating, fishing and menial caste of Dravidian links, in Sundarban; they emerged as one of the largest fisher communities in Sundarban (Chakrabarti and Chakrabarti, 2013). However, the generally accepted explanation is its derivation from the Sundari tree, the most common tree in these forests.

2.2 The History of the Landscape

The Sundarban delta came into existence two million years ago in the quaternary age long before human beings evolved. At the early stages of the history of this area, the entire Bengal basin was submerged under the sea and sedimentation from the Ganges –Brahmaputra riversystems created a landmass which is today's Bengal Delta. The Sundari trees presumably first took root below the Rajmahal Hills, establishing the northern extent of the Sundarban in history (Cultivation of Hindoostan, 1980).

Sundarban, as we know it today, has a fairly recent history. Much of the present tidal delta only stabilized in 5th – 7th century AD. The formation of the lower delta plain started during the middle Holocene and most of the presently occupied area of 10,017 km^2 of Sundarban was formed over the course of the last 6,000 years. The coastal region of the Sundarban delta is not older than 5 to 2.5 thousand years and was developed by formation of four overlapping and eastward-younging deltaic lobes. Accreted by biotidal processes and shaped by marine and atmospheric agencies, the intensity of which varies over space and time, the Sundarban is now fluvially abandoned (Bandyopadhyay, 2007).

According to the 'classical successional view of mangrove dynamics' (Sneadaker, 1982), as the shoals formed by tidal deposition start to emerge above the low tide line, pioneer mangrove species like *Porteresia coarctata* soon start to colonise on the muddy tidal flats and the bio-tidal accretional processes take over, inducing sedimentation and thereby reducing the tidal inundation time of a particular locality. At the end of the process, largely non-mangrove vegetation community evolves as the land is raised sufficiently above the tidal limits (Chapman, 1976; Thom, 1984). Further details are discussed in Chapter 3. The Bengal Delta was originally occupied by vast stretches of grassland filled with saline marshes and tropical wetlands and rich forests – the Bengalian Rainforest. These forests were some of the richest wildlife areas of the world, holding elephants, tigers, gaur, leopards, wild buffaloes, three species of rhinoceros, even species of deer and a wide variety of other fauna (S.K Sen, 2007). Nearly 1000 years ago, the Bengal Basin tilted eastward, resulting in a raise of the western part of the delta and dissociating ancient branches of the Ganges from the present Indian Sundarban. This alteration caused the eastward migration of the Ganga reducing the freshwater flow which in turn resulted in the creation of a saline water environment gradually affecting the flora and fauna of the area (Sanyal, 2013).

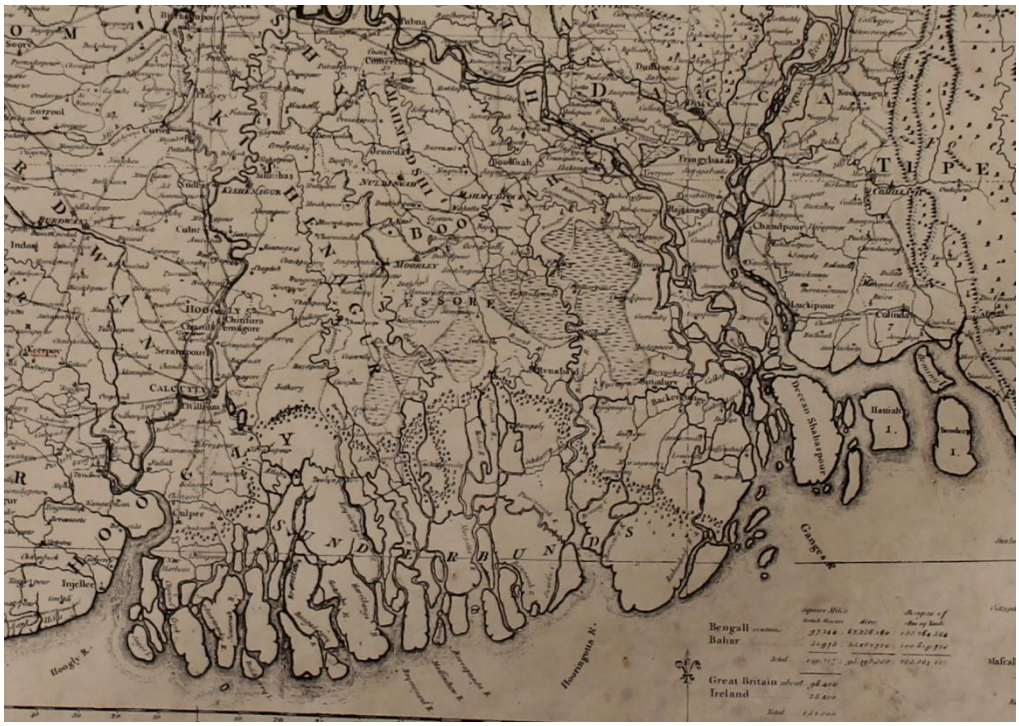
Among the wildlife of the Sundarban, at least four species have become extinct since the beginning of the 20th century, which are Javan rhinoceros(*Rhinoceros sondaicus)* , wild water buffalo (*Bubalus arnee)*, swamp deer(*Cervus duvaucelii)* and hog deer (*Hyelaphus porcinus*) (Hendrichs 1975, Blower 1985, Tamang 1993, Hussain and Acharya 1994, Khan 2008a). Since the names of these species did not appear widely in old documents, it is difficult to say whether they really had existed in the Sundarban, but originally the Sundarban had covered much wider area and the northern fringes of the forest was probably not typical mangroves. Therefore, the above mentioned wildlife could have occurred along the fringes, but not in the Sunderban interior. As the surrounding woodlands diminished due to overexploitation,island based tidal forest emerged as the only landscape in the Sundarban, a habitat not suitable for fresh water dependent grazers like wild buffalo, rhino, swamp deer leading to disappearance of these wildlife from the landscape. Baker (1887) had killed three rhinoceros in the Sundarban in 1881, and according to the Bengal District Gazetteer (1908) the rhinoceros became 'rare' as early as 1908 and was restricted in the southern Sundarban. The buffalo was 'fast disappearing' and was found only in the 'waste lands of the Backergunge portion of the Sundarban (eastern Sundarban)'. Groups of 8-10 buffalos were sighted in tall grass of the riverbanks in Sarankhola Range, Bangladesh Sundarban, until 1925-1930 (Khan 2004a). Jerdon (1874) mentioned the occurrence of the swamp deer for the eastern Sundarban. In 1914, the Bengal District Gazetteer mentioned that the hog deer is 'not uncommon', but being very shy, are seldom seen along the banks of streams in the northern Sundarban,

while Curtis (1933) also noted the Hog Deer in the northern areas of the Sundarban. The barking deer (*Muntiacus muntjak*) is no longer seen in the Indian part of Sundarban (Sahgal *et al.* 2007), it exists in the Bangladesh Sundarban where it is not rare, but difficult to see since it is not a grazer. Some experts believed that Leopard (Curtis 1933), gaur and marsh crocodile (Blower 1985) were once found along the edge of the Sundarban.

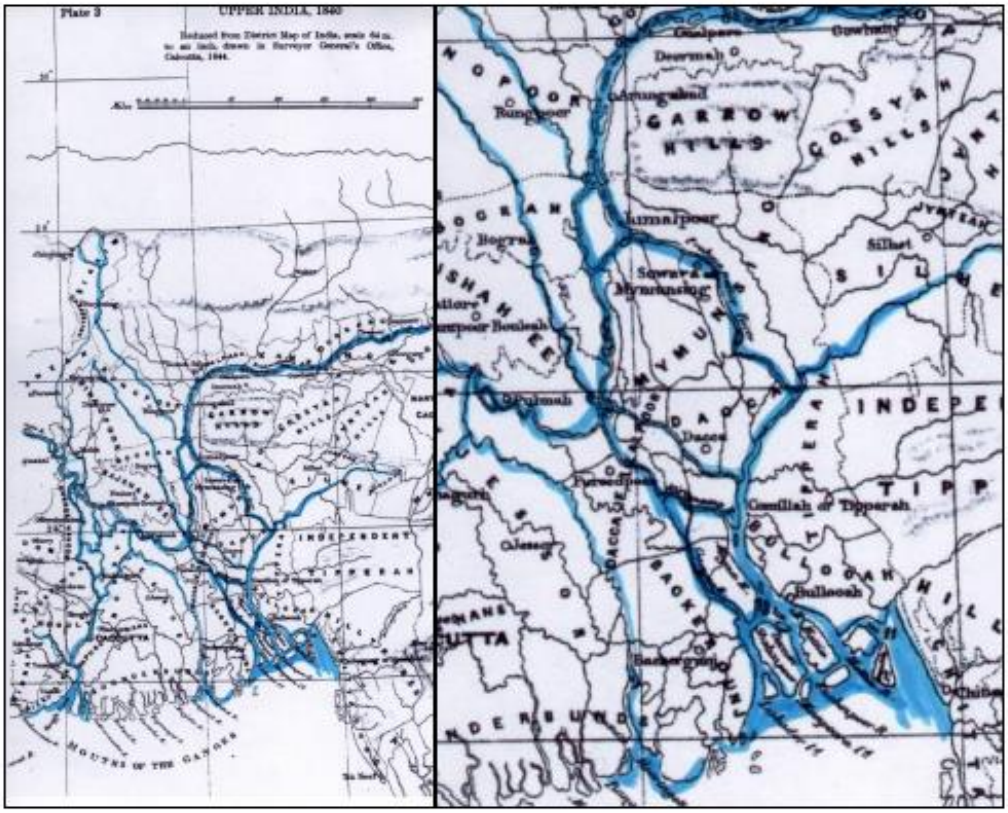
There has been a great deal of change in the landscape of the Sundarban over the past centuries. On one hand the mangrove forest has been reduced in its total area especially in the British period and on the other hand the coastline has gradually receded. Rudra (2013) has overlaid and compared seven to eight historical maps and found that up till now the Bay of Bengal has encroached almost 12 km since Rennal's[6] time (1776) from its original position. The study revealed that in the west side of the Sundarban where mangroves have been cut off, ocean has come forward more rapidly compared to the places where deforestation has not occurred. This is because where the forest has been cut off; sea wave and air have been able to initiate their combined effect completely. It is found that the coastline of the Sundarban have extensively eroded over the last three centuries. Figure 2.2 shows the change in boundary of the Sundarban from 1776 to 2010 and compares the forest area over the last three centuries. The chages were analysed by the overlaying of four maps of the Sundarban produced at different times. The first map used here is the Rennell's map produced in 1776 by Rennell (shown in Figure 2.1 (A)), a Surveyor General of the East India Company which was by far the most accurate and detailed map of the region to that date (Bristow, 2009). The second map that has been used was produced by Tassin[7] in the year of 1841 which is known as a new and improved map of the provinces of Bengal and Bihar (Tassin's map is shown in Figure 2.1 B). The 1954 Indian topographic map was used next which is a geodetic datum for topographic mapping and is considered one of the most impressive topographical maps of India of that time (Kapur, 1998). Finally the 2010 satellite imagery was used to identify the most recent land change in the entire Sundarban.

[6] Major James Rennell, FRS (3 December 1742 – 29 March 1830) was an English geographer, historian and a pioneer of oceanography. Rennell's survey of Bengal, which was commenced in the autumn of 1764, was the first ever prepared. The headquarters of the surveyor-general were at Dacca.

[7] Jean-Baptiste Tassin: Pioneering Lithographer in India established the Oriental Lithographic Press in Calcutta in 1830 which produced*Tassin's Atlas of the Ganges* (1835); *Tassin's Atlas of the Delta*(1840).



(A)



(B)

Figure 2.1 (A) Rennels Map of the Ganges Delta (Source: Bangladesh National Archives) (B) Upper India 1840 (reduced from Tassin 1841) (Source: Saunders and Chapman, 2006)

The greatest degradation of the forest area of the Sundarbans occurred during the period of 1841-1954 which falls, primarily, during the British rule on the subcontinent (1756-1947). During this period, land reclamation and revenue extraction was the primary focus of the colonial government in the Sundarban and leases were granted from early on in its administration. In order to achieve better control over the reclamation of land of the Sundarban for revenue purpose, the Sundarban boundary was defined by the Dampier-Hodges line. Named after the Dampier, the then Commissioner of Sundarban and Lt. Hodges, the Surveyor, this line is closely associated wit Sundarban's settlement history and currently demarcates the northern boundary of the Sundarban Biosphere Reserve in West Benagl. Figure 2.2 clearly shows how the mangrove forests started to disappear in the western side of the Sundarbans, and the south-east and eastern parts. In the centre of the Sundarbans, land also started being cleared (Jalais, 2010). Among the three original Sundarban districts (24-Parganas, Khulna and Bakarganj, Bakarganj is now Barisal division), deforestation of the eastern Bakarganj was almost complete by 1910 (Jack, 1918). The forests of the Khulna, bounded by the Raimangal and the Baleswar, were never subjected to the scale of reclamation seen in Bakarganj and 24-Parganas. Contemporary Survey of India maps indicate, extent of mangroves in Khulna did not reduce appreciably after 1920s. The reclamation activities and management system during colonial period is given in detail in the following sections.

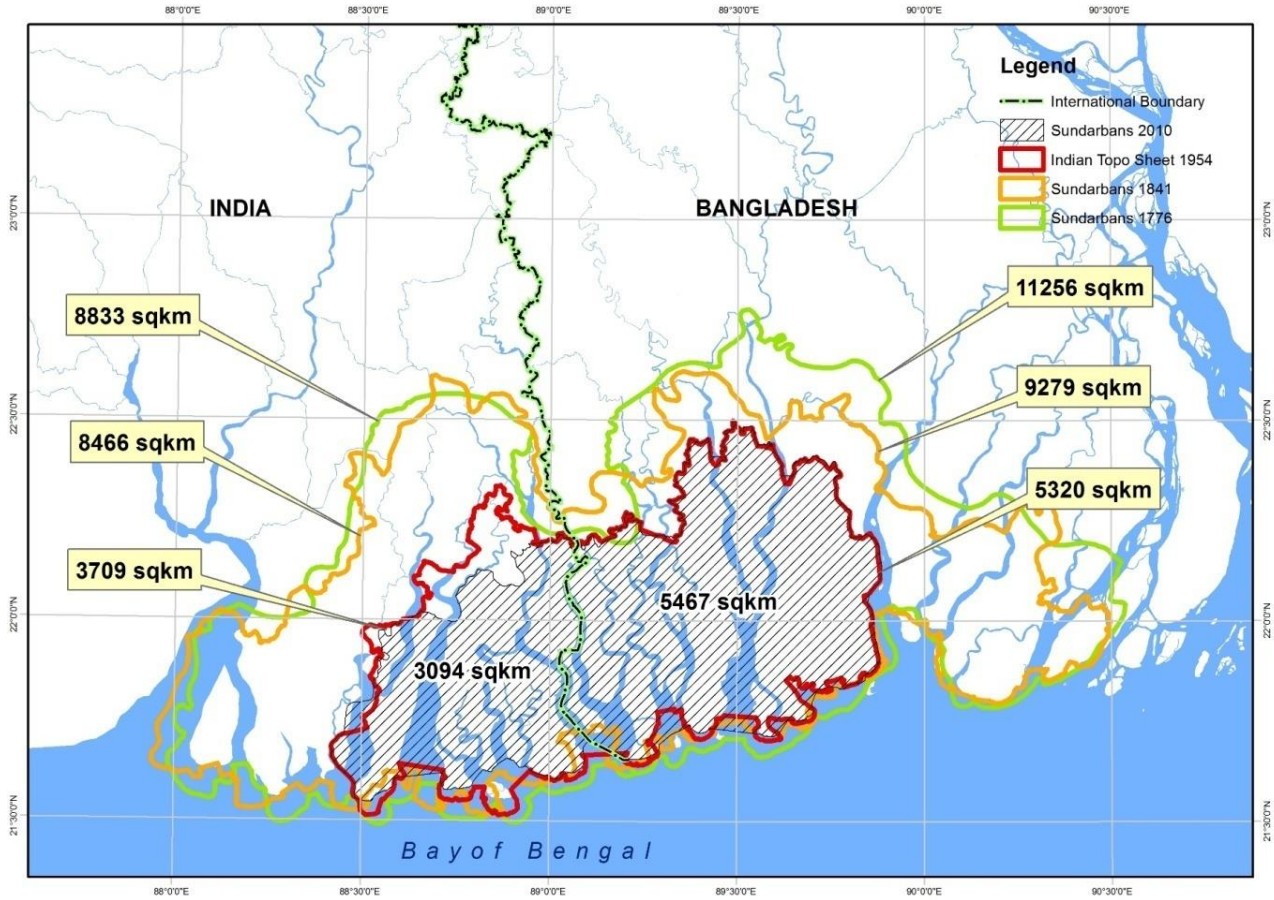


Figure 2.2: Mangrove forest change of the Sundarban from 1776 to 2010

2.3 Early history and first inhabitants

It is difficult to trace the historical pattern of how the Sunderbans came to be inhabited. The little information that is available is generally from British colonial records. Human artefacts, including some old and new Stone Age weapons, provide archaeological evidence of the presence of humans in the region as early as 150,000-40,000 BC (Chaudhuri and Ahmed 1994). Centuries later, texts from Ramayana, Mahabharata, Puranas and Kabikankan's Chandi indicate that people had already settled in Sundarban during 300 BC to 300 AD. The earliest reference of the Sundarban tract can be traced back to the epic Mahabharata (ca. 300 BC to 300 AD) where the eldest and second Pandava brother Yudhistir and Bhima visited 'Gangasagar' (literally means 'place where the river Ganges met the sea') during their pilgrimage (Dutta 1989). Even today, thousands of Hindu pilgrims visit the Sagar Island to the west of the Indian Sundarban and Dubla Island in the Bangladesh Sundarban.

Moreover, the Asram of Kapilmuni, the ruins of Pratapaditya's fort, the temple of the period of King Jayanta Chandra and fort of Bharat Raja are evidences of civilized human inhabitancy in the area of Sundarban. Prior to the 5th century BC the Proto-Australoid group called 'veddoid' or 'kobil', started to settle in the upper parts of the delta (Sahgal et al. 2007). The Aryans (Proto-Nordic) invaded the area much later. Civilization flourished in the delta during the reign of Asoka (273 – 232 BC) and in subsequent Hindu periods. The discoveries of the relics at Harinarayanpur south of Diamond Harbor (Indian part) of Sundarban clearly indicate the existence of a civilization over this region which evolved around 3rd century BC during the Mauryan period (Times of India, 2016). The villages and townships flourished as they had an advantageous position well connected to river routes creating opportunities for trade and commerce (ref).

Figure 2.1: Artifacts including terracotta human and animal figurines dating back to the pre and early Christian era unearthed in the Sundarban (Source: Times of India, 2016)

During the Gupta Dynasty (320-415 AD), a large protion of the Sundarban was cleared for agriculture (Khan 2011). Hiuen-Tsang, the Chinese monk, scholar and explorer who visited India between 627 and 643 AD) described the Sundarban as a "low-lying country bordering on the sea and rich in crops". In the 10th century AD, Srichandra founded the Chandra dynasty in the northeast of the Sundarban which was known as Chandradweep, this area is now located in the Barisal district of Bangladesh (Choudhury et al. 2001). The presence of large tanks, masonry structures and embankments within the Sundarban is seen

as evidence of prosperity in the region which was probably destroyed by pirates. Although some historians argue that these structures could have been constructed by Portugese and Magh pirates, who displaced local populations and started inhabiting the Sundarban forest. Their livelihood centred on piracy, preying on the numerous merchant ships which passed through the region (Jalais, 2010). The process of human settlement continued unabated till the 11th century, when shifting river channels and epidemics seemed to have forced settlers to abandon the area for a while. These findings show that Sundarban was well populated over a number of centuries, but settlements would emerge and many of these would decline due to natural or political adversity (Sarkar, 2010; Ray 1993).

Sultanate years

Post 1200 AD, and beginning with the reign of the Bengal sultanate (1204 – 1575), the history of the Sundarban is one of the continuous conversion of forest tracts to wet-rice cultivation under the influence of pioneers professing an Islamic Sufi identity. In Jessore and Khulna during the early 15th century, Khan Jahan Ali acquired forest areas from Sundarban, clearing dense forest areas in order to establish human settlements and townships, he founded mosques, constructed roads and bridges and excavated tanks for freshwater. The Shat Gombuj Masjid (Sixty Domed Mosque) still standing near the periphery of the Sundarban illustrates the architectural style he had introduced in the region (Chakrabarti and Chakrabarti, 2013).

Archaeological evidence indicates that the Sunderban were inhabited by some indegenous tribes before the Indo-Turkish sultans began their reign in Bengal in the early 13th century. These tribes were later identified as communities of fishermen. The available evidence, contained in oral tradition and sometimes land revenue records, suggests that by the Mughal period the process of clearing forests and introducing settled agriculture was well under way. By the mid-fifteenth century, the reclamation process had brought the southern extent of cultivation to the edges of South Jessore and northern Khulna.

Mughal years

The process of bringing virgin forest under cultivation continued unabated in the Mughal era (1575 – 1765). During this time the Ganges changed the course from the original Hugli channel to combine upstream with the Brahmaputra (S.K Sen, 2007). As a result, most parts of the 24 Parganas Sundarban faced increased salinity and this gradually affected the biodiversity of the area. The era also witnessed devastating cyclones, like the one in 1584, which is reported to have claimed about 2,000,000 living creatures. At the end of the Mughal rule, settlers had successfully pushed back the northern boundaries of the Sundarban forests to the very edges of Kolkata.

During the early period of the eighteenth century, population began to decrease mainly because of a change in course of main part of Ganga, and predatory activities of the Portuguese and the Mogs. At least from the end of the 18th century up to early 20th century AD, there were small salt-farms in many parts of the southern and central Sundarbans. The salt manufacturers were called ‘malangis’ and ‘mahinders’ (Barui 1985). Ruins of earthen pots that people once used to make salts, and the mounds of

their shelters, still exist in some areas of the Sundarbans. Ruins of old temples and watchposts still exist in Sheikher Tak, central part of the Bangladesh Sundarbans, which date back to 1700s (Ahmed 1989).

The Mughal policy on forest was one of indifference. During this period forests served mostly as game reserves for the purpose of sports. They were interested in trees from the gardening point of view, and also for avenue planting. There was no comprehensive policy on problems of forestry including its preservation, propagation, protection or improvement.

British era

The British presence in the Sundarban dates from the treaty of 1757 signed after the Battle of Plassey, through which the lands of 24 Parganas were ceded to the East India Company. The British East India Company set up their headquarters at Kolkata (Calcutta) at the edge of the Sundarban. The area was then mapped by the Surveyor General as early as 1764 showing that the forests at that time stretched uninterrupted for 19,200 km^2 and retained much of their splendour and diversity. First lease was granted by British East India Company to individuals for land reclamation for cultivation and timber supply in 1770-1773 and over the next century the British would relentlessly pursue a policy of deforestation and extension of cultivation in the Sundarban. Land reclamation transformed into an institutionalised effort from 1783 (Pargiter, 1934) manifesting administrative policies that viewed the wetlands mostly as wastelands (Jalais, 2010). The lease-holding landowners encouraged poor farming communities from other parts of Bengal as well as from neighboring states to come and settle in the Sundarban. Various types of land use systems and land tenures grew up in Sundarban (Ray, 1993). By 1810, the areas down to Sagar Island in the west and the south-east and the eastern part (near Bakerganj) of the Sundarban were cleared. In the centre of the Sundarban (Hingalganj and vicinity), land also started being cleared under the magistrate of Jessore (Jalais, 2010). By 1831, reclaimable portion of the region between the Hugli and the Pussur was divided into 236 compartments or 'lots' south of the Dampier–Hodges Line(S.Chacraverti, 2014).The scheme was later extended up to the Baleswarin the east and subsequent reclamation efforts continued until 1910 (Jack, 1918).

In 1828 the British Government assumed proprietary rights to the forest and in 1830 began leasing out tracts of the forests for reclamation – a process which continued until 1875-76. As a result, the recent mass settlement in this basin was started in the early 19th century (Chaudhuri and Choudhury 1994) and from the very beginning the principal occupations of the settlers of this area were woodcutting, fishing and honey gathering. This period saw a great decline in the diversity of large mammals. Increasing regular revenues from the so-called Sundarban 'waste land' was the main inspiration behind the all-out attack on the forests which was covered with impenetrable forests and seen as the hideout of different types of wildlife.

2.1. Conservation steps – pre 1947

This section gives a brief description of past and current conservation plans and activities; a more detailed account is given in chapter 6 of this Narrative.

An edict passed by Emperor Asoka for the protection of animals, fish and forests, can be considered the earliest documented case of formal forest conservation and management (Rahman, 2005). The first call to preserve the forests in India through scientific management was made by Dr Brandis, the Conservator of Forests in Burma in 1862. Based on his recommendations, additional reclamation grants were stopped, but deforestation continued regardless. The rate of forest clearance had increased and forest wood was used for ship building and railway sleepers. By 1873, almost 5,100 km^2 of forests had been converted into agricultural land and the Sundarban area forest cover had been effectively reduced to about 14,100 km^2. The Forest Act was formulated in 1855 but it is only post 1873-1874, when faced with dwindling forest produce; the colonial rulers started reviewing the policy of transformation of all available wetland forest to taxable agricultural land in the Sundarban. Under the Forest Act some parts of the Sundarban were declared as reserved forest in 1875-1876 and from then on the resource harvest became the subject of Government control. Fishing or collection of natural resources became subject to permits, and paying revenue to the Government through the Forest Department (Hussain and Acharya 1994). Entry without permit was prohibited from that time, this system is still practiced in both countries, permits are needed to enter parts of Sundarban which are accessible. The first working plan, including prescriptions for wildlife and biodiversity conservation, came into force during 1893-1894.

The 1875 – 1876 government declaration placed the reserved forest under the jurisdiction of the Forest Departmen, a move which created today's Sundarban Forest. Encroachment continued despite reservation and 1,200 km^2 of the protected forest were deforested, mostly in the western oart of the Sundarban, over a ten-year period ending in 1903 – 1904. The 'Lloyd Plan' and the 'working plan' of Mr Heinig covering the period 1903 -04 to 1903-08 were the basis of forest administration until 1913. But these steps did not reverse or reduce reclamation.

In the early 19th century, being threatened with possible loss of revenue, the Government set out to demarcate the non-leased forest area as khas mahal. The then government drew a line to avoid paying legitimate revenue which started large-scale encroachment of forest adjacent to the estates of the local Zamindars (landlords). This line roughly corresponds with the Kakdwip-Bashirhat-Dhaka lineament. , known as the Dampier-Hodges line. Dampier was the then Commissioner of Sundarban and Lt. Hodges was the Surveyor. They drew the line from Kulpi on the river Hugli to Basirhat on the river Khhamati, south of which lies the Indian Sundarban Delta. The 'Dampier-Hodges Line' marks the northern limit of the Sundarbans, running in a slightly zigzag pattern from Basirhat in the north-east to Kulpi along the Hugli in the west.

Till 1912 Sundarban was managed under working schemes. F. Trafford wrote the first management plan for Sundarban for the period 1912-13 to 1931-32. He suggested two working circles as eastern working circle and western working circle. The eastern working circle had the richer growing stock. He prescribed selection system and suggested a 40 year felling cycle with an exploitable BHG of 106.6 cm for Sundori *Heritierra fomes* and 122 cm for *Sonneratia apetala* (Choudhury, J.K, 1997)

The second management plan for Sundarban was written by S. J. Curtis. Curtis' plan came into operation in April 1931. Curtis developed and applied volume functions for the first time in the management of Sundarban. He suggested two working circles but a large number of exploitable BHG limits for given species was prescribed. 12 different diameters were prescribed for Sundori and also other dominant

trees were brought into the management system. Curtis' plan was elaborate and needed professional skill to apply the precise prescriptions. The field staff was found to be incapable to cope with his prescriptions and thus this management plan was revised by S. Choudhury in 1937. Choudhury's plan was in force from April 1937 to 1947. From early 30s of the 20th century, the Sundarban forests were managed using Curtis' working plan which focused on scientific harvesting. This plan was in effect in 1947 when the Radcliffe Commission[8] divided the Sundarban between East Pakistan (now, Bangladesh) and India. Both countries continued to protect the area after independence.

2.4 Conservation - Post 1947

The Sundarban being the largest mangrove forest in the world was brought under management since 1875 that initially aimed at collecting revenue by enforcing simple felling rules. Gradually policies and acts were formulated and clubbed into management practices including restrictions on felling, collecting and even entrance into the forest. The human population in the Sundarban increased rapidly in the post-colonial era after 1947, especially in the Indian part of Sundarban. Between 1873 and 1968 in the Indian SBR, the mangrove-covered area decreased by about half on account of conversion of forest to agricultural land and settlements and the boundary of the forest shifted further south as mangroves were cleared between the Hooghly River and the Matla River. On the other hand, in Bangladesh, the extent of mangroves did not reduce appreciably after the 1920s. Figure 2.1 shows a timeline of management iniatitives.

2.4.1 Conservation and management in Sundarban Biosphere Reserve, India

The forested part of Indian Sundarban Delta (ISD) is overseen by the Director of the Sundarban Biosphere Reserve (SBR) through the Divisional Forest Officer of 24-Parganas (South) Forest Divisions and the Field Director of the Sundarban Tiger Reserve which came into being through a notification in December 1973. All of the ISD was declared as Biosphere Reserve in March 1989 but the human inhabited part is de jure not under the jurisdiction of the Director of Biosphere Reserve. The Sundarban National Park within the Tiger Reserve was declared a World Heritage Site in 1987 and is provided with the highest level of official protection, classified as a Category Ia (Strict Nature Reserve) Protected Area under the IUCN classification system (Danda et al, 2011).

[8] The Radcliffe Line was published on 17 August 1947 as a boundary demarcation line between India and Pakistan upon the Partition of the sub continent. It was named after its architect, Sir Cyril Radcliffe, who, as chairman of the Border Commissions, was charged with equitably dividing 175,000 square miles (450,000 km2) of territory with 88 million people. Today its western side still serves as the Indo-Pakistani border and the eastern side serves as the India-Bangladesh border.

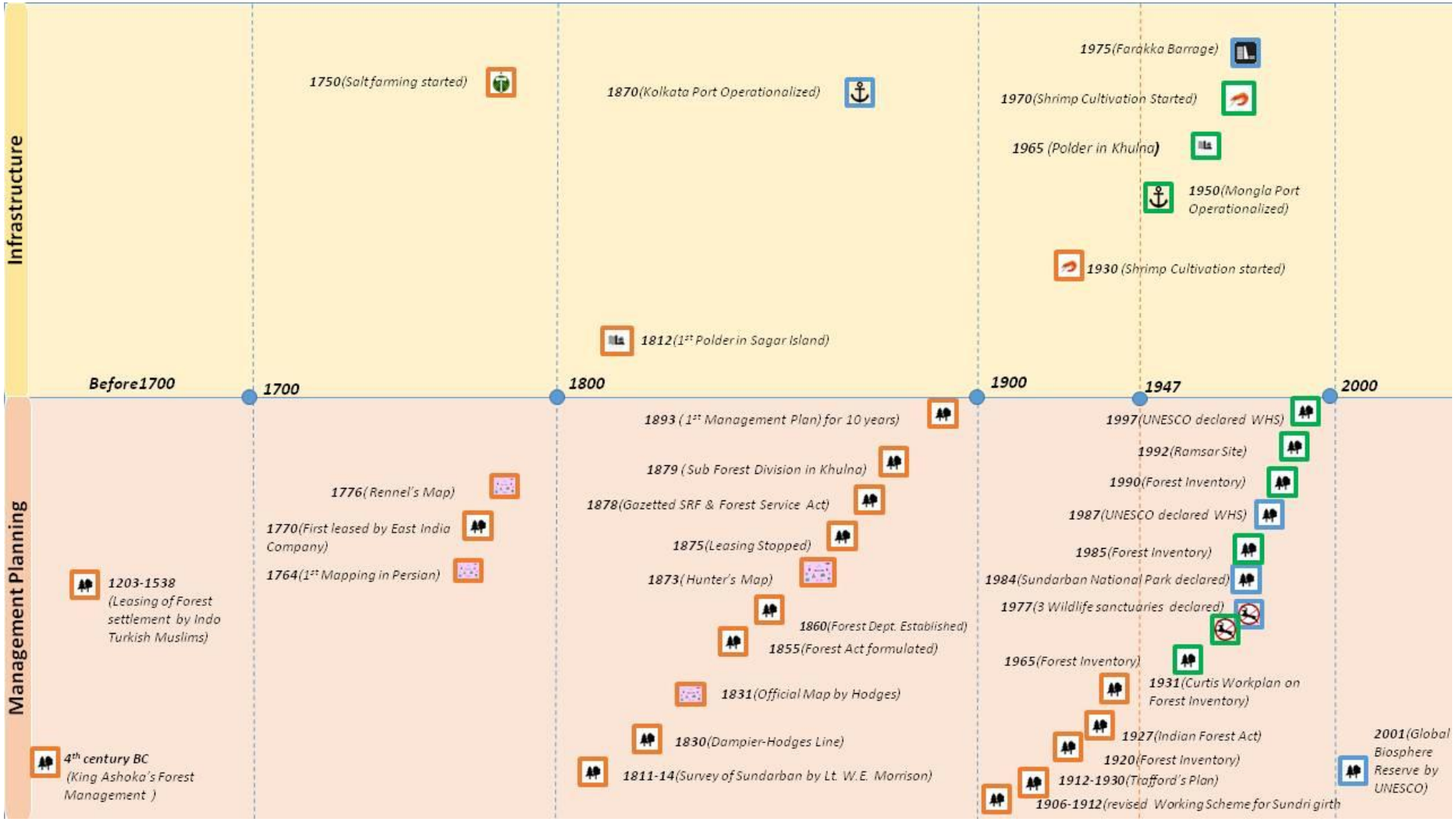


Figure 2.1: Forest Management Planning and Infrastructure Development in Sundarban. Source: based on Banik, H. (1999); Das Gupta, R., R.Shaw.(2013); Ghosal, S. (2011)..; IUCN (2014); KoPT (2014).Robiul Islam. (2001); Sarkar, S.C. (2010)

In order to improve consideration of environmental sustainability issues, conservation, and social and economic values of forests, the National Forest Policy was redrafted in 1988, which subsequently led to the Joint Forest Management Resolution of 1990. In accordance with this policy shift, the Government of West Bengal issued two specific guidelines in 1991 and 1996, both of which have a bearing on the management of Sundarban forest. These are (1) Mangrove forest areas of Sundarban, and (2) National Parks and Sanctuaries of the State respectively.

The notifications helped to devise increase community involvement in ecosystem management as well as to redistribute the benefits of appropriate management more fairly. Accordingly, 51 Forest Protection Committees (FPCs) and 14 Eco Development Committees (EDCs) associated more specifically with National Parks and Sanctuaries, were constituted in Sundarban Biosphere Reserve between 1993 and 1998 in 46 forest fringe villages of Sundarban Biosphere Reserve. The EDCs, which were formed in villages adjoining sanctuaries, are entitled to 25 percent of tourism receipts (DasGupta and Shaw, 2016; WWF, 2011).

2.4.2 Conservation and management in Sundarban, Bangladesh

The Sundarban Reserve Forest has been under management by the Forest Department from the middle of the 19th century. From 1947 to 1959-60 Sundarban was managed on short-term schemes in Bangladesh. Initially the forest used to be considered as a source of revenue. The department focuses on the harvest of commercially important resources rather than managing the whole ecosystem and neighboring impact zones under an integrated plan. Later the government realized the importance of conservation and formulated policies and acts over the last few decades. The new conservation acts banned timber extraction and wildlife hunting, restricted fishing in some canals, established three wildlife sanctuaries, and introduced a co-management system in some parts of the Sundarban. A band of 10 kilometres around the Sundarban was declared as an Ecologically Critical Area (ECA) by the Ministry of Environment and Forest in 1999.

In order to conserve the wildlife and biodiversity of the Sundarban, the Government of Bangladesh established three Wildlife Sanctuaries (Sundarban East, Sundarban South and Sundarban West) in 1977, under the Bangladesh Wildlife Act 1974, covering an area totalling 324 km^2, which was declared a World Heritage Site by UNESCO in December 1997. In 2012, three river areas (Chandpai, Dudhmukhi and Dhangmari) covering a total area of 10.7km^2 were declared as Wildlife Sanctuaries, mainly for the protection of dolphins. The rest of the Sundarban remained as Reserved Forest, which was declared in the colonial era. Since the Sundarban is also treated as a wetland of international importance, the entire Sundarban gets protection under the Ramsar Convention (which Bangladesh ratified in 1992). Contiguous with the Sundarban there is an additional 20 km wide marine zone with an area of 1603 sq. km. that is included in the Sundarban (TRC Focal Point BD, 2014). Presently there is a moratorium on tree felling in the reserve forest, only Non Timber Forest Products (NTFPs) are being harvested, this harvest is based on seasonal licenses issued from the Forest Department. However studies show that at present, the Forest Department does not control permit licenses to reduce overharvesting of fish or

shrimp fry or prawn seed and there is no monitoring or implementation of ban on harvesting of wild shrimp fry or prawn seed (Roy and Alam, 2012; Hoq, 2007).

2.5 Upstream developments

The Sundarban is a situated in the estuary of the Ganges basin and many developments upstream impact the fragile mangrove ecosystem. Kolkata and Haldia in India and Mongla in Bangladesh are the principal seaports on the Ganges Delta and situated just upstream of the Sundarban. The pressure of increasing population, development of these ports, the Farakka barrage and other human activities including construction of embankments or polders has impacted the hydrological processes and geomorphologic conditions of the (Islam and Kibria, 2006). Sundarban and created significant changes in the forest resources.

Infrastructure development in and around the Sundarban and even in the upstream areas has impacted the natural dynamics of the Sundarban ecosystem. As mentioned in previous sections, the presence of embankments can be traced back to early habitation in the area. These embankments were tuned into the natural hydrological processes and played an important role in flood management and unique community practice of overflow irrigation and sediment by farming communities as noted by researcher Sir William Wilcox (Wilcox, 1930). The embankments were mostly seasonal infrastructure known as aushtomashi gher (embankment constructed for eight months) or dosher bandh and allowed tidal flow into the floodplains thus raising the lands from sediment deposits carried in by the tides. Modern embankments built during 19th century onwards in the West Bengal part of Sundarban and during 1965-1970 in the upstream areas of Bangladesh have affected river dynamics and tidal flows undermining the natural processes of sedimentation. While these interventions initially played an important role in flood protection and improved crop production in the region, these embankments restricted tidal flow disrupting sediment flow into the flood plains. As a result sediments were allowed to raise the riverbeds causing widespread floods and waterlogging (Kibria, 2011). Furthermore poor management and high intensity weather events has caused severe damage to the infrastructure. In many areas, especially in West Bengal, the embankments are unable to provide protection against cyclones and storm surges rendering the population helpless against these natural calamities (World Bank, 2014).

Many of the ports in this region has a long history as the maritime trade had greater interaction in this area as the sub-continental coastlines have provided natural ports of call to the distant traders and ships of the South East Asia and West Asia. These ports were the hub of commerce and trade for the entire region. Located near forests rich in high quality timber, these trading ports of Bengal, were also important centers for shipbuilders. Two types of tree were especially popular with Indian shipmakers—teak and sundari, which provided a hard, reddish wood similar to mahogany. The woods of the Sundari were much more durable than oak and pine, in some cases lasting more in saline water before any repair or replacement was needed. These boats were used for carrying various types of merchandise to Hoogly, Saptagram, Kolkata, Chalna and other areas. Boats made of Sundari were recorded to have been supplied to Nawara, an imperial naval department establishe by Emporer Akbar during the Moghul period (Roy, 1972).

Thus, one of the first development works that happened in the Sundarban region is the establishment Kolkata port which was set up as a trading post on the banks of the Hoogly, during the Maurya and Gupta period and grew into a prominent port in 1870. In the 19th century this port was the premier port in British India. After 1947, because of acute sediment deposition in the Hoogly-Bhagirathi system, the port was facing navigation problem. It required a huge amount of money and effort for mechanical dredging to keep the harbour operationalized. In 1975 the Farakka Barrage was created by India to divert water from the Ganges River system to the Bhagirathi-Hoogly river system to flush out the sediment deposition from the Kolkata harbour without the need of regular mechanical dredging. Unfortunately the diverted water flow from the Farakka barrage was not adequate to satisfactorily flush the sediment from the river (A.R. Mital, 2016). On the other hand because of the diversion of Ganges water at Farakka Barrage in India from early 1975, salinity levels increased drastically in the south western part of the coastal region of Bangladesh and ultimately impacted the Sundarbans. Despite this, the Indian government is contemplating to lining or widening and deepening the Farakka feeder canal to increase the flow towards Kolkata (Wikipidia).

Further port developments in this region were seen as advantageous to the development of railway lines from 1853 onwards wich required vast amount of timber. In 1853 the British set up Port Canning along the river Matla and this port was connected to Kolkata by railway. However the Canning port and adjacent Diamond harbour soon lost a large part of its population after a huge tidal wave destroyed much of the infrastructure in 1867. Port Canning still exists as a major exit point out of the Sundarban, as it is well connected by road and railway to Kolkata.

The third largest city of Bangladesh, Khulna is located 59 km north of the Sundarban on the banks of the Rupsha, which flows through the Sundarban to reach the Bay of Bengal. Khulna encompassing Mongla was set up as a first sub division in 1842 and was used as the centre of activities to suppress river pirates in the area and establishing law and order in the river routes/canals. Due to its location, newsprint mills were set up in Khulna in 1959 with gewa wood of the Sundarban as raw materials. However, following the declaration of the Sundarban as a world heritage site, the Forest Department reduced the allocation of gewa to the newsprint mills and currently there is a ban on gewa felling. Located around 20km north of the Sundarban periphery, the Mongla Port was established in 1954. Besides, cement, petroleum and numerous brick industries, a massive 50,000 ton grain silo have been developed along the banks of the Pashur River just upstream of the Sundarban. This causes various kinds of pollution by ships plying through the Sundarban, as well as those anchored at Mongla port and the pollutants generated by the port (IUCN, 2014). There is also a Mongla Export Processing Zone situated in the region which extends facilities to investors and many industrial plots are being allocated to polluting industries including ship breaking industries.

Over the last few decades, shrimp farming has emerged as an important industry in the coastal region of Bangladesh and India. However, unplanned and unregulated practices is shrimp aquaculture has led to land degradation. This is mostly due to the nature of shrimp culture which requires letting in saline water into empoldered shrimp beds. Over the past two decades, the practices of shrimp farming have caused increased water and soil salinity, massive loss of crop production, loss of fruit, loss of indigenous floral species and fresh water crisis for drinking. The absence of national policy and strategy on

sustainable shrimp aquaculture has been a fundamental problem of this sector (Kabir and Eva, 2014; John Kurien, 2016)

Very recently the Government of Bangladesh has developed plans to establish a 1320 megawatt coal-fired power station at Rampal upazila in Bagerhat district. The proposed project, on an area of over 1834 acres of land, is situated 14 kilometres north of the Sundarban. In January 2016, the Government of Bangladesh awarded the contract for construction of the plant to Bharat Heavy Electricals Limited. Governments in both the countries have been criticized for the decision as the protesters and activists believe that the plant will destroy the biodiversity of the forest (The Guardian, 2nd March 2016). Industrial waste is indiscriminately thrown into the river in the upstream of the Sundarban. Mega-establishments in the vicinity of the Sundarban will not only increase the pollution risk, but will also stimulate urbanization and influx of people along the boundary of the Sundarban.

3. The Physical Landscape

An integrated approach to management and conservation of Sundarban region has to be based on the understanding of the inter linkages and the ecological implications of geo-morphological, hydrological and biogeochemical processes. The Sundarban ecosystem along the Bay of Bengal has evolved over the millennia through natural deposition of upstream sediments accompanied by intertidal segregation. The physiography is dominated by deltaic formations that include numerous rivers and canals associated with surface and subaqueous levees, splays and tidal flats. There are also marginal marshes above mean tide level, tidal sandbars and islands with their networks of tidal channels and subaqueous sand bars.

It is evident that the Sundarban, like most mangrove forests, are dynamic products of complex hydro-morphological coastal processes and tidal cycles that manipulate the physiological systems, chemical adaptations and metabolic parameters govern the composition and structure of a mangrove forest. Alternately biotic factors play a significant role in physical coastal evolution, and formation and regulation of new landmass. Upstream water withdrawals have led to reduced freshwater flows and embankments have caused increased instream sediment deposits thereby reducing the carrying capacity of the river system. Coupled with sea level rise, this has resulted in increased levels of salinity, particularly during the dry season (low flow period) affecting biodiversity (Brij Gopal, 2006).

Yet, the natural resources management of the Sundarban in both countries focus on protection of plants and wildlife, rather than conservation of the habitat and overlooks the spatial progressions and interlinkages of the entire ecosystem. One reason for omission of such linkages has been that many of the environmental processes occur outside the physical boundaries of the forest. In a watershed, for example, upstream activities and infrastructure can be situated at large distances from their impacts downstream, complicating the task of tracing cause and effect and of gathering the data necessary for analysis. Many actions typically have impacts off-site, so that costs and benefits may be spatially separated and involve different participants. Even within the ecosystem itself, many of the physical relationships and natural developments are imperfectly understood (Gregersen et al. 1988, Dixon et al. 1989). On the other hand, administrative jurisdiction and capacities often limit the planning boundaries. Management of the Sundarban will therefore need to expand its spatial as well as subject matter boundaries if it is to capture such interrelationships. This chapter thus focusses on the different physical processes and landscape parameters that form the mangrove ecosystem.

Based on recent studies and research documents, this chapter describes the complex interplay of diverse physical development processes of the Sundarban region. The physical landscape is detailed according to the following sections,

- Evolution and geomorphology of the Sundarban
- The Sundarban Waterscape
- Natural disasters and climate change

3.1. Evolution and Geomorphology of the Sundarban

The Sundarban mangrove wetlands occupy the western part of the lower Ganga–Brahmaputra delta in Bangladesh and India. Located at the northern apex of the Bay of Bengal, the Ganga–Brahmaputra delta is the world's largest both in terms of land area (about 120,000 sq km) and yearly discharge of sediments (about one billion tons per annum). The delta is contributed by a combined catchment area of 1.6 million sq km, drained by many small to medium sized peripheral streams that emanate from the surrounding uplands apart from the Ganga and the Brahmaputra.

The Ganga–Brahmaputra delta, of which Sundarban forms the coastal part, is bordered by highlands on all three sides barring a 125-km-wide passage that links the region to its northern provenance. This is known as the Rajmahal–Garo Gap, a worn-down saddle of the Indian craton between the Rajmahal and the Garo hills (Fig. 3.1). The northern and eastern boundaries of the delta are defined by the crystallines[9] of the Meghalaya plateau, the Rajmahal hills and the Chhotanagpur plateau. The eastern boundary of the delta is delineated by the Neogene sedimentaries of Chittagong–Tripura Fold Belt. The entire southern boundary is along the Bay of Bengal, where the delta surface slopes into the Bengal deep sea fan.

The subaerial and subaqueous parts of the delta can be seen as integral parts of the Bengal Depositional System that stretches from south of the Himalaya to the distal edge of the Bay of Bengal (Curray, 2014). Its deltaic components include a higher-gradient fan delta in the north, characterised by vertically and laterally migrating sand-dominated braidbelts; a lower-gradient fluvio-tidal section in the southeast which is building into the sea with comparatively stable channels; and a fluvially abandoned tidal section in the southwest that is accreting vertically but also declining irreversibly in certain sections (Wilson and Goodbred, 2015).

The current orientation of the Ganga–Padma–Lower Meghna river diagonally divides the Ganga–Brahmaputra delta into two parts. The southwestern portion, along with southern coastline of the delta between the Hugli and the Baleswar estuaries, is primarily contributed by the distributaries of the Ganga system—active or dissipated. Its 200-km littoral stretch constitutes about 47% of the delta coastline and harbours the Sundarban. This section first reviews the evolution of the Sundarban region as a part of the Bengal basin and the Ganga–Brahmaputra delta. It then discusses the main natural and anthropogenic forcings working on the area and how the region is responding to them.

[9] Hills of crystalline rock**,** any rock composed entirely of crystallized minerals.

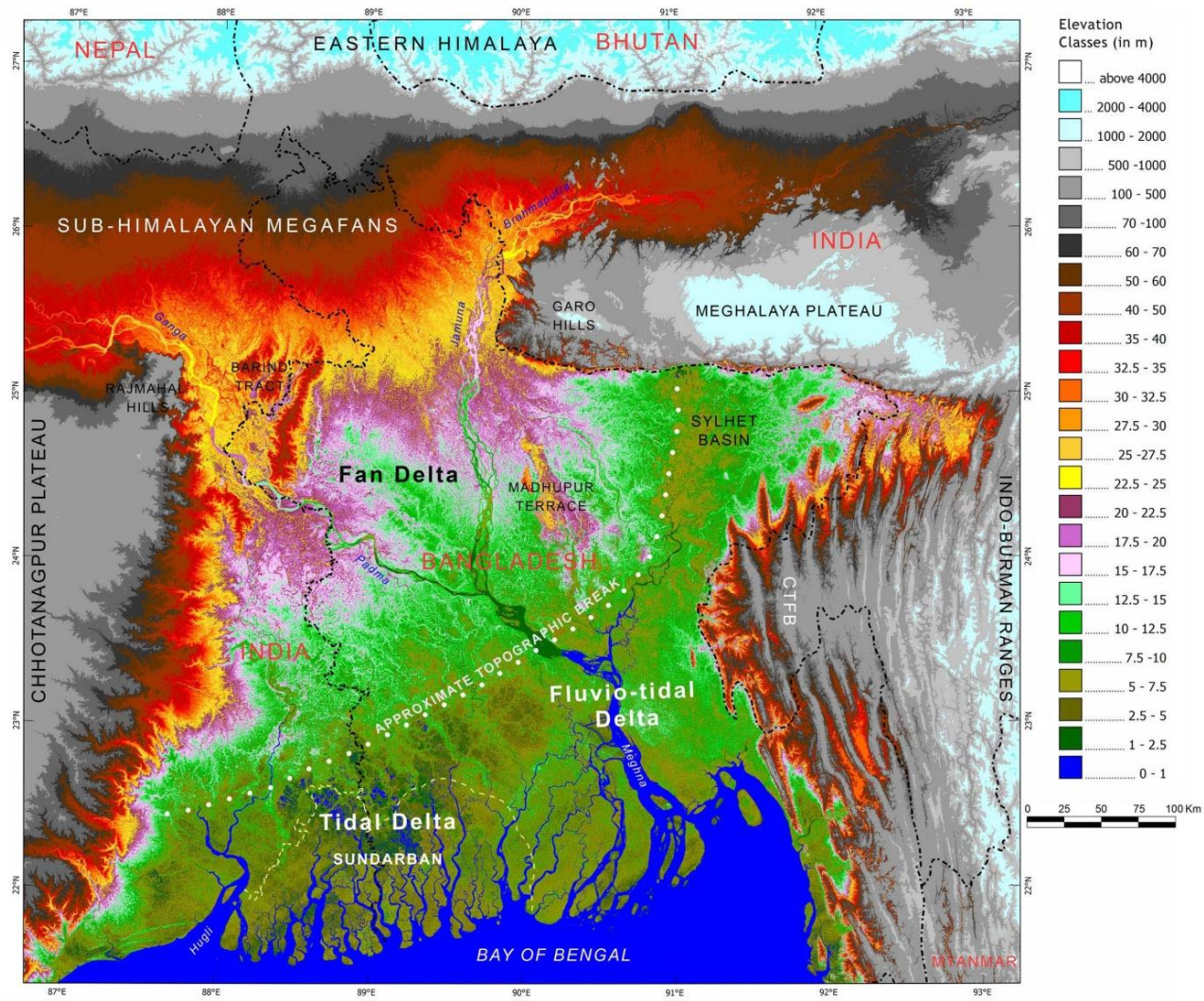


Figure 3.1: Physiographic setting of the Ganga Brahmaputra delta. The plateaus and other highlands generally occupy the zones above 60 m. Elevation of the alluvial fans, terraces of Barind and Madhupur approximately range between 25 and 60 m. Areas lower than this form the delta proper. The elevations of the delta roughly decrease from NW to SE. Gradient- and process-based divisions of the delta adapted from Wilson and Goodbred (2015). Limit of the Sundarban region shown in yellow dashed line; see Fig. 3.9 for details of this boundary. CTFB stands for Chittagong–Tripura Fold Belt. *Source*: Elevation model prepared from 90-m Shuttle Radar Topography Mission data of 2000

3.1.1 Evolution of the Delta

Formation of the Bengal basin, the cradle of the Ganga-Brahmaputra delta, started in the Jurassic[10] with initiation of rifting of the Pangaea[11] and completed by the Miocene[12] with docking of eastern India with

[10] The Jurassic was a geologic period and system that spanned for 56 million years, 201.3 million years ago
[11] Pangaea was a supercontinent that assembled from earlier continental units nearly 335 million years ago
[12] Miocene is a geologic Epoch, 23.03 to 5.3 million years ago. It's notable in that two major ecosystems made their first appearances: kelp forests and grasslands.

the Burma platelet. Sedimentation of the basin started almost contemporaneous to rifting and occurred in the three geotectonic provinces of continental shelf, deeper basin areas, and Chittagong-Tripura Fold Belt. The delta originated with the opening of the Rajmahal-Garo gap in the Plio-Pleistocene. It acquired its present form during the late Holocene after the sea level neared its present position (Figure 3.2).

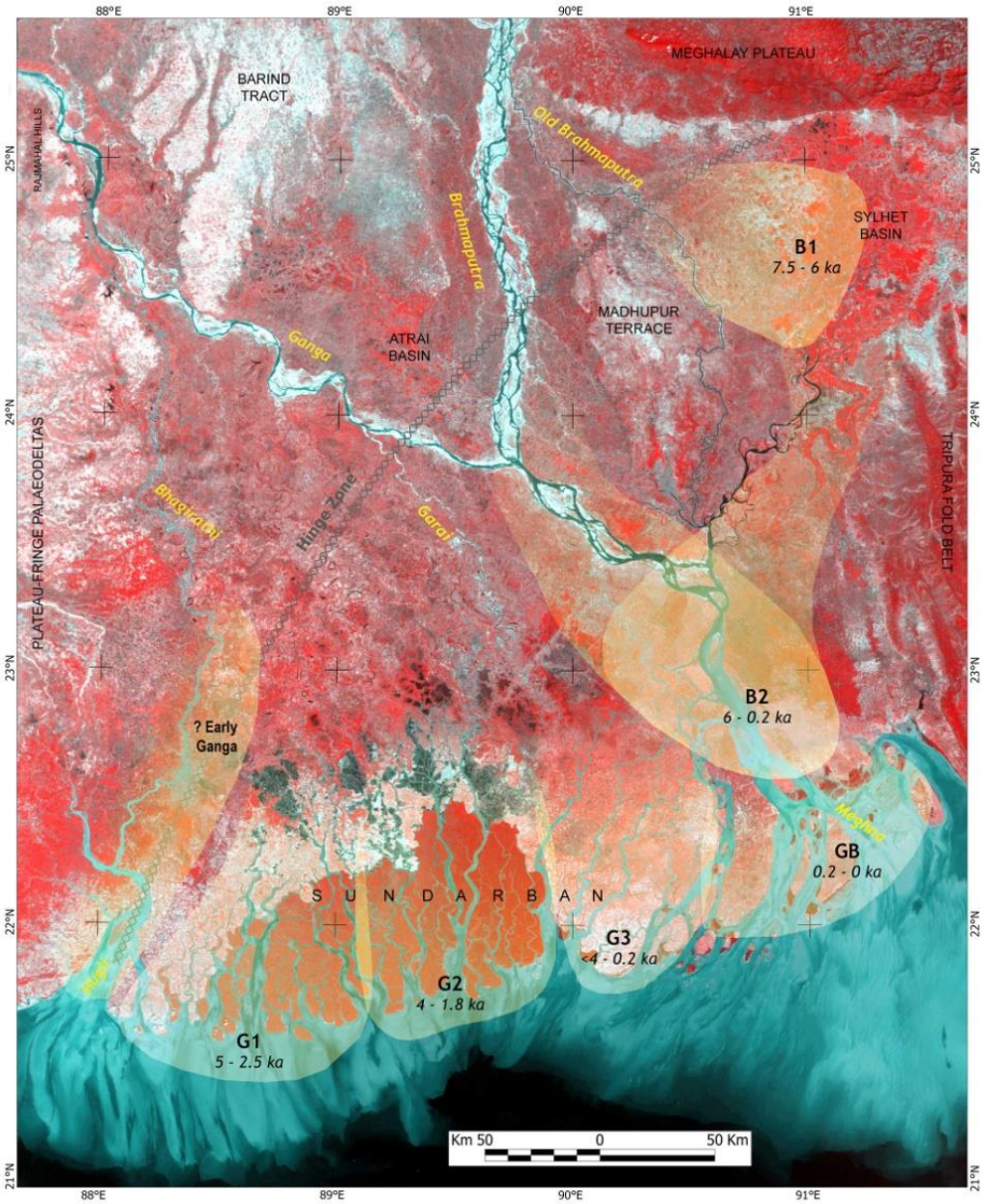


Figure 3.2: Phases of late Holocene growth of the delta, associated with progressive shifts of the Ganga (G1, G2 & G3), Brahmaputra (B2 & B2) and combined Ganga–Brahmaputra (GBD-1) discharges as suggested by Allison *et al*. (2003). Major morphological features of the GBD are also shown. The Barind tract and Madhupur terrace are uplifted blocks that separate the delta into compartments and hinder free swinging of rivers across the delta. Morphostratigraphically equivalent formations are seen in the palaeodeltaic surfaces bordering the Chhotanagpur plateau. The hinge zone is a flexure of the subsurface continental shelf to the deeper basin areas. False Colour Composite prepared from IRS-1D WiFS data of 3 March 1998. *Source*: andyopadhyay (2007)

The Pleistocene[13] is marked for fluctuations in global temperature that brought four cool glacial stages and the intervening warm interglacials. Intrinsically linked to the global hydrological cycle, the cool (warm) epochs caused worldwide fall (rise) in the mean sea level. The Ganga-Brahmaputra delta, like all modern deltas of the world, was primarily shaped during this period. The Holocene history of the delta was characterised by fluctuations in monsoon-related sediment discharge, land and seaward migrations of depocentres[14] and at least five switching in the course of the Brahmaputra. The coastal region of the delta is not older than 52.5 thousand years and was developed by formation of four overlapping and eastward-younging deltaic lobes.

During the last five thousand years, the delta development shifted its focus mainly towards the east and the eastern coastline gradually swung southward to its present position. At least another eastward avulsion of the Brahmaputra occurred after which it gradually abandoned its course through the Sylhet basin between 1810 and 1850 (Fergusson, 1863:334; Hirst, 1915:180) and established into its modern channel. In fact, the paths of the Ganga and the Brahmaputra swung across the central part of the delta for the major part of the Holocene.

3.1.2 Evolution of the Sundarban Region

3.1.2.1 Accretion of the Sundarban

Delta-building bio-tidal processes, at the southern frontier of the Ganga-Brahmaputra delta, was responsible for phased accretion of all sea-front islands of the Sundarban five to two thousand years ago raised by the deposition of sediments formed due to soil erosion in the Himalayas (Fig. 3.7), from what probably was a number of disconnected incipient subtidal and intertidal shoals to the supratidal landmass it is now identified with.

Riverine sediments undergo rapid transformation as they enter the estuaries. The bulk of them are carried as colloids in the still water period at the high water level of a tidal cycle, individual or groups of flocs settle on the bed of a stream or mudflat and get slowly consolidated during the subsequent slack water period. During the next tidal cycle, velocity of the mid-tide currents may not be sufficient enough to erode all the materials deposited previously. In the continuous cycles of tidal deposition and erosion, accretion only occurs if a net edge of deposition exists over erosion (Dyer, 1979; Barnes, 1984; Furukawa, *et al.*, 2014).

As the shoals formed by tidal deposition start to emerge above the low tide line, pioneer mangrove species like *Porteresia coarctata* soon start to colonise on the muddy tidal flats and the bio-tidal accretional processes take over. According to the 'classical successional view of mangrove dynamics'

[13] Pleistocene often colloquially referred to as the Ice Age is the geological epoch which lasted from about 2,588,000 to 11,700 years ago, spanning the world's most recent period of repeated glaciations.
14 Depocenter refers to an area or site of maximum deposition, or the geographic location of the thickest part of any specific geographic unit in a depositional basin.

(Sneadaker, 1982:111), plant communities such as these literally 'prepare the ground' for the next community as they raise the level of the shoal by inducing sedimentation and thereby reducing the tidal inundation time of a particular locality. At the end of the process, a climax — largely non-mangrove — vegetation community evolves as the land is raised sufficiently above the tidal limits (Chapman, 1976; Thom, 1984) (Fig. 3.3). There are many processes how the mangroves can induce an increased level of tidal accretion. For example, their stems often cause eddies that trap sediments. The sticky algal mats that develop under the plant cover can also do the same. Apart from processes like these, the entire surface of the colonising mangrove species becomes an area for sediment deposition during their inundation. This sediment is contributed to the accreting land surface when the veneer gets dry and then flecks-off during their subsequent low tide exposition (Pethick, 1984).

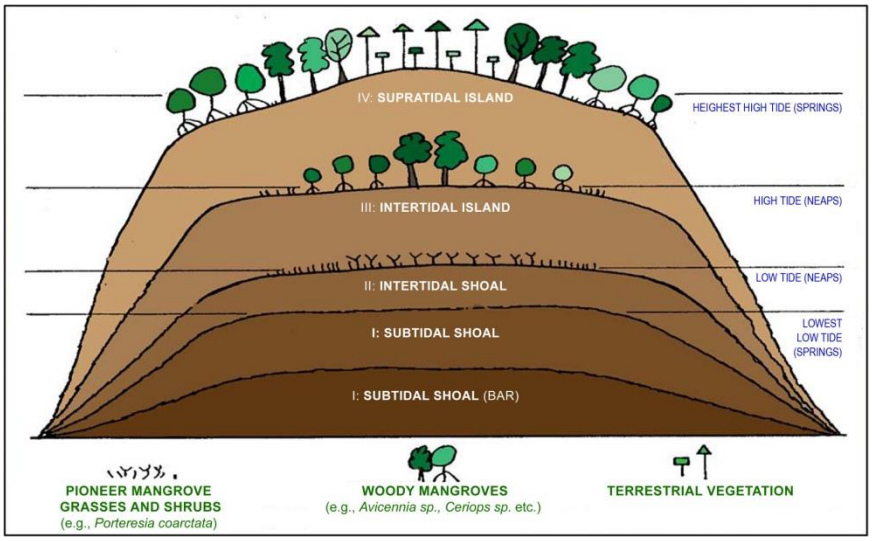


Figure 3.3: Stages of biotidal accretion in a tropical delta. The process starts from colonisation of grasses, herbs and shrubs that help to stabilise intertidal shoals. With rise in elevation, interval of tidal inundation reduces, and leads to successive changes in mangrove species. At maturity, the shoal evolves into a supratidal island with non-mangrove climax vegetation that is inundated only during episodic storm surges. *Source*: after Untawale and Jagtap (1991)

One problem with the succession model of mangrove ecology is that it is only observed in prograding shores (Tomlinson, 1984:19). The scheme is difficult to apply in areas where the coastline is primarily eroding for a long time, as in the southern Sundarban. However, newly emerged tidal islands of the region do show vegetation succession. For example, the Nayachar island, situated in the upper reaches of the Hugli estuary, progressively accreted during 1948–2008 and developed four semi-concentric vegetation zones that distinctly coincide with growth stages of the island and relate to environment gradients like decreasing inundation-interval and fining-upward sediment characteristics (Bandyopadhyay, 2008).

3.1.2.2 Reclamation and present status of the Sundarban

Although the frontiers of the Sundarban mangroves started to move southward for expansion of rice farms from the 13th century (Eaton, 1990), forests still occupied some 16,500 km^2 of tidal seaface of the

delta between the Hugli and the Meghna estuaries about 240 years ago (Rennell, 1779).

Prevention of tidal inundation in a permanently reclaimed region stops the natural process of delta building and keeps the area lower than the highest high water and storm surge levels. The region remains and forever prone to hazards like saltwater ingression and flooding due to breaching or overtopping of the embankments. This problem was recognised long ago by authors like Ascoli (1921:155), Addams-Williams (1919), and Mukherjee (1969, 1976). Embanking the coastline and major channel banks, apart from completely blocking the smaller creeks to prevent inundation of the interior areas from highest high tide or storm surges, had been the usual reclamation procedure of the Sundarban since 1770. The indigenously designed earthen dykes required extensive annual maintenance and offered little protection against storms (Hunter, 1875). While they essentially remain unchanged in many areas in the western (Indian) Sundarban, in the east (Bangladesh), extensive areas in the south west region of Bangladesh adjacent to the Sundarban are protected by large-scale polder construction since the 1960s (Bari Talukdar, 1993).

Large-scale polder[15] construction in the 1960s permanently arrested tidal inundation in much of the areas adjacent to the Sundarban in Bangladesh. Recently, Auerbach *et al.* (2015) showed that this resulted in a loss of 1–1.5 m of elevation inside the polders compared to neighbouring mangroves which continued to receive sediments through tidal inundation. Removal of forest biomass, ground compaction and sea level rise also contributed to the difference. This translates into an elevation loss of 20–30 mm/year during the last 50 years inside the reclaimed region, greatly increasing its vulnerability to sea level rise rise and storm surges. Embankments were breached by the tropical storm Aila in 2009 and opened them to tidal spill for up to two years before complete repairs were made. In Polder #32, located on the eastern bank of Sibsa adjacent to the mangroves, an average accretion rate of 180 mm/year was achieved during this period (Auerbach *et al.*, 2015). In Sundarban Biosphere Reserve, tidal sedimentation is used ingeniously by around 3000 brick kilns that operate along the banks of the Hugli and the Ichhamati (upper Raimangal). Basins adjacent to the channels are kept open to tidal spills all through the monsoons. They are drained in the post monsoon season and the sediments, deposited at 50100 mm/year, are utilised for brick making.

3.1.3 Landforms

Morphology of a deltaic coast represents the interactions between sediments brought in by the rivers, and their reworking by the tidal and wave processes that increase during storms. Generated by the winds, the waves give rise to different types of currents that work on a coast longitudinally, transversely or obliquely. Tidal rise and fall change the site of wave action besides generating huge volume of water, called tidal prisms that enter and leave the coastal plains. (Reading and Collinson, 1996). With amplitudes raging from 3–4 m at the estuary mouths and 4–7 m in the interior, tides play a crucial role in landform development in Sundarban. Landforms produced by winds and waves are less important and are restricted to its southern fringe (Table 3.1).

[15] A polder is a low-lying tract of land enclosed by dikes that forms an artificial hydrological entity, meaning it has no connection with outside water other than through manually operated devices

Table 3.1: Generalised classification of landforms in the islands of Sundarban

LANDFORM SYSTEM	BROAD GENETIC MORPHOTYPES	LOCATION	MATERIALS	DOMINANT PROCESSES	LANDFORM UNITS				GEOMORPHIC HAZARDS
					SCALE [1]	FEATURE(S)	PERMANENCY [2]	SYSTEM OF CHANGE	
I: COAST (area: 5%)	**1**. Beach	Outer (seaward) strand of the southern islands	Mostly very fine sand (sub-angular to sub-rounded; well-sorted; positively skewed & mesokurtic) &, in eroding sections, beach clay sequences formed of sticky grey clay associated with old mangrove trunks, roots and pneumatophores	Marine erosion and deposition; Bioturbation	S	(i) Bedforms like ripples, rills and swash-marks; Mud balls; Bioturbation structures	D–E	(i) Individual forms change with every tidal cycle but the overall pattern may emerge unaltered or change slowly over the years with changing sedimentological character / flow conditions.	Coastal erosion; breaching of embankments and other coastal structures in reclaimed sections
					M	(ii) Beachforms like megaripples. Cusps and horns over sands	C	(ii) Changes slowly with changing sedimentological environment and wave conditions over the year.	
					L	(iii) Beachforms like ridges, runnels, berms and tidal sandflats. Clay windows, occasionally with sea-facing cliffs	C	(iii) From and dissipate or change in size and extension with annual cycles of wave environment and tidal conditions	
	2. Dune (Aeolian)	Back of the beaches. Not present in eroding sectors	Mostly very fine sand (sub-rounded to sub-angular; positively skewed and mesokurtic)	Aeolian erosion and deposition; biostabilisation; storm / tidal overwash. Anthropogenic modification in reclaimed stretches	S	(i) Bedforms like aeolian ripples	E	(i) Extremely responsive to aeolian transportation, can be destroyed by slightest interference	Dune progradation and deposition of wind-blown sand onto interior areas of reclaimed stretches
					M	(ii) Sandforms like barchanoid embryo dunes or neo-dunes	C	(ii) From in the late pre-monsoon and dissipate in the monsoon with annual cycle of wind regime	
					L	(iii) Sandforms like dune humps, transverse fore and back dunes, blow-outs, dune slacks. Aeolian sandflats	B–C	(iii) Initiated regionally by vegetation or coastal embankments. Parts of foredunes are wave-eroded during spring tides and / or storms while parts of back dunes transgress landwards during the pre-monsoon. Other forms are bio-stabilised and change slowly	
	3. Beach–bank transitional (tidal / fluvio-tidal)	At the mouths of seafacing estuaries and tidal inlets	Very fine sand – properties same as 1 above.	North-directed longshore drift, bioturbation in intertidal areas	S	(i) Bed forms like ripples, rills and bioturbation structures	D–E	(i) Same as 1(i) and 2(i) above	Storm erosion
					M-L	(ii) Megaripples, sandflats, mudflats	C–D	(ii) Same as 1(ii) and 2(ii) above	
	4. Estuary bank (tidal / fluvio-tidal)	Along the sides of the estuaries and tidal channels	Sticky grey clay to silty clay, hard when dry, traces of old mangrove vegetation may be present	Mostly tidal. Fluvial influence present in channels connected with up-country rivers	S	(i) Biogenic forms, rills over mudflats	D	(i) Same as 1(i) above	Same as 1 above
					M-L	(ii) Clay forms like slip-face and mudflats	B–C	(ii) Changes episodically mainly during the monsoon and / or cyclonic storms	

LANDFORM SYSTEM	BROAD GENETIC MORPHOTYPES	LOCATION	MATERIALS	DOMINANT PROCESSES	LANDFORM UNITS				GEOMORPHIC HAZARDS
					SCALE [1]	FEATURE(S)	PERMANENCY [2]	SYSTEM OF CHANGE	
II. ISLAND INTERIOR (area: 95%)	**5**. Interdistributary estuarine swamp (bio-tidal)	Inner parts of all tidal island where mangroves are present	As above – characterised by thriving mangroves / mangrove marshes. Greyish-black less-sticky clay over mudflats	Tidal and biotic accretion in different cycles (diurnal to equinoctial) of tidal inundation and storm surges	S	(i) Biogenic forms, features associated with mudflats	D	Same as 1(i). above	Storm inundation / erosion
					M–L	(ii) Creek bed and banks, inter-creek mangrove swamps / marshes, mudflats, saline blanks	B	Accretes vertically with bio-tidal accretion	
	6. Inter-creek reclamation (bio-tidal / anthropogenic)	Almost whole of the supratidal interior areas	As above – traces of old mangrove roots and pneumatophores abundant. Soil types are mostly Entisol (Fluvaquent) and Inceptisol (Haplaquept).	Anthropogenic modification (agriculture, aquaculture). Storm surge inundation.	L	Embanked deltaic plain with palaeochannels. Surface elevation lower than High Water Level Springs	A	Natural bio-tidal processes non-operative due to embanking. Changes extremely slowly with tectonic / eustatic modification and eutrophication of abandoned channels. Rare storm inundation due to overtopping or breach in marginal dykes induces some vertical accretion	Storm surge inundation, coastal erosion. Sand encroachment in southern sections of seafacing reclaimed islands

NOTES: **1**. S: small, M: medium, L: large. **2**. Permanency is indicated by 5-point scale A–E (A: most permanent, E: most ephemeral)

3.1.4 Coastal forcings

3.1.4.1 Tides

In Sundarban, the tidal cycle is semi-diurnal with minor diurnal inequality. As the high water moves in along the estuaries, it is complicated by the resonance and other factors that break down any straightforward pattern in the magnitude of tidal rise and fall. Along the seaface of the Ganga-Brahmaputra delta, the lowest tidal range is recorded at the mouth of the Pussur estuary (Hiron Point, 2.95 m). The range increases towards its flanks at the mouths of the Hugli (Sagar island, 4.32 m) and the Meghna estuaries (Sandwip, 6.01 m). Besides this, the increasing landward morphological constriction of the hypersynchronous estuarine channels also induces the tidal range to increase northward, up to 2.5 m in some sections (Fig. 3.3). The Sundarban tides are also asymmetrical with pronounced flood dominance. This means that the rising tide occupies shorter time in a cycle, inducing faster landward velocity of the tidal current that turns the estuaries into sediment sinks. Like the tidal range, the asymmetry also amplifies northward, suggesting an increasingly higher rate of sedimentation in the upper part of the estuaries. Called tidal pumping (Postma, 1967), the net inflow of sediments has profound implication on vertical accretion Sundarban region which receives little or no sediment discharge from the up-country rivers barring the Hugli and the Baleswar.

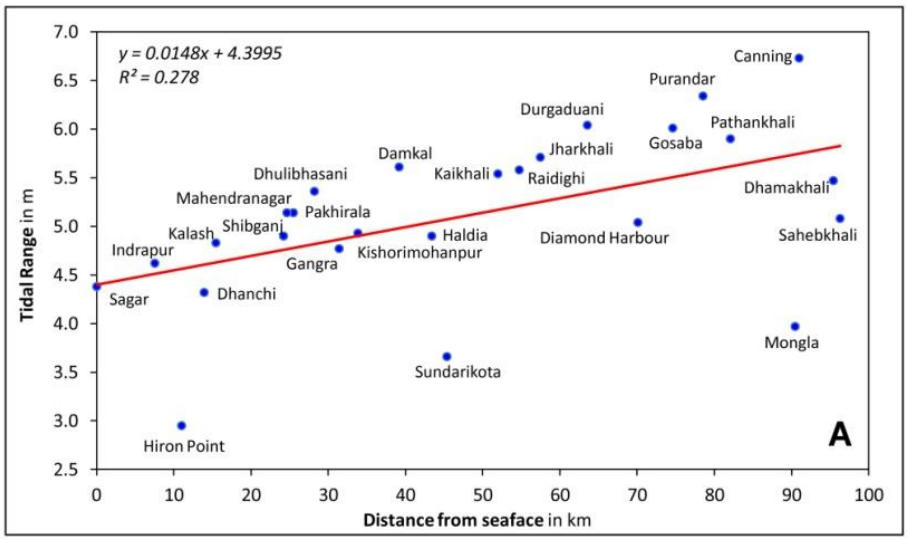


Figure 3.4: Tidal characteristics of the lower GBD at or close to the Sundarban region. (**A**) Landward amplification of tidal range (n=26). Sagar, Gangra, Haldia, and Diamond Harbour are situated along the Hugli estuary. Hiron Point, Sundarikota, and Mongla are situated along the Pussur, where the tidal range is comparatively lower. *Source*: SoI, 2015 (Hugli estuary stations); Chatterjee *et al.*, 2013 (Indian Sundarban stations); BIWTA, 2015 (Bangladesh stations). See Fig. 3.9 for location of stations. *Source*: SoI, 2015 (Hugli estuary stations); Chatterjee *et al*., 2013 (Indian Sundarban stations); UoH-SLC, 2015 and BIWTA, 2016 (Bangladesh stations)

3.1.4.2 Climate

The rhythm of the seasons, reflected in the yearly cycles of wind, temperature, and precipitation regimes, has an important bearing on the tidal and supratidal landforms of the Sundarban. In general, wind speeds decrease eastward. Highest south and southwesterly wind velocities are observed in the exposed western part of the region (about 25 km/hour) during April and May, which, coincided with the hottest (30 °C, also dry) period of the year, bring about significant changes in the morphology of sandforms in the southern seafacing islands. The southerly gusts continue through the rainy monsoon season (June–September). This is the time when, becoming moist with consistent precipitation, sand-movement stops but a rise in the local mean water level joins hand with wind-beaten waves and tropical cyclones to increase the intensity of coastal erosion and reworking of tidal sediments. From October, the winds start to alter their direction and speed (northerly, 5 km/hour), the wave climate also undergoes significant change and, with the onset of the winter, deposition processes take over the beaches (IMD, 1983; FAO-UN, 1985).

3.1.4.3 Cyclones

A six-hour pounding by the waves during a full-blown tropical cyclone can be equivalent to many years' worth of normal wave action. The destructive action of a cyclone is mostly felt on the right of its track (northern hemisphere) and on the islands that face an advancing system perpendicularly (Coch, 1994). Working on the gently sloping shelves of the delta, the winds associated with a cyclone whip-up waves that pile water against the coast and culminate in storm surges capable of completely inundating small low-lying islands of the Sundarban (Walker, 1983). As a storm surge moves into the interior, its levels are further augmented by the northward squeezing estuaries of the region. In the reclaimed Sundarban, properly maintained marginal dykes provide reasonable protection against the highest level of spring tides. However, chances of their overtopping greatly increase if the landfall of a storm coincides with the regional high water level. For example, the tropical storm Aila made its landfall in the western Sundarban on 25 May 2009 between 1:30 and 2:30 pm India Standard Time. This matched closely with spring high water and caused widespread inundation of the region although the storm was a relatively low-power system with its highest sustained wind speed of 112 km/hour (IMD, 2010).

3.1.4.4 Sea level rise

The estuaries are particularly sensitive to changes in the mean sea level because, apart from enhancing vulnerabilities to erosion and storm inundation, it alters tidal forcing and influences sedimentation by setting up flood-dominated tidal asymmetry (Dyer, 1995; Goodbred and Saito, 2012). From the seasonal-signal-removed data available at sealevel.colorado.edu, sea level rise in the Bay of Bengal can be estimated at $+3.30 \pm 0.13$ mm/year. These are somewhat lower than the value obtained from the raw data for the sea adjacent to the Sundarban: $+3.90 \pm 0.46$ mm/year (Tile 22°N/88°E, Data up to May 2016).

Trends of relative mean sea level (RMSL) changes are obtained from tide gauge records and reflect vertical land movements, if any, at the gauging points[16]. Data from three other stations obtained from

[16] The relative mean sea level (RMSL) values may provide an indication of land level changes at a deltaic locality and can be compared with rates of vertical accretion through sedimentation, since a 50-year dataset is considered more consistent for offsetting all local and short-term deviations like influences of El Niño / Southern Oscillation and tropical cyclones (Pirazzoli, 1996; Pugh, 2004). Among the six usable data from stations around the Sundarban, only the Sagar and Diamond Harbour record spans 48 years and 64 years, respectively (Table 3.5).

Sarwar (2013) and Pethick and Orford (2013) are also shown in Table 3.2. The table also incorporates land level rise values due to glacio-isostasy to indicate region-wide contribution of this factor to the RMSL trends.

Table 3.2: Trends of relative mean sea level from tidal observatories of the coastal GBD in the vicinity of the Sundarban

Station (with channel location)	**Period covered** [1,6,7]	**Available annual data** [1, 6, 7]	**Distance from sea** (km) [2]	**Estuary or channel width** (km) [2]	**Tidal range** (m) [3, 4]	**MSL change due to glacio-isostatic** (GI) **rise** (mm a^{-1}) [5]	**RMSL trends without adjusting for GI rise** (mm a^{-1}) [1, 6, 7]
Diamond Harbour (Hugli)	1948–2011 (64 a) [1]	62 a [1]	70.1	1.88	5.04 [3]	–0.35	+3.97 ± 0.34 [1]
Haldia (Hugli)	1971–2011 (41 a) [1]	38 a [1]	43.4	10.47	4.90 [3]	–0.34	+2.67 ± 0.49 [1]
Gangra (Hugli)	1974–2006 (33 a) [1]	27 a [1]	31.4	17.25	4.77 [3]	–0.33	+1.19 ± 0.76 [1]
Sagar (Hugli)	1937–1988 (48 a) [1]	48 a [1]	2.3	51.58	4.38 [3]	–0.30	–2.98 ± 0.93 [1]
Khepupara (Nilganj)	1979–2000 22 a) [1]	18 a [1]	25.6	0.31	3.73 [4]	–0.28	+19.15 ± 2.18 [1]
Hiron Point (Pussur)	1983–2003 21 a) [1]	21 a [1]	11.0	6.91	2.95 [4]	–0.28	+3.56 ± 2.13 [1]
Mongla (Pussur) [6]	1998–2010 (13 a) [6]	13 a [6]	90.5	1.02	3.97 [4]	—	+6.25 [6]
Amtali (Payra) [7]	1958–2002 (45 a) [7]	45 a [7]	44.2	1.81	—	—	+3.16 [7]
Rayenda (Baleswar) [7]	1969–2001 (33 a) [7]	31 a [7]	51.3	2.42	—	—	+3.64 [7]

Notes: **A**. The PSMSL data occasionally undergo correction, updating, and addition that affect the trends derived from them. **B**. The basic dataset is available in Revised Local Reference (RLR) datum, which is approximately 7 m below the mean sea level. **C**. RMSL data of Sagar and Khepupara are anomalous from the regional trends and may not represent actual conditions (see text for explanation).

Source: **1**. www.psmsl.org, retrieved on 2016-05-30; **2**. L8 OLI images of 2015; **3**. SoI (2015); **4**. BIWTA (2015); **5**. Glacio-isostatic rise values from Richard Peltier's VM-2 model: <http://www.psmsl.org/train_and_info/geo_signals/gia/peltier/drsl250.PSMSL.ICE5Gv1.3_VM2_L90_2012b.txt>; **6**. Data of Mongla from Orford and Pethick (2013), originally sourced from Mongla Port Authority; **7**. Data of Rayenda and Amtali from Sarwar (2013), originally sourced from Bangladesh Water Development Board

The records at Sagar show a falling mean sea level, which do not agree with the continuous coastal erosion documented around the tidal observatory for decades (Bandyopadhyay, 1997), denoting some problem with the gauge data. Khepupara (+19.15 mm/year), on the other hand, records an anomalously high rate of mean sea level rise, which suggests subsidence at this locality. The mean sea level trends at Amtali (+3.16 mm/year), Hiron Point (+3.56 mm/year), and Rayenda (3.64 mm/year) are similar to regional secular sea level trends obtained from satellite altimetry (+3.33.9 mm/year). This indicates some stability at these sites and is not inconsistent with the millennium scale RMSL change of +1–4 mm/year, estimated for the eastern Sundarban through core analysis (Allison and Kepple, 2001).

RMSL trends from Gangra through Haldia and Diamond Harbour show a progressive landward increase along the Hugli estuary (Fig. 3.5). This may be accounted for by the fact that the increasingly smaller cross-sectional area of the north in the flood-dominated Hugli (Column 5 of Table 3.5) is filling-up at a faster rate than its southern sections, causing mean tidal levels to rise at a progressively higher rate in

the landward direction (Nandy and Bandyopadhyay, 2010). Similar observation is also made along the Pussur, between the seaface-located Hiron Point (+3.56 mm/year) and the interior Mongla (+6.25 mm/year). The Mongla data, however, spans only for 13 years and may not be very reliable.

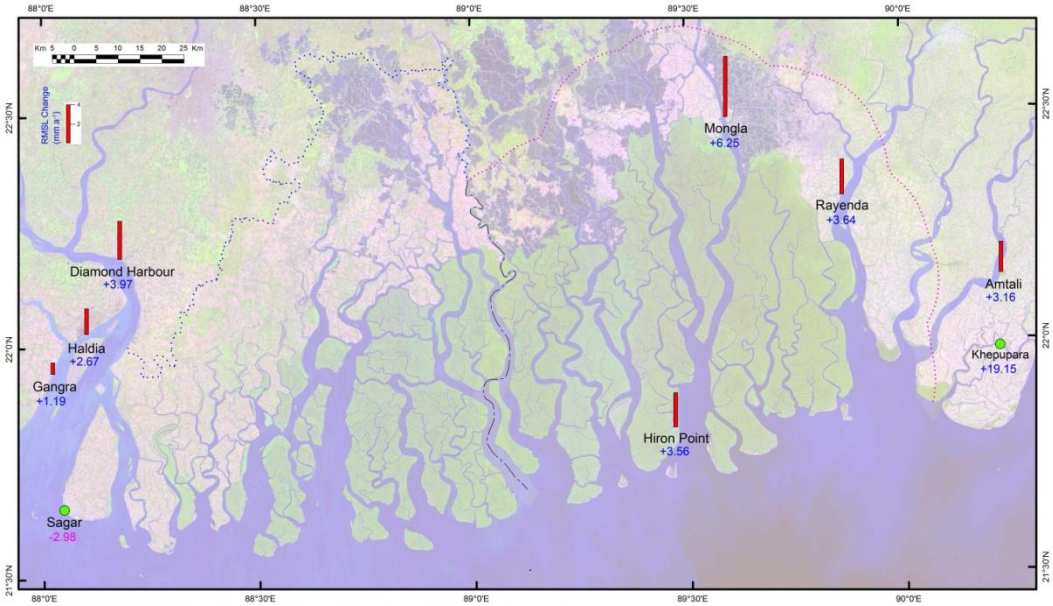


Figure 3.5: Available RMSL trends (in mm/year) in the coastal Ganga–Brahmaputra delta at or close to the Sundarban region. Blue and magenta dotted lines denote the limits of the Sundarban Biosphere Reserve in India and Sundarban Impact Zone in Bangladesh, respectively; black line is the international boundary. *Source*: see Table 3.2

3.1.5 Coastal changes

Sherwill (1858) was probably the first worker to deal with the progradation of the Ganga-Brahmaputra delta. Estimating the sediment discharge rate of the Ganga–Brahmaputra as 1,133 $\times$ 10^6 m^3/year, he speculated that at this rate the delta should have advanced many kilometres into the sea. Many studies and estimates of coastal change related to the Sundarban, mostly by super imposing maps from 1842[17] to recent satellite images, have clearly brought out the eroding nature of the Sundarban and shown that during the last 100 years little or no seaward extension of the coast has taken place (Reaks 1919, Chakrabarti, 1995; Bandyopadhyay and Bandyopadhyay, 1996; Allison, 1998; Hazra *et al.*, 2002; Bandyopadhyay *et al.*, 2004; Ganguly *et al.*, 2006; Rahman *et al.*, 2011; Rahman, 2012; Sarwar and Woodroffe, 2013; Raha *et al.*, 2014; Chakrabarti and Nag, 2015; Ghosh *et al.*, 2015). None of these works, however, cover the entire Sundarban region beyond a few kilometres north of the seaface and

[17] Rennell's 1779 map of the Bengal was the first map to show Sundarban delta. Because of planimetric inaccuracies, reliable georeferencing is not possible and their value lies mainly in qualitative assessment. R. Lloyd's 1842 *Sea Face of the Soondurbans* (1:253,440, 4 miles to an inch) . Later came the 1:253,440 maps of the *Atlas of India* series by the Survey of India (SoI) in c. 1860. The standard 1:63,360 (one inch to a mile) 15'×15' topographical maps representing Sundarban were started to be surveyed from 1901. For the Indian part of the Sundarban, the 1:63,360 topomaps were replaced by the 1:50,000 (2 cm to a km) series, surveyed during 1967–1969. From this time onward, satellite images including the 1967 Corona space-photos were available.

mostly have either been confined either to the west (Indian) or to the east (Bangladeshi) of the Raimangal–Hariabhanga.

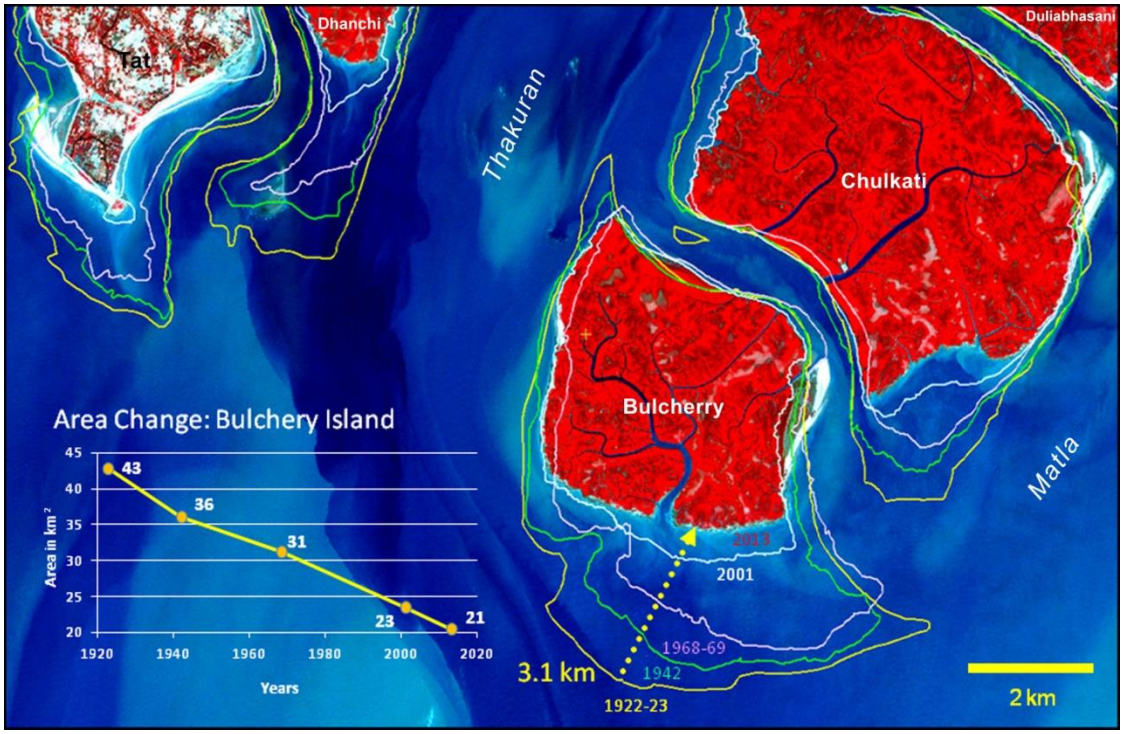


Figure 3.6: Coastal retreat in the Sundarban is highest between the Saptamukhi and the Hariabhanga estuaries. Here the Bulchery island is represented to show relentlessness of the erosion through different years. Like other sea-facing islands of the area, its area reduced by 50% within the last 100 years and is likely to get obliterated within the next 100 a or so. *Source*: 1922-23 & 1942: SoI 'inch' topomaps #76C/06 on 1:63,336 (two editions); 1968-69: SoI 'metric' topomap #76C/06 on 1:50,000; 2001: IRS-1D LISS-3+Pan 5.6-m data of January 2001; 2013 (base image): IRS-R2 LISS-4fx 5.6-m data of 23 Feb 2013

If the drainage and high water lines of SoI's 1901–23 'inch' maps of the Sundarban are overlaid on recent satellite images (Fig. 3.7), five things become apparent:

- ◊ In continuation of the trend brought out by Reaks (1919), nearly the entire southern face of the region is retreating, irrespective of forested or reclaimed portions. Rate of erosion is maximum at the west-central section between the Saptamukhi and the Gosaba estuaries (Fig. 3.13), reaching up to 40 m/year, and gradually reduce west- and eastward, almost to reach zero on the west bank of the Baleswar .
- ◊ A number of interior creeks and estuaries are getting silted, mostly (partly) in the western (northern) section.
- ◊ Outside this region, banks of most major estuaries are eroding; the situation is somewhat mixed for the smaller creeks of the forested islands.

- ◊ Fairly large sections of the western Sundarban became reclaimed in 24 Parganas. On the island level, the progressive and irreversible transformation of intra-island creeks into stagnant water bodies; their degeneration and integration into the farmlands are some of the notable post-reclamation changes that took place within an approximate span of 50 years (Fig. 3.8).

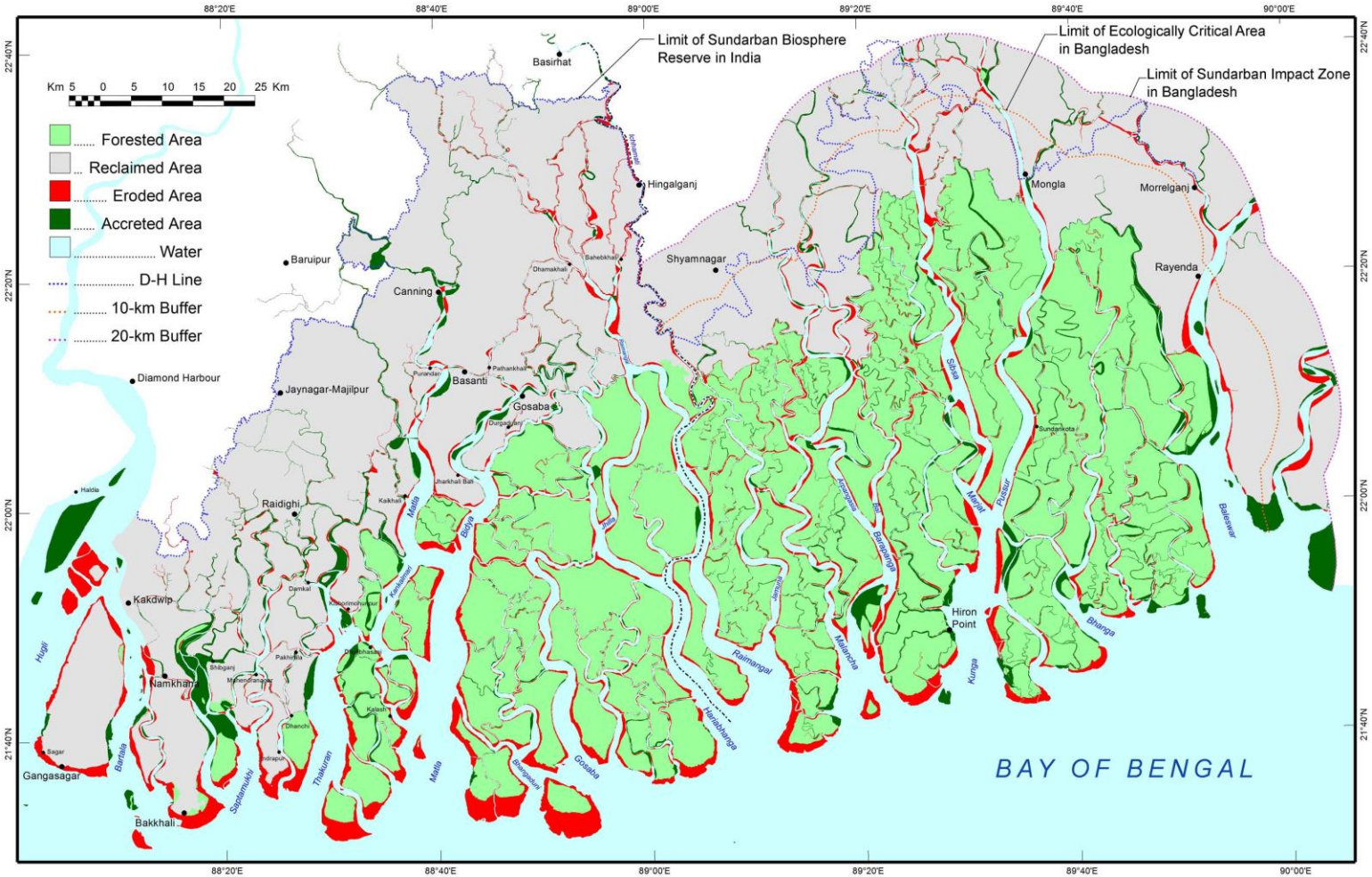


Figure 3.7: Composite map of the Sundarban. 1829-30 extent of the mangrove wetlands is indicated by the Dampier–Hodges (D–H) Line that is still regarded as the northern limit of the Sundarban region in India. In Bangladesh, Sundarban refers to the forests only, with its impact area demarcated by two buffers. Comparison between 1901–23 topographical maps and 2013–15 satellite images brings out the extent of erosion along nearly the entire seaface of the delta and accretion in the interior parts, mainly in the west. Tide stations referred to in Fig. 3.10 are also shown in the map, as are selected populated places. *Source*: coastline and channel banks extracted from 37 mosaiced Survey of India 1:63,360 topographical maps of 1901–23, belonging to 79B, C, F & G series; Landsat 8 OLI 15-m panfused data of 17 Mar 2015 & 8 Mar 2015 (for Bangladesh part); IRS-R2 LISS-4fx 5.6-m data of 23 Feb 2013 & 1 Jan 2014 (for India part). D–H Line extracted from 1:253,440 *Atlas of India* Map #121 & 122 of c. 18

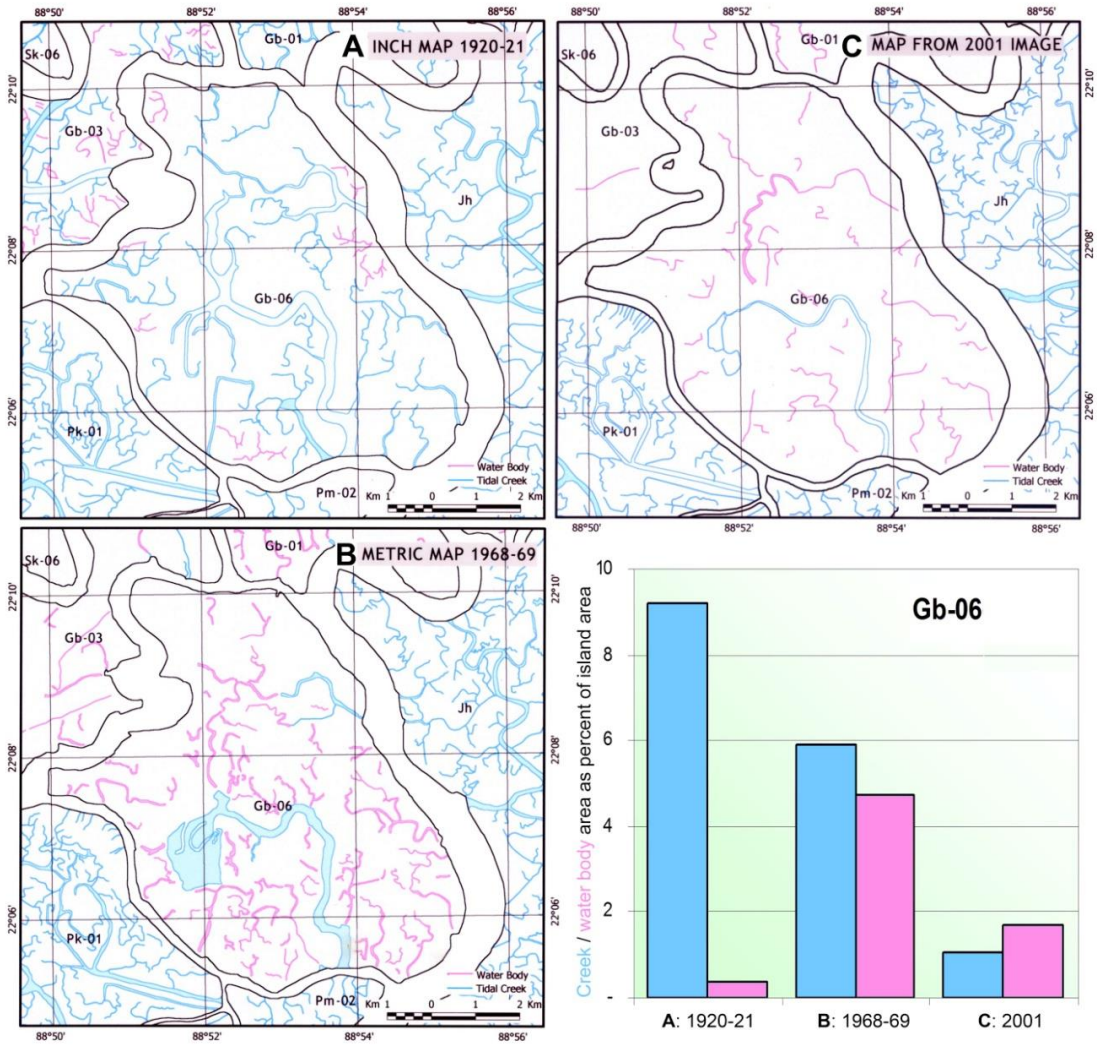


Figure 3.8: Transformation of tidal creeks into water bodies in Satjaliya island (coded Gb-06) of Gosaba block of western Sundarban from 1920-21 (A) through 1968-69 (C) and 2001 (D). The changes are compared in the bottom left diagram. In 1920-21, when the island was under forests, there were hardly any water bodies in the island. During its subsequent reclamation, a number of tidal creeks were blocked at their entrances and a marginal embankment was constructed all around the island and along the major channels. This transformed the free-flowing water courses to stagnant water bodies. With time, these water bodies were subjected to eutrophication and/or land-filling for expansion of farmlands or for habitational use. In contrast, none of the creeks in the adjacent non-reclaimed areas lost their original density. *Source*: (A) SoI 'inch' Map # 79B/16 on 1:63,360; (B) SoI 'metric' Map # 79B/16 on 1:50,000; (C) IRS-1D LISS-L3+Pan data of January 2001

3.1.5.3 Causes of change

Stability of deltaic coastlines is often a function of the accretional fluvial inputs and the erosional wave and tidal forcings. As the Sundarban forms a part of the fluvially abandoned western Ganga-Brahmaputra delta (Fig. 3.1), its sediment supply must come from the tidal sources to render it any long term stability against the sea rise. The average annual sediment input of the Meghna estuary is estimated at 10^9 t (Milliman and Syvitski, 1992), 95% of which is pulsed during the monsoon season (Goodbred, 2003). As this sediment moves west during the high energy conditions between May and

September, a part of it gets intercepted by the Swatch of No Ground submarine canyon and escapes southward into the deep sea Bengal fan (Kuehl *et al.*, 1989, 1997, 2005). The continuous erosion of the southern Sundarban for the last 200 years, increasingly more towards the west (Reaks, 1919; Fig. 3.7, 3.9), points to the absence of sediment replenishment at the exterior delta and along the channel banks that take the maximum brunt of monsoon waves and tropical storms.

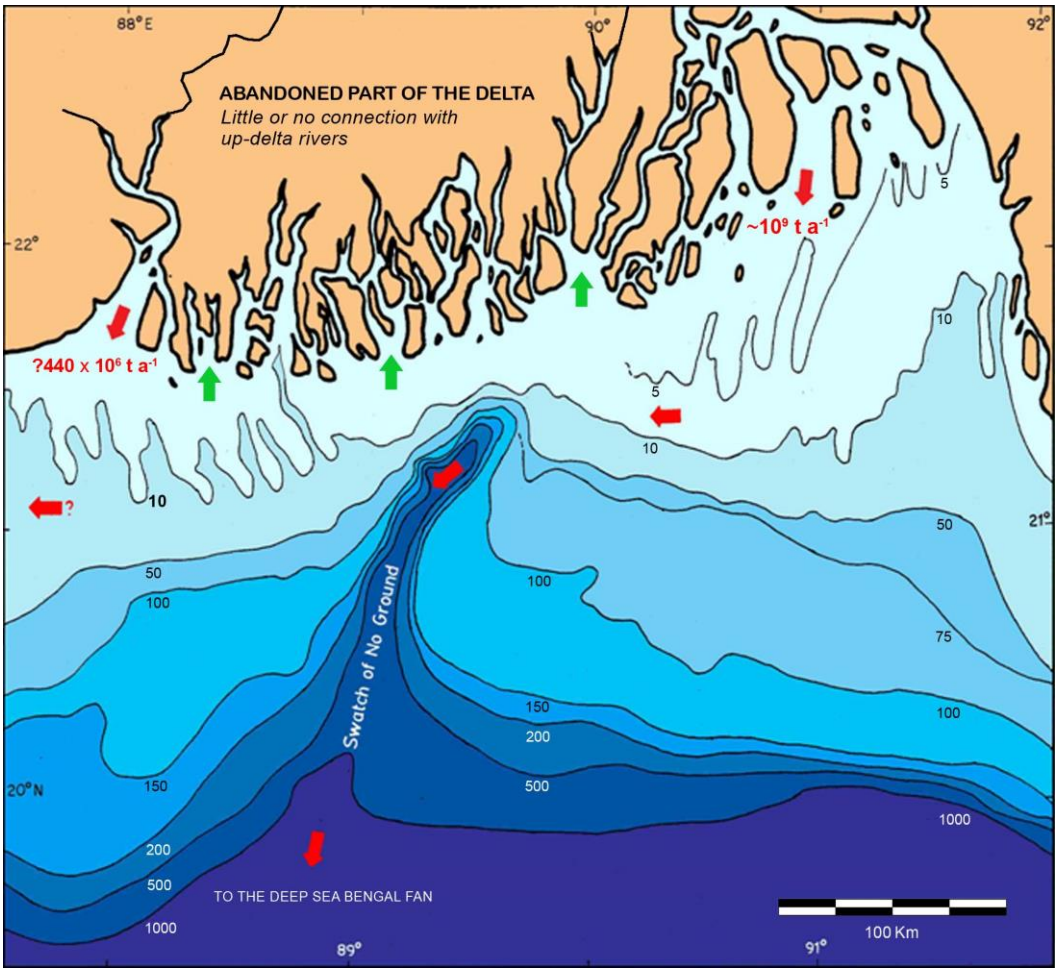


Figure. 3.9: Position of the Swatch of No Ground canyon in the continental shelf of the GBD. The swatch bisects the shelf region into two and acts as a conduit for interception and transportation of the Meghna sediments into the deep sea Bengal fan (red arrows). This may have augmented the lateral erosion of the coastline in the fluvially abandoned Sundarban region. It seems that most of the sediments brought by the Hugli also do not find their way into the delta. However, interior parts of the Sundarban are getting vertically accreted by tidal reworking of sediments (green arrows). *Source*: isobaths from National Hydrographic Office chart No. 31

In the west, the sediment input of the Hugli is variously estimated as 0.616×10^9 tonnes/year (Sengupta *et al.*, 1989) and $0.473–0.481 \times 10^9$ tonnes/year (Bandyopadhyay and Bandyopadhyay, 1996). This means that the sediment contribution of the Hugli, although considerably smaller than the Meghna, is not insignificant. However, in contrast to the prograding eastern delta (Sarwar and Woodroffe, 2013), the century-scale retreat of the western delta coastline indicates that the Hugli sediments do not replenish its erosion and probably escape westward following the regional trend. In addition to this, the tidal range of the western Sundarban (Sagar: 4.38 m), which is 1.4 m higher than its eastern sectors

(Hiron Point: 2.95 m) also aid the process. The existence of prominent tidal channels off the western Sundarban is indicated by the 10-m isobaths in Fig. 3.9.

Conversely, in the interior part of the delta away from the tidal channels, radioisotope geochronology and direct measurements in 2008 indicated that the island tops of the Khulna mangroves are actively accreting by tidal inundation, at a mean rate of 10 ± 9 tonnes/year (Rogers *et al.*, 2013). The rate of deposition was seen to be less inland, implying tidal sources. These values appear to be adequate for coping with the current rates of sea level rise (Section 3.4.4), but not sufficient to prevent *lateral* erosion seen in the seaface and along the edges of many tidal channels (Fig. 3.9). Most of the sediments that sustain the high rate of vertical accretion are sourced from the annual monsoon pulse apart from older sediments, reworked from the creeks and the shelf. It is estimated that the Sundarban acts as a significant sink for the Ganga–Brahmaputra sediments, storing 8–10% of its annual discharge (Table 3.3) (Rogers *et al.*, 2013).

Table 3.3: Sediment budget of the Sundarban forests (source: Rogers *et al.*, 2013)

Province	**Surface area** (km^2)	**Storage** (10^6 t a^{-1})	**Percent of total sediment discharge of the Ganga and the Brahmaputra** [1]
Bangladesh	4,800	62.4	6.2
India	3,000	13–32	1.3–3.2
Total	8,000	77.4–96.4	8–10

Note: **1**. Total Ganga–Brahmaputra sediment discharge is estimated as 10^9 t a^{-1} by Milliman and Syvitski (1992).

Northward increasing flood-dominance of tidal currents is common in most areas of Sundarban (Fig. 3.10). It has been argued that the siltation of the interior estuaries, especially in the western Sundarban, might be a response to reduction in tidal spill due to reclamation (Bandyopadhyay, 1997; Nandy and Bandyopadhyay, 2010). Construction of marginal embankments increases channel depth and accentuates flood dominance of tidal current to induce sedimentation as the channel tries to restore its equilibrium (Pethick 1994).

3.1.5.4 Consequences of reclamation

Effective Sea Level Rise: Using monthly averages of tide-gauge data of Hiron Point (22 a), Mongla (13 a), and Khulna (32 a), Pethick and Orford (2013) showed that, owing to the tidal range that amplified landward and over the years, the mean high water level (MHWL) along the Pussur rose at a much higher rate than the RMSL. Extensive polder formation in the 1960s reduced the tidal prism of Pussur by 109 m3, cutting discharge of the channel by half. This made the landward constricting channel oversized, and decreased the frictional damping of tidal waves. Dredging operations for navigability aggravated the situation even more, inducing tide range amplification (Pethick and Orford, 2013). The very high rate of sea level rise would have a major concern for future flooding of the region.

Export-oriented shrimp farming received major impetus from the mid-1980s in Bangladesh (Hossain *et al.*, 2013). About 500 km^2 of reclaimed region located in the former spill area of the Pussur are converted into aquaculture farms during the last few decades and receive a large amount of discharge from the river for their maintenance. Citing example from northern reaches of the Bhagna (upper Raimangal) in western Sundarban, Bhattacharyya *et al.* (2013) stated that proliferation of shrimp farms led to an increase in tidal discharge and accelerated erosion of the embankments placed along the channel.

Reduction in tidal accretion: Prevention of tidal inundation in a permanently reclaimed region stops the natural process of delta building and keeps the area lower than the highest high water and storm surge levels. The region remains and forever prone to hazards like saltwater ingression and flooding due to breaching or overtopping of the embankments. Large-scale polder construction in the 1960s permanently arrested tidal inundation in much of the south west region of Bangladesh. Recently, Auerbach *et al.* (2015) showed that this resulted in a loss of 1–1.5 m of elevation inside the polders compared to neighbouring mangroves which continued to receive sediments through tidal inundation. Removal of forest biomass, ground compaction and ESLR also contributed to the difference. This translates into an elevation loss of 20–30 mm a^{-1} during the last 50 a inside the reclaimed region, greatly increasing its vulnerability to ESLR and storm surges. Dykes of some of these polders were breached by the tropical storm Aila in 2009 and opened them to tidal spill for up to two years before complete repairs were made. In Polder #32, located on the eastern bank of Sibsa adjacent to the mangroves, an average accretion rate of 180 mm a^{-1} was achieved during this period (Auerbach *et al.*, 2015). In Sundarban Biosphere Reserve, tidal sedimentation is used ingeniously by some 42 brick kilns that operate along the banks of the Hugli and the Ichhamati (upper Raimangal). Basins adjacent to the channels are kept open to tidal spills all through the monsoons. They are drained in the post monsoon season and the sediments, deposited at 50100 mm/ year, are utilised for brick making.

3.2. The Sundarban Waterscape

Around 40% of the Sundarban mangrove forest is covered by water, making it the largest mangrove wetlands of the world (CEGIS, 2016). Most importantly, the ecosystems and the landscape of this mangrove forest is shaped by the rivers, creeks and canals and given the hydrological setting, any alterations on water and water resources will critically affect all aspects of the ecosystem, lives and livelihoods and the overall growth and development of Sundarban. In general, waterscape refers to a landscape in which an expanse of water is the dominant feature. The idea of narrating the waterscape of the Sundarban in this section focuses on recognizing its river system, hydrology, water quality, mainly salinity, and land cover and how the Sundarban is greatly dependent upon its waterscape. Already, upstream water withdrawals have led to reduced freshwater flows and embankments have caused increased instream sediment deposits thereby reducing the carrying capacity of the river system. Coupled with sea level rise, this has resulted in increased levels of salinity, particularly during the dry season (low flow period) affecting biodiversity (Islam and Gnauck, 2009; Brij Gopal, 2006). Salinity increase has affected the species combination and regular succession patterns in the Sundarban as some non-woody shrubs and bushes are replacing the tree species, reducing the forest productivity and habitat quality for valuable wildlife. Thus, managing the water resources system is equally important for sustainable management of the unique mangrove ecosystem.

3.2.1. The River System

The Sundarban, lying in the delta of the mighty Ganges, Brahmaputra and Meghna, is crisscrossed by a complex network of interconnected rivers and streams of varying hydrological and morphological characteristics. These rivers, providing lifeline to the ecosystem of this vast mangrove forest, stems primarily from the Ganga/Ganges river system (Siddiqi, 2001). The numerous rivers traversing in a dendritic fashion through the entirety of the south west region and through the Sundarban, ultimately fall into the Bay of Bengal, forming the distributary system of the Ganga/Ganges. All the rivers have low flow from February to April (dry season). On the other high flow occurs in July to September (monsoon season). Understanding the origin and flow path of these rivers thus mandate importance in order to fully comprehend the waterscape of the Sundarban. Rivers exerting substantial influence on the ecosystem of the Sundarbans can be identified spatially from the western side in India to the eastern side in Bangladesh, from the Hoogly, Muriganga, through to the Madhumati and the Baleshwar. Table 3.4 culminates the major river system of the Sundarbans.

Table 3.4: Major river system of the Sundarban

Rivers of Sundarbans	
Western (Indian) Side	**Eastern (Bangladesh) Side**
1. Hoogly	1. Mathabhanga
2. Muriganga	2. Gorai
3. Shaptamukhi	3. Bhairab
4. Bidyadhari	4. Madhumati

Rivers of Sundarbans	
Western (Indian) Side	**Eastern (Bangladesh) Side**
5. Thakuran 6. Matla 7. Gosaba 8. Harinbhanga	5. Kapotaksha 6. Raimangal 7. Arpangaisa 8. Sibsa 9. Passur 10. Baleshwar

Hoogly, the main river of West Bengal, forms the western border of the Sundarbans. Though it gets a continuous flow from the river Ganga/Ganges, it does not contribute much to feed the Sundarbans as very small quantity of Hoogly's water passes through its system directly. The river Damodar flowing from Barddhaman is one of the important tributaries of the Hoogly river. The Churi River near Naida and the Ichamati-Kalindi River near the Northern 24 Parganas stem from the Bhagirathi and the Jalangi Rivers which are the distributaries of the Ganges in the Indian side. These rivers used to provide flow to the southern rivers in the Indian side of the Sundarbans. But over time, due to numerous reasons these flows subsided substantially.

Muriganga is a distributary of Hoogly River. Sagar, the largest island in the deltaic complex is separated by Muriganga from the main Sundarbans which flow along its eastern banks and carry a substantial amount of inflow along the western boundary of the Sundarbans. But like the Hoogly, this inflow also does not make much impact into conserving Sundarbans's ecosystem.

The Saptamukhi River has lost its upstream connection with the Ganges during the 1200s and is presently connected with the Muriganga branch of Hoogly River (Ghosh, 2012). The Thakuran River which begins near Jayanagar in South 24 Parganas similarly lost its link with the upstream during the same period as that of Shaptamukhi and has a number of links to the Saptamukhi (Morgan and Mcintire, 1959).

The river Matla which originates at the confluence of the Bidyadhari, Khuratya River and the Rampur khal near the Canning town in south 24 Parganas ultimately flows through the Sundarbans (Ghosh, 2012). The freshwater discharge to this river from the upstream river Bhagirathi has been lost in recent times due to constant heavy siltation along with solid waste disposal from the nearby urban areas. The Bidyadhari was a thriving branch of Bhagirathi river during the 1500s to the 1600s, but now serves only as a sewage and excess rainwater outlet for the city of Kolkata (Ghosh, 2012). The river bed of Bidyadhari is completely silted up and its condition has deteriorated to such an extent that it is presently considered as a dying river. Up till 1830, the East Kolkata Wetland was a backwater swamp and spill area of the river Bidyadhari (Bhattacharya et al. 2012). But with the expansion of Kolkata along with its increasing demands for drainage and waste disposal has also led to rapid silting and reclamation of the East Kolkata Wetlands over the years thus affecting the river Bidyadhari.

The inflow from Matla forms the Gosaba Riverwhich flows through numerous creeks and canals into the Sundarbans. This system and its numerous creeks flow through the mangrove forests. The Harinbhanga is the easternmost river in the Indian Sundarbans deltaic complex which forms a natural boundary between India and Bangladesh. Harinbhanga is also known locally as the Raimangal and in some places, the Ichamati.

The four major estuary systems encompassing the Bangladesh portion of the Sundarbans are the Raimangal, Arpangasia, Passur and the Baleswar. Arpangasia off-takes from Kapotaksha River in South Bedkashi union of Kayra upazila of Khulna district and it falls into the Bay of Bengal through Naliyan Range union of the same upazila. Raimangal river flows around the Sundarbans in North 24 Parganas district in the Indian state of West Bengal and later through Satkhira District in Bangladesh. The Ichamati breaks up into several distributaries below Hingalganj the chief of which are the Raimangal, Bidya, Jhilla, Kalindi and Jamuna. Pashur is situated at Khulna and Bagerhat which offtakes from Kajibacha river and falls into the Bay of Bengal. A large part of this river flows through the Sundarbans and has joined the river Shibsa before falling into Bay of Bengal. The Baleshwar forms along the eastern border of Bagerhat District and the western border of Barguna District. Off-taking from Kalinganga River of Pirojpur the Baleshwar River flows south into the Haringhata River, which flows into the Bay of Bengal.

Figure 3.10: Major River Systems connected to the Sundarbans

From the western part of the India-Bangladesh boundary, there exists Kapotaksha and Mathabhanga Rivers which originates from the Ganges. These Rivers have lost their connection with the Ganges during

the 1800s due to siltation. As a result both these rivers contribute very little quantity of freshwater to the Sundarbans during the dry season (Islam & Gnauck, 2009). Contribution of flow from the Kapotaksha-Sibsa system, flowing though the Sundarbans contributes zero freshwater flow at present time into the mangrove forest.

Apart from Sibsa, the other tidal river systems which dominate the flow of the southern part of the Sundarbans are Passur and Baleswar, where both are part of the Gorai-Modhumati river system. The central Gorai subsystem is maintaining weak connection with the Ganges and carries significant amount of freshwater during the dry season to the Sundarbans. The distribution of the Gorai River flows through the Madhumati and Nabaganga rivers at Bardia. Garai-Madhumati is the major spill river of the Ganges and carries about 12% of flow of the Ganges (Hussain and Acharya, 1994).

Since the late 1900s, the upstream part of the Madhumati River has been declining while the Nabaganga River has been gradually taking its place (EGIS, 2001). In the easternmost side of the Sundarbans, the Baleshwar river system carry large amount of freshwater from Nabaganga during the dry season. Chandana-Barasia river is an offshoot of the Padma river. In the past this river was connected with Gorai and Kumar thus providing flow from Padma through Kumar to the river Madhumati. But this river has lost connection with Gorai and Kumar shifting of river course and various flood-proofing structures.
Passur River of the Sundarbans is connected with the Garai-Madhumati system as well through the river Nabaganga and flows through the middle part of the Mangrove forest thus supplying considerable amount of freshwater into the Sundarbans ecosystem.

Other noteworthy rivers along which ecological niches of the Sundarbans occur mainly are Malancha, Arpangsia and Selagang. These rivers to a lesser extent have indirect connections with the Ganges and receive its overflow during the monsoon.

Impact of Human Intervention on the Major River system

Over the years, the intricate web of rivers fuelling life through this vast mangrove eco-system has substantially reduced as these rivers got disconnected due to upstream interferences in both Bangladesh and India. These interventions in the upstream regions hinder flows, as a result the rivers have either dried up or have reduced flows thus affecting the freshwater flow of the Sundarbans. The Farakka barrage can be singled out as the earliest most devastating blow upon the river flow in Sundarbans as it substantially reduced the seasonal water gain for the Gorai system. Other major human interventions include embankments, barrages and dams in India and the polders and irrigation in Bangladesh. A number of embankments have been constructed during the colonial period and later in the 1900s in western side of the of Sundarban to protect the area from the flooding, salinity intrusion, and prevent land erosion. Four different types of earthen embankments are commonly found in this part; such as a) 2m high earthen embankments bordering small channels, b) 2.7 m high earthen wall with brick pitching on island margins, c) 3m high embankment with brick pitching on wave exposed

coasts, d) 3.67m high wall with boulder pitching on eroding stretches. The total length of the Embankments in the Indian Sundarban has been found to be 3,638 kilometers (Hazra, et.al, 2010).

In Bangladesh, starting from the eastern side of the country boundary, more than 129 polders have been constructed in the upstream areas of the Sundarban, encompassing 13,000 square kilometres of land, or about 44% of the total land area in the south-western region of Bangladesh (EGIS, 2001). These were constructed in the late 1960s to protect the land from saline water and to increase the crop production, ultimately reducing tidal flows of the rivers. The impact of these polders and embankments on the Sundarbans is also evident in the silting up of the rivers which were once the perennial source of freshwater. The impacts of upstream infrastructure on the Sundarban can be summarized as follows:

- Polders in the south-western region of Bangladesh reduce the tidal prism just north of the reserve forest, which subsequently encourages sedimentation in the river bed.
- The so-called tidal pumping process in the polders brings the sediment to the channels to deposition prone areas.
- Polders thus cause large-scale drainage congestions in the tidal plains, along the northern periphery of the Sundarbans.
- The dams and barrage have resulted in the reduction of fresh water inflows during dry season and also impacted sedimentation process and increased salinity in the rivers especially in the dry season. The salinity limit has moved inland and the duration of high salinity period has also increased.

Interventions outside of Sundarban

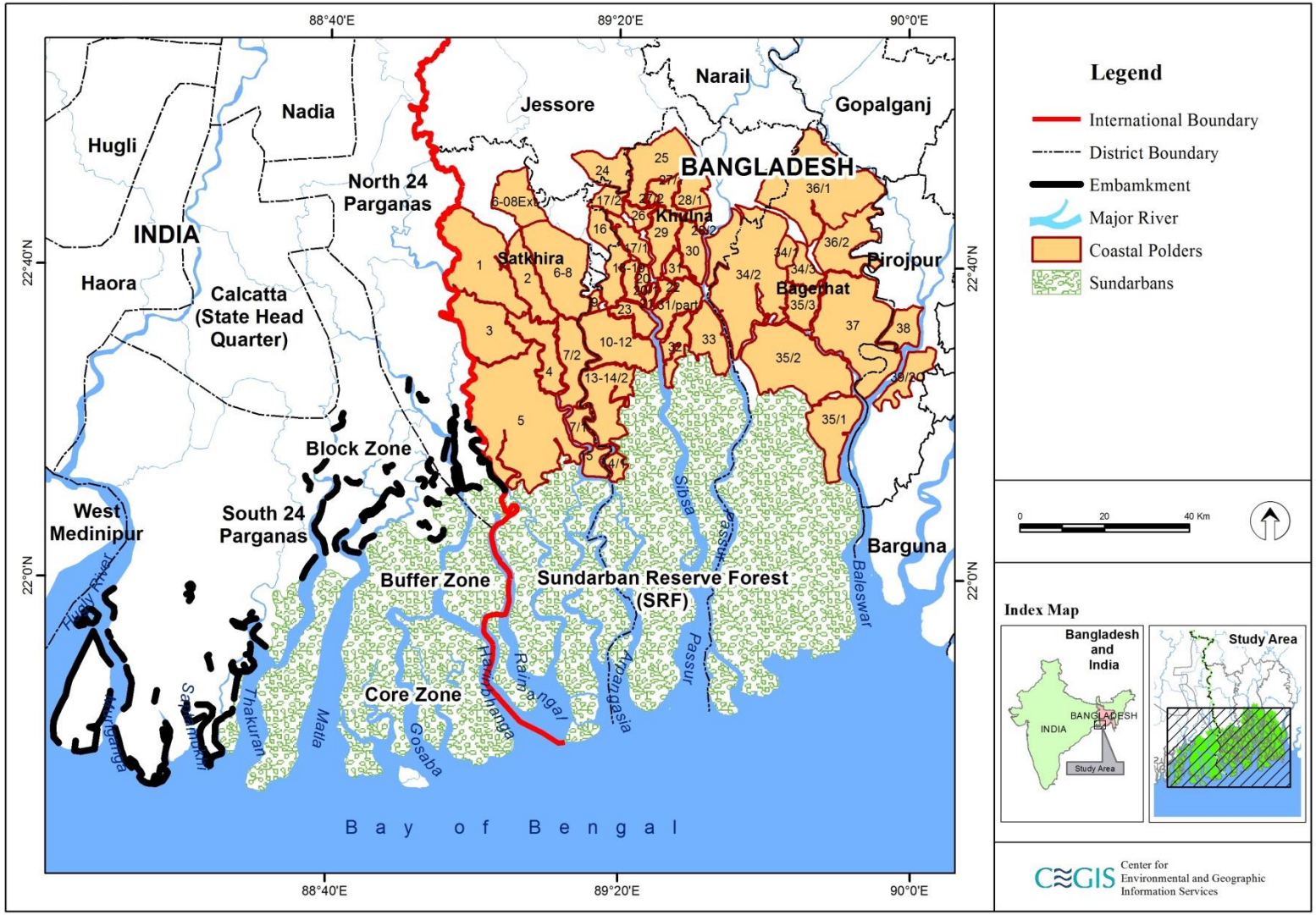


Figure 3.11: Embankments and Polders in the Sundarban

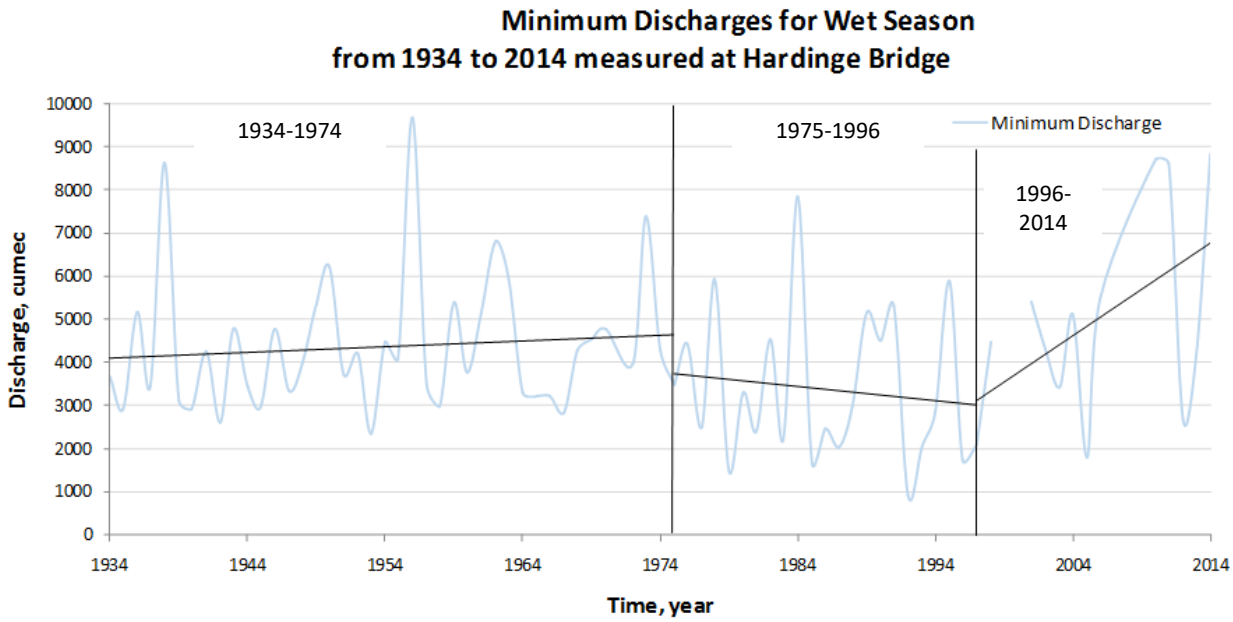
3.2.2. Hydrology of the Sundarban

The mighty Ganges-Brahmaputra-Meghna system, is particularly vulnerable to rising sea levels, extreme storms, and altered freshwater regimes due to climate change and human activities, the Sundarban mangrove forest bearing the brunt of all three. As mentioned previously, the sources of fresh water in the Sundarban are the upstream rivers which receive annual supply from rainfall in the vast upstream catchment, generating the Ganga flow. Annual rainfall in the Sundarban is in the range of 1640-2000 mm, rainfall increases eastward. Most rainfall occurs during the monsoon from May to October. Frequent and heavy showers occur from mid-June to mid-September.

The Ganga is one of the most important basins in South Asia. The area of the total basin is 1,087,300 square kilometres (Islam & Gnauck, 2008). Although rainfall in this huge catchment area is the prime contributor to riverine flow, melting snows from the Himalayas also contributes substantially to the perennial discharge. In 1975 the operation of the Farakka barrage started on the Ganga and has affected its perennial flow by diverting a maximum flow of 1,133 cumec water through a feeder canal into the Bhagirathi-Hoogly River (Banerjee, 1999). The river Hoogly in the extreme west is the only river carrying freshwater from upstream of lower Gangetic delta in the Indian Sundarban. Due to upstream diversion and narrowing of the distributaries of the Bhagirathi - Hoogly in the Sundarban, presently freshwater discharge in these rivers of Sundarban are negligible or mostly absent except during monsoon months when downpour in the southern parts of Sundarban occur.

In 1996 the Ganges water sharing treaty was signed which ultimately resulted in increased freshwater flow into the eastern part of the Sundarban. The historical analysis of the hydrological regime can consequently be divided into three periods: the pre-Farakka, post-Farakka/ pre-Ganges Treaty and the post-Ganges Treaty periods. The general pattern of water availability falls after operational capacity of the Farakka began and this continued until 1996 when the treaty was signed, after which there appeared a rising trend in upstream flow availability.

The discharge at Hardinge bridge point of the Ganges from 1934 to 2014 reflects the chronology of the events mentioned earlier. Figure 3.12 (a) and (b) represents the minimum discharge at the Ganges in the periods of 1934-1974, 1975-1996 and 1997-2014 for the wet and dry season respectively. Both the wet and dry season during 1934-1974 period flow showed an increasing trend, during 1975-1996 period showed a decreasing trend and during 1997-2014 period again showed an increasing trend. The average minimum discharge for the wet season being 4381, 3433, 5016 cumec and 1997,865, 1004 cumec during the dry season for the aforementioned periods respectively. As mentioned earlier, Mathabhanga and Gorai being the major tributaries of the Ganges, their freshwater flow to the contributing rivers to the Sundarbans is also influenced by the events concerning the construction of the Farakka barrage.



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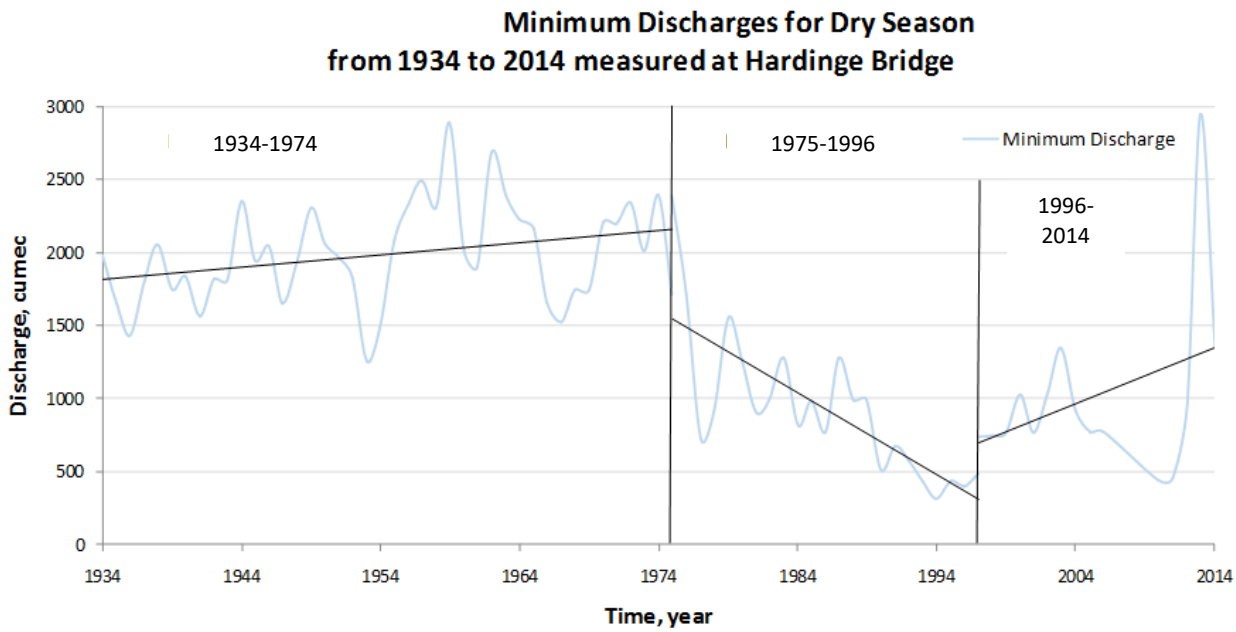
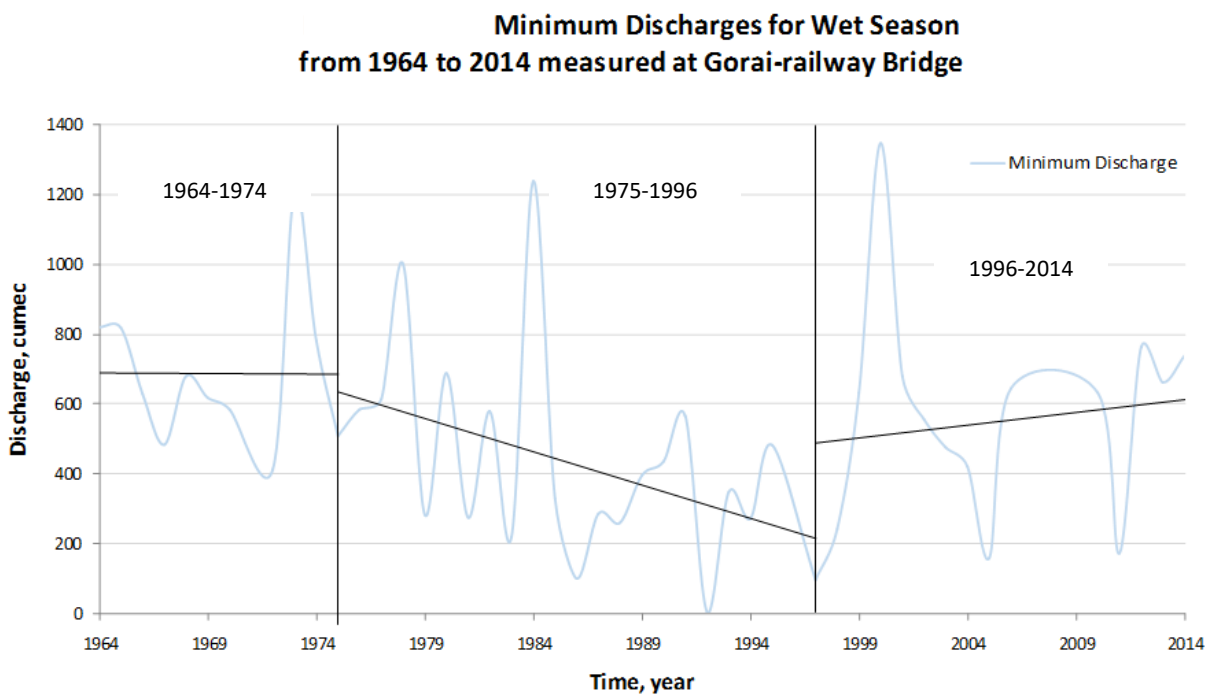


(b)

Figure 3.12: Variation of Discharges from 1934 to 2014 at Hardinge Bridge of the Ganges for Wet and Dry season (*source: National Water Resources Database (NWRD)*)



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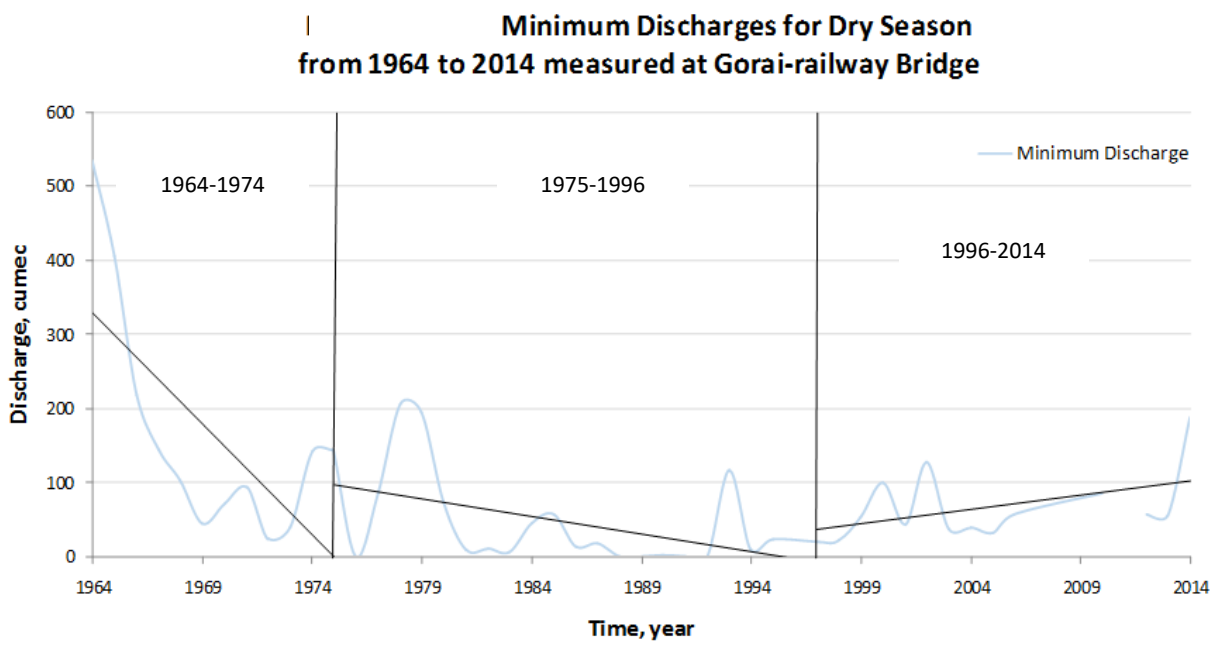


(b)

Figure 3.13: Variation of Discharges from 1964 to 2014 at Gorai-Railway Bridge of the Gorai river for Wet and Dry season (*source: National Water Resources Database (NWRD)*)

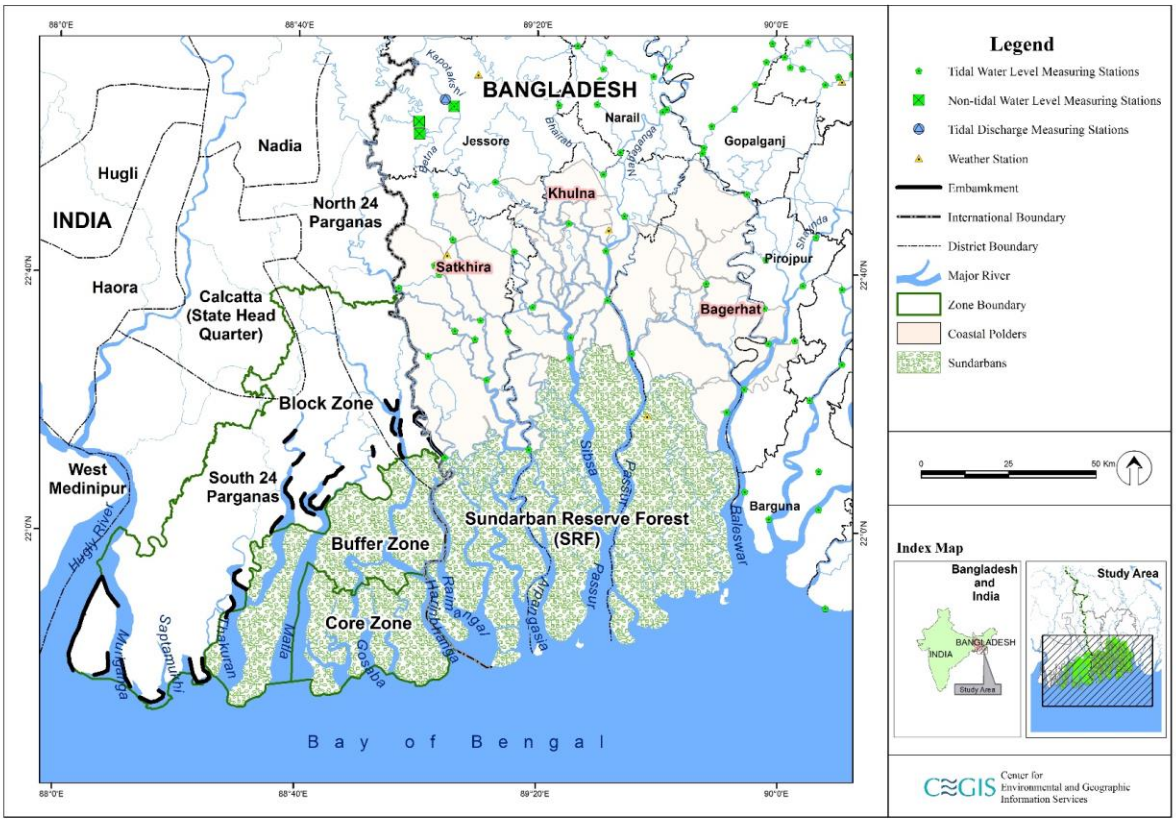


Figure 3.14: Hydrological stations of River systems in Sundarban (*source: National Water Resources Database (NWRD)*)

The variation of discharge for the Gorai-railway Bridge point interestingly, shows somewhat differing patterns for both wet and dry seasons for the three periods as can be seen from **Figure 3.13 (a) and (b)**. Although, the average minimum discharge for the wet and dry season for the periods of 1934-1974, 1975-1996 and 1997-2014. Figure 1.2 (b) shows a drastic reduction in Gorai flow, further aggravated in the post-Farakka operation period. This can be attributed to the decrease in Ganges inflow to the Gorai as well as the aftermath of tectonic activity in the greater region.

The lower part of Gorai is called Madhumati and carries fresh water to the Baleswar River. Besides these, the Sibsa, Kopotakha and Kholpetua Rivers also carries significant quantities of freshwater into the Sundarban. The Kholpetua and Kopotakha River receive fresh water mainly from the surface runoff and the polder areas in addition to a proportion of the Gorai inflow. Another river along the same system situated in the north which historically had significant influence over the fresh water flow towards the Sundarban is the Mathabhanga River but currently contributes little to no flow of freshwater to the Sundarbans.

Table 3.4: Comparison of discharge of the two major river systems contributing flow to the Bangladesh Sundarbans

River System	River Name	Season	Period		
			1966-1974	1975-1996	1997-2014
Mathabhanga-Kapotaksha-Sibsa System	Mathabhanga	*Wet*	16.6	20.3	25.0
		Dry	11.7	9.9	14.5
	Kapotaksha	*Wet*	5.2	2.8	4.7
		Dry	3.4	2.6	3.8
	Sibsa	*Wet*	-	110.6	107.6
		Dry	-	5.5	4.9
Gorai-Modhumati-Passur System	Gorai	*Wet*	1997	865	889
		Dry	704	451	525
	Madhumati	*Wet*	522.0	467.1	-
		Dry	144.7	91.8	-
	Passur	*Wet*	-	295.8	263.6
		Dry	-	11.4	10.4

Source: National Water Resources Database (NWRD)

From Table 3.4 it is clear that freshwater flow along the Mathabhanga-Kapotaksha-Sibsa river system is very less compared to the Gorai-Modhumati-Passur river system. Thus the Gorai-Modhumoti-Passur river system is the dominating river system which contributes significantly to the fresh water flow of the eastern part of the Sundarbans. The locations of the hydrological stations are depicted in Figure 3.14. It can be seen from the map that there are far too few discharge measuring stations in close vicinity to the Sundarban which makes flow determination for the major estuary systems difficult. Discharge stations need to be located strategically such that flow to all the four major estuary system can be monitored.

3.2.3. Water Quality (Salinity)

Fed by rainfall and snowmelt from the Himalayas the overall hydrological balance in the Sundarban has always been achieved through ample inflow from the upstream rivers contributing in supressing the upward salinity influx from tidal influences. Growth and reproduction of aquatic plants and animals of the Sundarban depend to a great extent on the salinity content of its waterscape. The ecosystem thus distressed if the waterscape becomes saline. The mangrove of the Sundarbans has been formed due to the ecological adaptation of the flora of the region to the altering salinity of the waterscape subject to semi-diurnal tidal variations, sustaining a closely knitted balance. Although the salinity of the Sundarbans in the coastal region varies up to 25 ppt[18], near the estuaries this water gets mixed with fresh water and transforms into brackish water.

[18] Salinity is usually measured in parts per thousand ppt or Practical Salinity Unit psu). The average ocean salinity is 35ppt or psuand the average river water salinity is 0.5ppt or psu.

Salinity data has been obtained from literature review (MoEF 2004, Rashid et al 2011 and Sarkar, et al 2013) separately for the Indian and Bangladesh part of the Sundarbans. These data have been combined to prepare a joint salinity map encompassing of the Indian and Bangladesh part of the Sundarbans. From this combined analysis, it is observed that salinity of the Sundarbans ranges between 10-30 ppt and varies with season as well as area. During wet period salinity decreases due to the heavy downpour in the upstream areas. Conversely, salinity increases in dry period due to the decrease of fresh water flow into the Sundarbans.

A temporal variation of the salinity of the Sundarbans is portrayed in **Figure 3.15** for the Indian and Bangladesh part of the Sundarbans. It is clearly seen that salinity remains well within 15 ppt in the wet period whereas in the dry period salinity increases and exceeds more than 25 ppt for both part of the Sundarban.

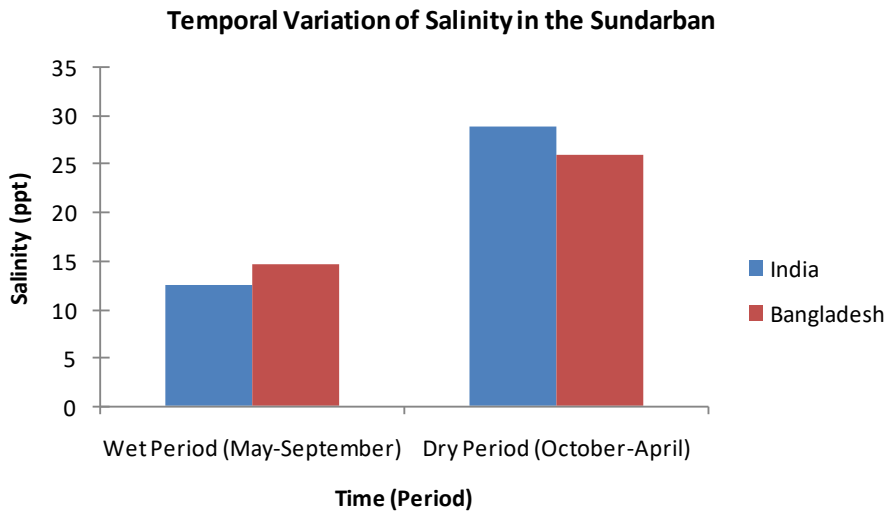


Figure 3.15: Temporal variation of Salinity in the Indian and Bangladesh part of the Sundarbans

Figure 3.16 and 3.17 exhibits the extent of salinity in the Sundarbans during wet and dry period respectively. It is observed from these maps that, salinity is relatively lesser in the eastern part of the Sundarbans compared to the western part in the Bangladesh side because the dominant freshwater river system Gorai-Modhumati-Passur supplies greater amount of water in this region whereas the Mathabhanga-Kapataksha-Sibsa river system supplies less freshwater into the Mangrove forest. The eastern part of the mangrove forest exhibits lesser (<5 ppt) salinity for both the periods although its extent is observed to be comparatively high (5-15 ppt) during the dry period. High salinity (> 15 ppt) is observed all over the coastal side of the Sundarbans as this side is facing the sea for both the wet and dry seasons. In most part of the mangrove forest in the Indian side, salinity is observed to be medium (5-15 ppt) during the wet period but becomes high (<15 ppt) in the dry period. This is because over the last century many of the rivers flowing through the Sundarbans such as, Saptamukhi, Thakuran, Bidyadhari, Matla etc. have lost their connection with the upstream rivers Damodar, Bhagirathi etc. which although contributes very insignificant amount of freshwater into this mangrove forest during the wet period but no supply in the dry period.

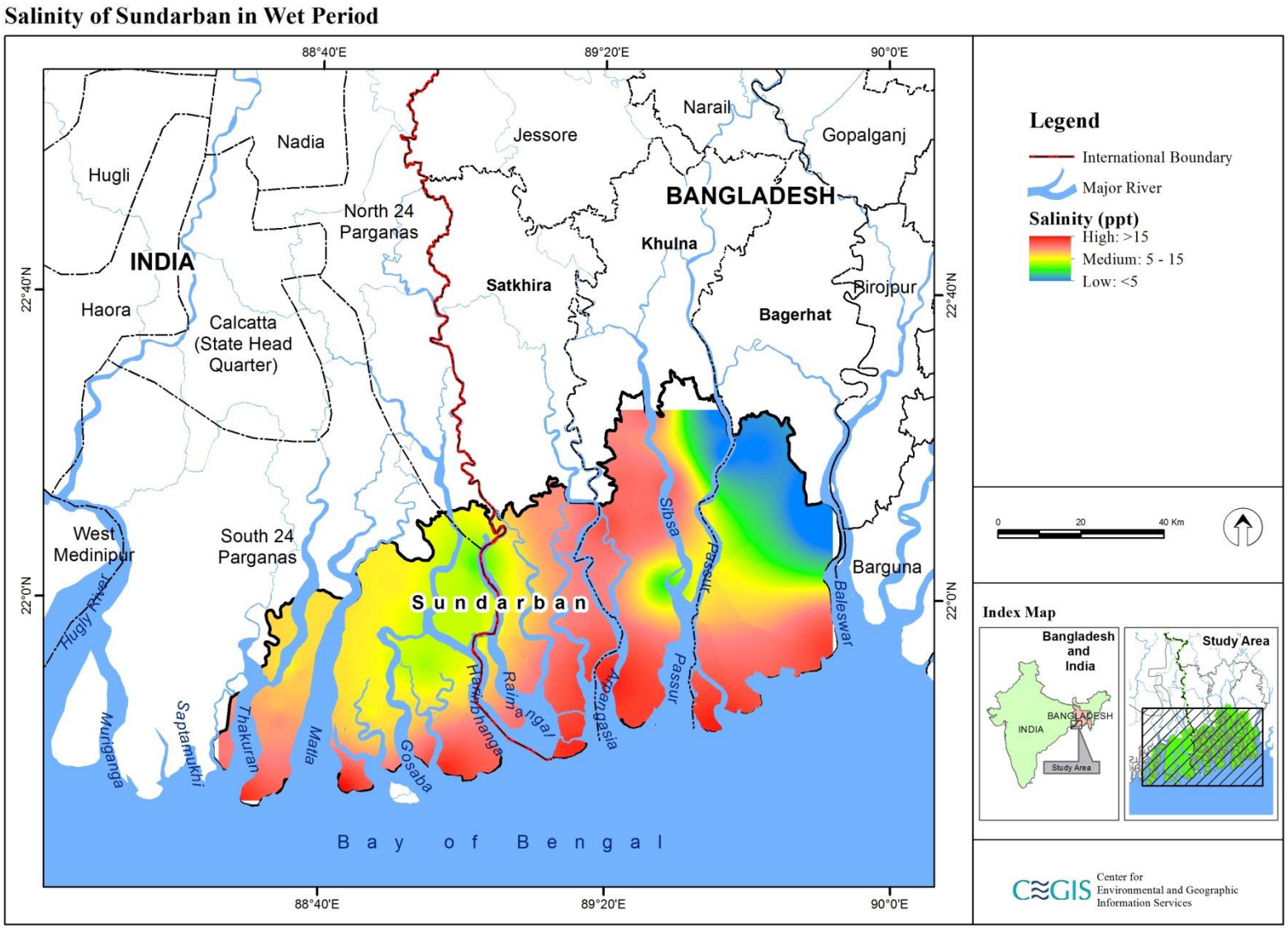


Figure 3.16: Salinity map of the Sundarbans in wet period (*source: (Sarkar, et al 2013, MoEF 2004, Rashid et al 2011)*)

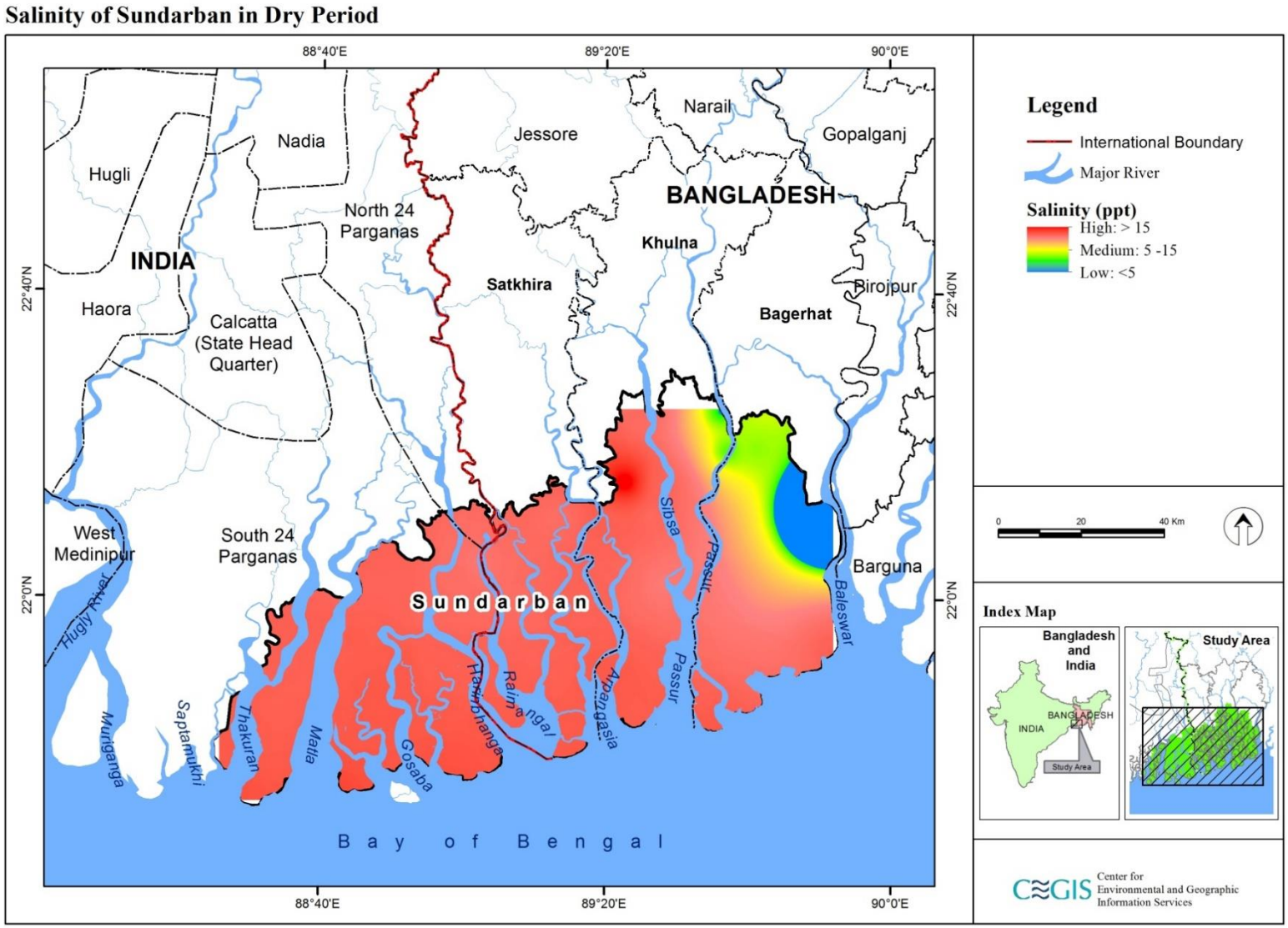


Figure 3.17: Salinity map of the Sundarbans in dry period (*source: (Sarkar, et al 2013, MoEF 2004, Rashid et al 2011)*)

As discussed in the previous section the Ganges river flow has a remarkable effect on the fresh water flow into the rivers flowing through the Sundarbans. Thus it affects the salinity of the surface water in the rivers of Sundarban. A study conducted by Islam & Gnauck (2011), comparing the water discharge and salinity of Passur river at Mongla point portrays such picture. It is observed from **Figure 3.18** that, water discharge until 1974 did not reduce dramatically, although after 1975 there was drastic reduction in water flow which clearly corresponds to the trend of salinity increase from that point on.

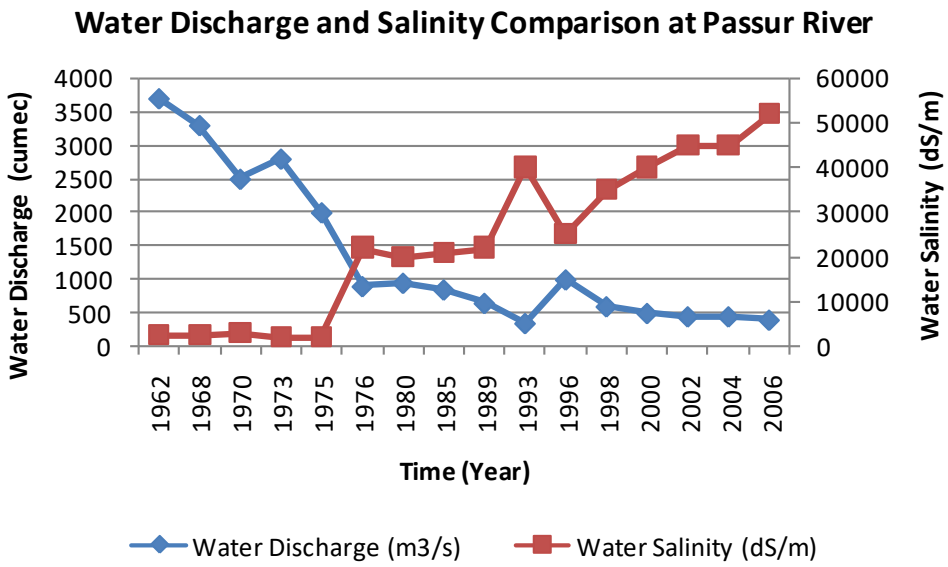


Figure 3.18: Increased salinity in the Sundarbans due to the scarcity of the Ganges freshwater (*source: Islam & Gnauck (2011)*)

Salinity increase in the Sundarban channel has also been attributed to clogging of the connections of the estuaries with the main channel of the Ganges on account of heavy siltation and solid waste disposal from urban areas, especially from large cities like Kolkata. Shrimp farming is one of the prominent sources of income of the people living on the fringes of the mangrove forest and unsustainable practices in shrimp farming are also leading to salinity intrusion. Shrimp farming in this region involves a significant portion land being used as shrimp gher, being filled with saline water for the entire duration of cultivation. But as this duration expires and this water evaporates, the salt content remains within the soil. Also, a portion of this water percolates through subsoil layer, thus increasing soil salinity. **Figure 3.19** portrays the systematic cause and impact of salinity.

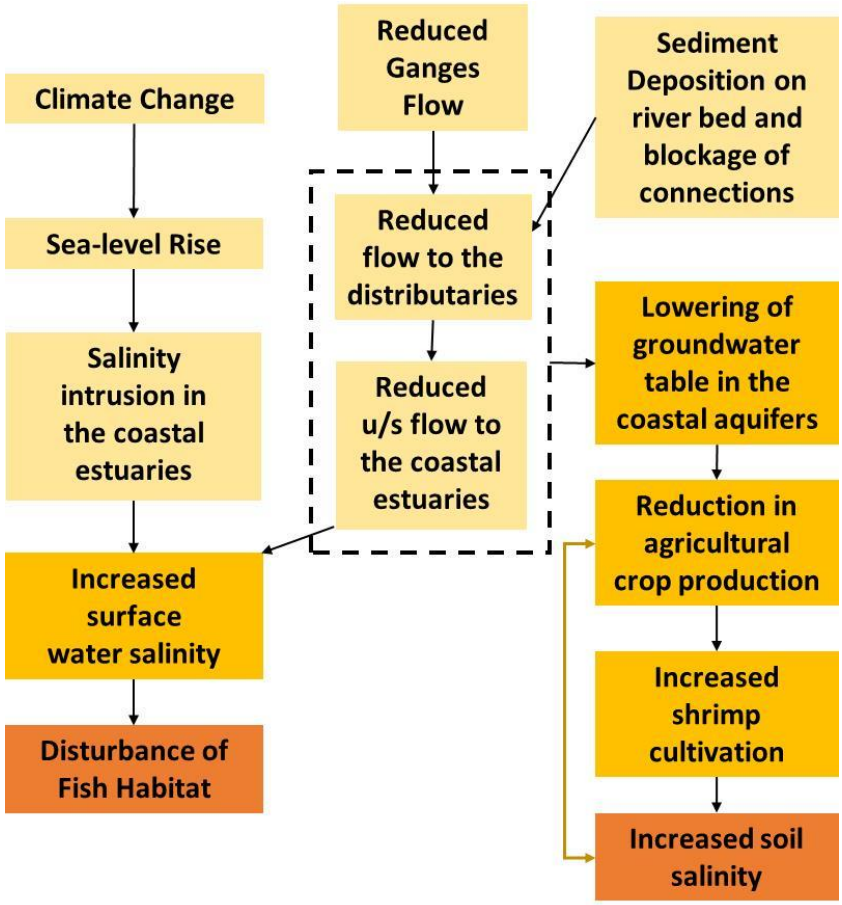


Figure 3.19: Cause and impact of salinity increase

Impact of Salinity increase in the Sundarban

Biodiversity of the Sundarbans is strongly influenced by the seasonal salinity content and sedimentation dynamics of its waterways, which in turn, are determined by seasonally and annually fluctuating freshwater flows and diurnal tides. The Sundarban comprises of 64 species of mangroves and other associated plants (Das, 2013). If salinity increases, the osmosis process of the saline water plants cannot be fully functional as the absorption of the water by the roots of the plants is hindered. Recent studies show that, due to long exposure to inundation of plants in the saline water, their respiration rate got reduced resulting in the hindrance of their physiological functions. It is observed that, young 8-10 feet high Bain trees located in the Sajne Khali and Prikhali islands are getting dried up, whereas the older Bain trees located in the upper side of the island do not exhibit any kind of abnormality (Das, 2013). there are also studies showing that salinity increase has affected the regular succession patterns and is the primary reason for top dying of Sundri trees (*Heritiera fomes*) in the Sundarban. Recently studies, linking fisheries habitat and river salinity salinity intrusion through the Sundarban estuaries, has resulted in significant loss to fisheries species for the area (Dasgupta et al 2016).

3.2.1. Land Cover

A comparison of the land and water area of both parts of the Sundarbans over the past 27 years provides a more clear understanding of the pattern of land loss in the Sundarbans during recent times. Comparison of satellite imagery of the years 1988, 1998, 2008 and 2015 is shown in **Figure 3.20**. From this figure the total area along with the land and water area of these four periods have been assessed and represented in **Table 3.5**. This table further provides a comparison of the mangrove forest area determined by Ghosh et. al (2015) with the land area determined from this analysis. A general observation from this comparison depicts that the Indian part of the Sundarbans cover about 65% of land and 35% of water. On the other hand, about 75% of the land exists in the Bangladesh part of the Sundarbans and the remaining 25% is water.

Table 3.5: Total Land/Mangrove Forest and Water area in the Sundarbans

	YEAR	Total area (km2)		Source
		BANGLADESH	INDIA	
Land/mangrove forest area	*1988*	4,139	2,016	*CEGIS, 2016*
	1989	-	1,983*	*Ghosh, 2015*
	1998	4,145	2,098	*CEGIS, 2016*
	2001	-	1,926*	*Ghosh, 2015*
	2008	4,054	1,989	*CEGIS, 2016*
	2014	-	1,852*	*Ghosh, 2015*
	2015	4,063	1,954	*CEGIS, 2016*
Water	*1988*	1,374	1,050	*CEGIS, 2016*
	1998	1,358	1,082	*CEGIS, 2016*
	2008	1,412	1,125	*CEGIS, 2016*
	2015	1,404	1,108	*CEGIS, 2016*

**Includes only Mangrove forest area whereas the CEGIS analysis includes both Mangrove forest area and area without Mangrove forest in Sundarbans*

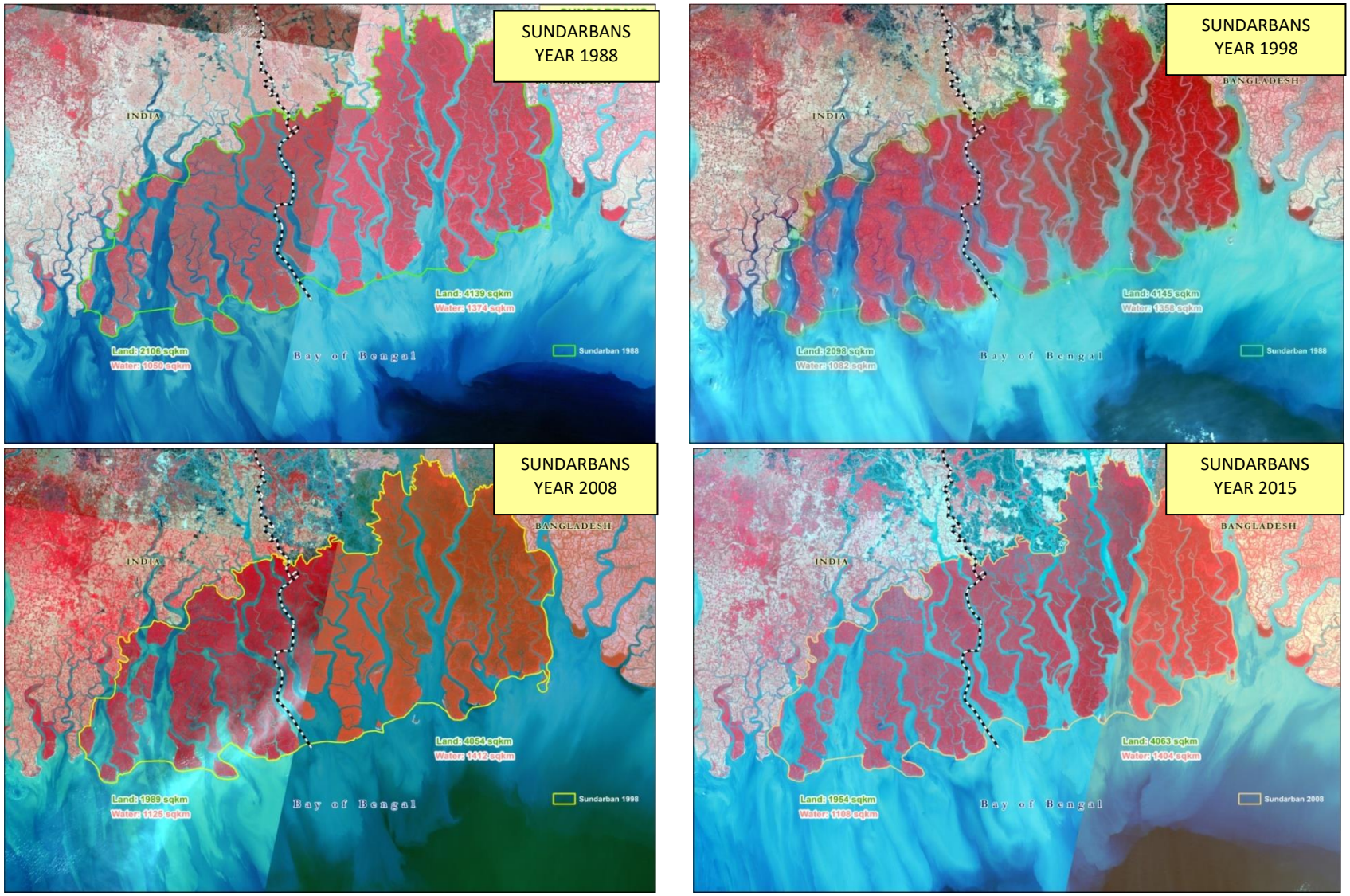
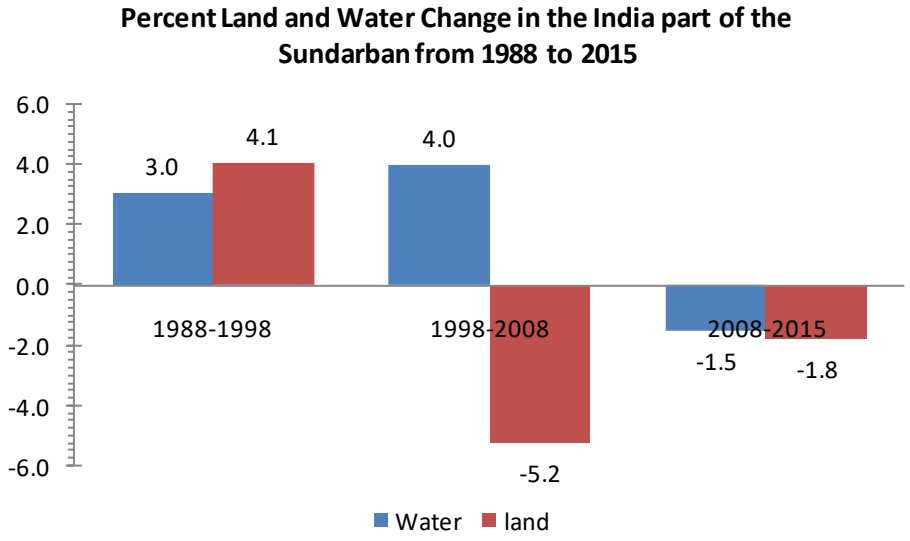


Figure 3.20: Comparison of Land and Water area of the Sundarbans for the years 1988, 1998, 2008 and 2015 (*source: CEGIS analysis 2016*)



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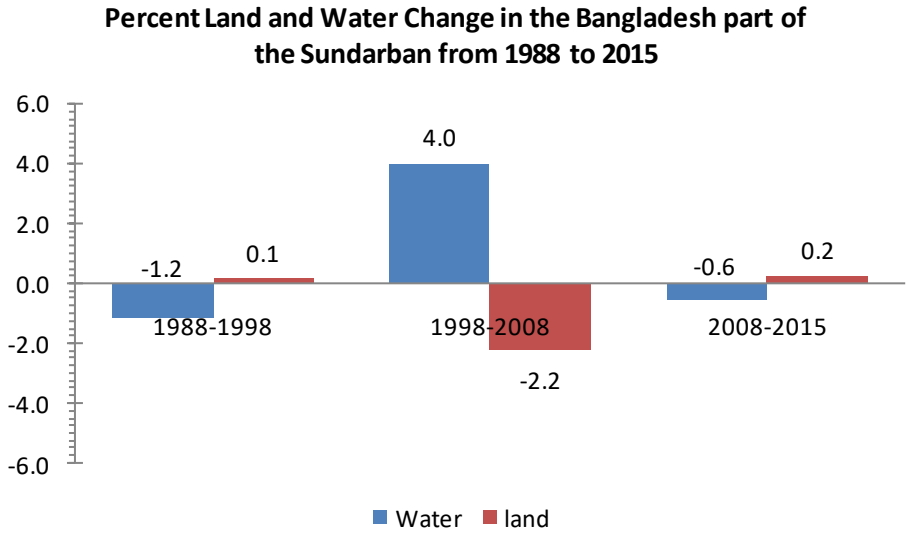


(b)

Figure 3.21: Land and Water change of the Sundarbans (a) Indian part and (b) Bangladesh part during the years 1988, 1998, 2008 and 2015 (*source: CEGIS analysis (2016)*)

From the satellite imagery of the years 1988-1998, 1998-2008, and 2008-2015 the land and water changes of the Sundarbans have been determined and presented in **Figure 3.21**. From this figure it is observed that the most deviation of land and water in both part of the Sundarbans have occurred during 1998-2008. This may be due to the frequent occurrences of cyclonic storms in the coastal region during this period. A study of the frequency of cyclonic storms in the northern Bay of Bengal indicated a significant increase of storms during the years 1999-2009 (Danda, 2010). The trend of land and water area deviation has decreased in the later years till 2015.

3.3. Natural disasters

The Sundarban, like many mangrove systems of the world is situated at the front line to many coastal hazards. The fragile ecosystem and communities living in and around the Sundarban Region are exposed to tropical cyclones, storm surges, erosion, frequent inundation by high tide causing loss and disruption to lives, livelihood and often irreparable or long term damage to the ecosystem. Slow onset disasters like salinity intrusion causing water scarcity also impact the forest and surrounding areas. Studies show, mangroves have the ability to cope with such hazards and in most cases, recover from impacts in due course (Spalding et al, 2014). It is these natural hazards coupled with the unpredictability of land and water that are a constant source of anxiety and vulnerability for the settlers around the Sundarban. Erosion and salinity intrusion have been discussed in previous sections.

3.3.1. Tropical Cyclones and Storm Surges

The North Indian Ocean accounts for seven percent of global cyclones (Singh et al 2000) and cyclones occur up to four times more in the Bay of Bengal than in the Arabian Sea. Thus the coasts of India, Bangladesh and Myanmar are susceptible to medium to severe tropical cyclones almost every year and many of these tropical cyclones travel directly over the Sundarban.

Tropical cyclones are characterized by a large low-pressure center and walls of deep thunder storms that produce strong converging cyclonic winds and heavy rain. Most damage and loss of life occur through seawater inundation of low-lying coastal regions. A tropical cyclone can have destructive winds having speeds as high as 250 km per hour. The tropical cyclones and associated storm surges cause great damage to the ecosystem and impact the life, property and economy of the inhabitants of the Sundarban Region in particular to the crop and fisheries sector and thus on the livelihood of the coastal habitants (World Bank, 2014).

Some of the most devastating tropical cyclones in the world have occurred in the Bay of Bengal. An analysis shows that out of 14 global tropical cyclones associated with the highest fatalities, nine have occurred in the Bay of Bengal (World Bank, 2014). The first documentation of a severe cyclonic storm in the Sundarban was during 1584, when 2,000,000 living creatures were recorded to have perished.

The following cyclones are the most devastating natural calamities to hit the Sundarban coast in recent history:

Cyclone Sidr hit the south-western coast of Bangladesh during the evening of November 15th 2007. The cyclone intensified to reach peak winds of 215 km/h (135 mph) according to the Indian Meteorological Department (IMD) and destroyed over 450,000 houses across 30 districts in Bangladesh, through wind damage, flooding and tidal surge. About a quarter of the world heritage site of Sunderban Reserve Forest in Bangladesh was feared to have been damaged.

Severe Cyclonic **Storm Aila** combined with storm surge was the worst natural disaster to affect the Sundarban since Cyclone Sidr. The storm was responsible for at least 339 deaths across Bangladesh and India; more than 1 million people were left homeless. Aila became a severe cyclonic storm on May 25

and made landfall at its peak intensity. The Sunderban was inundated with 6.1 m (20 ft) of water and many tigers were feared to have drowned in Aila's storm surge along with deer and crocodiles. Post cyclone impacts include salinization of soil due to salt ingress caused by storm surge, tidal inundation as many embankments were damaged

A list of cyclones is shown in Figure 3.23 and 3.24.

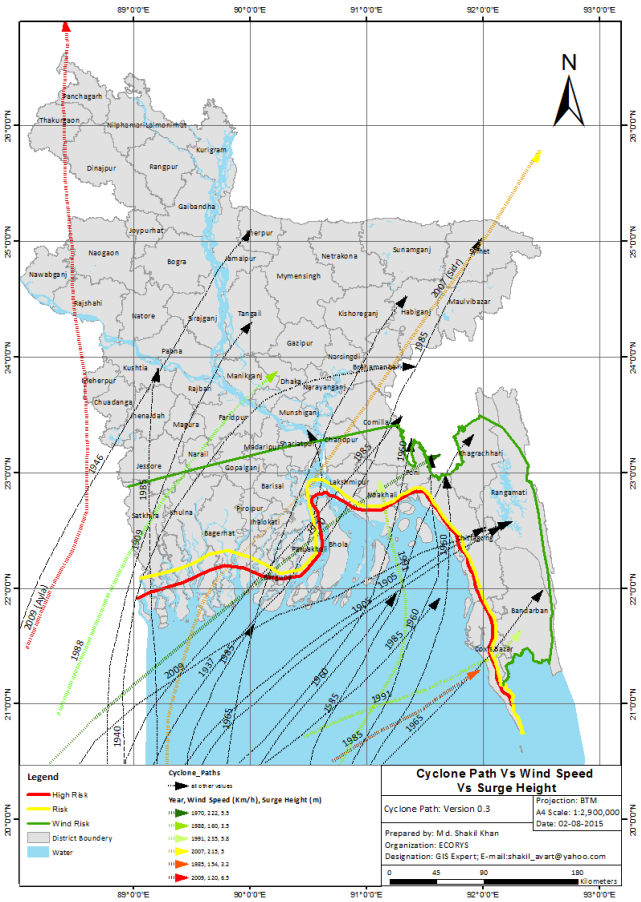


Figure 3.23 : Pathways of cyclones over the Sundarban

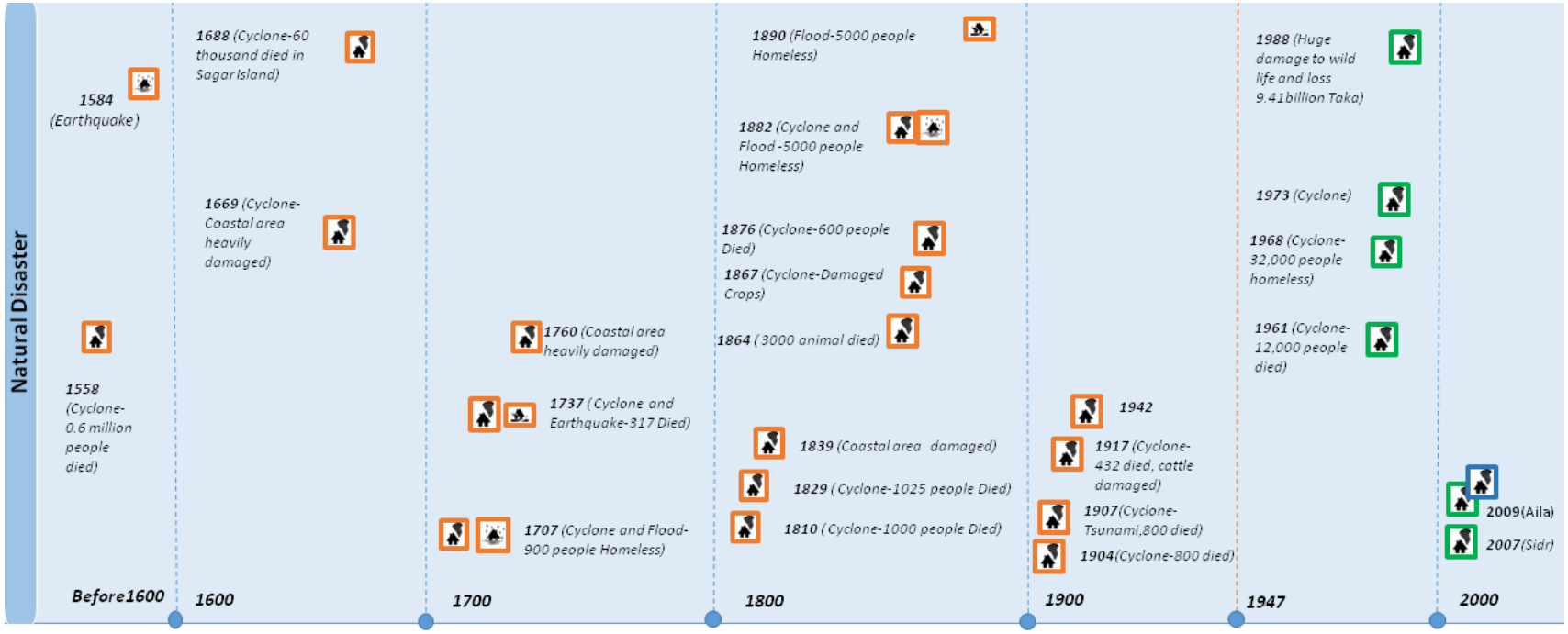


Figure 3.24 : Timeline of cyclones happening in the Sundarban

4. The Biological Landscape

The word mangrove originated from the Portuguese word 'mange' or the Spanish word"mangle" which means trees or shrubs in association with English word 'grove' for a stand of trees (Online Entymology Dictionary, 2016). Mangroves, like the Sundarban, occur in equatorial, tropical or subtropical regions at the intersection of land and sea and are characterized by sweltering heat, huge amount of mud and silt, and salinity levels that most plants will not be able to tolerate. Mangroves have thus adapted to high water stress, fluctuations in temperatures and salinity and exhibit mechanisms that permit water against a gradient and have extensive and specialised root systems (Saenger, 2002; Naidu, 1985; Popp et al 1993). The saline intertidal hydrological system provides the foundation for a highly productive, naturally dynamic and biologically rich ecosystem that provides habitat for a wide range of species. The total mangrove area of the world has been estimated to be around 152,000 sq km (UNEP, 2014). Throughout the tropics, mangroves are much alike in their physiognomy -evergreen, closed canopy, floristically pauperate vegetation, although they differ in their structure and floristic composition.

The estuarine wetlands of the Sundarban are constantly fed by nutrients brought in by freshwater of the Ganga/Ganges river system and flushed by the ebb and flow of the tides, their inticrate three-dimensional landscapes promote richly complex interdependencies and thus support a diverse population of plant and animal species, both terrestrial and aquatic. These wetlands also sustain billions of worms, protozoa, barnacles (*Balanus spp.*), oysters (*Crassostrea spp.*), lichen and other invertebrates. These organisms in turn feed fish and shrimp, which support wading birds, pelicans, and the endangered Crocodile. Prain (1903) recorded 334 species of plants belonging to 245 genera from Sundarban mangrove forest and adjoining areas. Of the 50 true mangrove plant species recorded throughout the globe, the Sundarbans alone contain 35 species (Rahman and Asaduzzaman, 2010). Henning (1892) reported 70 species from 34 families for the entire Sundarban Region. As many as 447 species of vertebrate wildlife (amphibians, reptiles, birds and mammals) including the iconic Bengal Tiger, Gangetic and Irrawaddy dolphins and the olive ridley turtles have been reported from Sundarban Heining, R. L. (1892).

The mangrove ecosystems play a key role in connecting marine and terrestrial ecosystems. This connection provides the maintenance of the stability, not only to the mangrove habitats itself, but also to the coastal ecosystems. The sediment and nutrients fluxes from Sundarban influence the primary productivity and carbon fluxes and support species richness, evenness and diversity in the near shore areas (Sanghi, 2013). The Swatch of No-Ground which has been declared a Marine Protected Area by Bangladesh, is a key breeding and spawning ground for dolphins, whales, sharks and turtles and home to three rare species of marine wildlife; Minke whale, masked booby and gastropod; is located around 45km south of Sundarban.

The land part represents four major habitat types, i.e. mangrove woodlands (70%), grasslands (10%), sea beaches (6%) and transitional zones (14%) with 40% of the Sundarban is under deep water in the form of estuaries and large rivers. Species composition and flora and faunal diversity depend on the morpho-physiological characteriestics of the habitat. Overall, the species composition of the Indian and Bangladesh parts of the Sundarban are quite similar, this is because the development of the mangrove system and landscape has been influenced by similar processes. However, as seen in previous chapters, there is a distinct variation of freshwater supply and salinity across the Sundarban from west to the east and this variation dictates the diversity and distribution of biota. 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. Many plant species like Heritiera fomes, Nypa fruticans and Phoenix paludosa were very abundant in the Sundarban 50 years ago, but recently they have declined relatively as the salinity has increased (Islam et al, 2014). 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.

The biological landscape has been detailed according to the following sections:

- ◊ Plants of the Sundarban
- ◊ Wildlife and fisheries of the Sundarban

4.1. Plants of the Sundarban

Defining mangrove species is truly complex and difficult work; various authors have put forward varying numbers. Chapman (1976) noted 90 mangrove species globally whereas Saenger et al. (1983) recorded 83 species. UNDP/UNESCO (1986) reported 65 species, but Tomlinson (1986) mentions only 48 true mangrove species. Moreover, he acknowledged two types of mangroves- True mangroves – the species with complete fidelity to the mangrove environment, and (2) Minor elements of mangals – not conspicuous in mangrove habitats, may rather prefer the peripheral habitats. Many other researchers, Watson (1928), Chai (1982), Mepham & Mepham (1984), and Naskar (1993) have applied the term 'Mangrove associate' as an equivalent to minor elements for the plant found in areas bordering the true intertidal mangrove habitats. Spalding et. al. (2010) noted 73 mangrove species, out of which 38 species, he recognized as core mangrove species. Kathiresan & Rajendran, (2005) have reported 69 mangrove species from India.

Based on the available water quantity and quality and characteristics of plant water-relationship, the vascular plants are classified in eight major categories, (i) Helophytes, (ii) Xerophytes, (iii) Mesophytes, (iv) Halophytes, (v) Oxylophytes, (vi) Psychoxerophytes, (vii) Lithophytes and (viii) Psammophytes (Warming, 1909). Out of them the first four categories, i.e. Helophytes, Xerophytes, Mesophytes and Halophytes are the major flora in Sundarban mangrove forest. However, Halophytes occupies the largest share of the true mangrove species. The habitats of halophytes are frequently inundated with tidal sea water and thus requiring them to counter this anoxic condition. Halophytes display selective water absorption quality and can tolerate dissolved salts as they grow on saline soil. They adjust in saline surroundings by osmo-regulatory means to prevail over the toxic effect of dissolve salts. They have succulent, small, evergreen and leathery leaf with thick cuticles and developed water storage and palisade tissues. Mangroves species resemble many of the characters of halophytes and sustain exposure to variance in salinity and the degree of water-logging. However, pneumatophores, knee roots, prop roots, root buttresses and unique viviparous, crypto-viviparous or pseudo-viviparous germination mechanisms are unique and are not available in all halophytes.

Mangrove forests are edaphic evergreen, occurring primarily on muddy shores of tropical coastal areas subject to periodic submergence by tidal waters. The mangroves in the Bay of Bengal, including the Sundarban, belong to the Indo-Malayan group and are regarded as a distinct sub-group.

Because of its floral richness and dominant species composition mangroves in the Sundarban occupy a unique position among the global mangroves. The Sundarban flora is distinguished by the wealth of Sundri (*Heritiera fomes*), *Gewa* (*Excoecaria agallocha*), *Goran* (*Ceriops decandra*) and Keora (*Sonneratia apetala*). The floras of Sundarban have drawn the attention since 19th Century. In 1895, a comprehensive list of Sundarban plants was presented by C.B. Clarke in presidential address of the Linnaean Society of London. A collection of the flora of the Sundarban and the surrounding area by Prain (1903) included the plants of swamp forest, grass-savannah, strand vegetation and the reclaimed areas across the entire expanse of the Sundarban and identified a total of 334 species belonging to 245 genera of Spermatophytes and Pteridophytes. Of these, no fewer than 123 species occur in the present reserve forest of the Bangladesh Sundarban. The working plans prepared thereafter have also taken into account of the Sundarban flora (Curtis, 1933). Although lots of changes have taken in the status of various mangrove species and taxonomic revision since Prain's report, a comprehensive botanical exploration of the Sundarban has never been attempted there after.

Studies of Maiti, (1999), Ghosh et. al. (2003), Mukherjee (2004) and Sharma & Naskar (2010) provides an estimate of approximate 180 species under 54 families and 118 genera in Indian Sundarban. The number would be similar in Bangladesh part as well. However, because of the forest canopy reaches a maximum height of about 20 m and in some cases highly stratified. The forest in the eastern and north central part shows higher strata, typical to the tropical rain forest structure. Epiphytes and woody parasitic species are common at the tree crown unlike to the description of mangrove by Amitav Ghosh in 'The Hungry Tide'.

Among the dicotyledonous plants, the tree species are characterized 30 genera of 22 families. Rhizophoraceae is represented by all the 4 known genera and at least 6 species. Avicenniaceae is represented by 3 species, Meliaceae is represented by 3 species, Combretaceae is represented by 2 species and Sonneratiaceae is represented by 2 species. Among the tree species Gewa and Sundri were found to be the most dominant species.

The shrubs or scandant shrubs are distinguished by 12 species belonging to 11 genera under 7 families. The forest is also abundant with climbers. At least 11 species belonging to 6 families have so far been identified. The monocotolydenous herbs are represented by Graminae, Palmae, and Pandanaceae. Besides the rooted plants, the swamp forests species also include the epiphytic and parasitic flora that survive on the rooted trees and do not come into contact with the forest floor. The epiphytes include *Hoya parasitica*, *Dischidia numularia, Derris heterophylla, D. scandens* and *D. trifoliata*. Family Orchidaceae is signified with 13 species. One of the orchids, the Roxburgh's Orchid, scientifically called *Bulbophyllum roxburghii* is reported to be endemic to the Sundarbans. Among parasites, *Cuscuta reflexa* and *Dendropthoe falcate* are common. Seven epiphytic ferns also reported, including *Lycopodium* sp. and *Psilotu* sp. The Tiger fern (*Acrostichum aureum*), though growing with salt marshes, sometimes form dense patches on river banks and other water logged areas.

Unlike other mangroves, the dominant floral species in the Sundarban is *Sundri* - a member of the Sterculiaceae family. Assemblage of species typical to the Sundarban once extended from the coast of Orissa through the Sundarban, Chakaria, and the Naf estuary in Bangladesh to Tanasserim and in the Irrawaddy delta in Myanmar. Most of the natural vegetation within this distribution range has been cleared for other land use. The near natural vegetation with Sundri dominant species is at present limited only to the fresh water dominating eastern part of the Sundarban.

In the Sundarban, three distinct vegetation types have been documented in relation with varying degree of water salinity and freshwater flow.

In the northeast, where freshwater flow is maximum now a day, Sundri either in pure patches or interspersed with Gewa, Passur (*Xylocarpus mekongensis*) and Kankra (*Bruguiere gymnorrhiza*) are the dominant vegetation type. With Sundri and Gewa some parts are associated with discontinuous distribution of the Dhundal (*Xylocarpus granatum*) and Kankra. Among grasses and palms the *Portresia cocoarctata, Myriostachya wightiana, Imperata cylindrica, Phragmitis karka* and Golpata (*Nypa fruticans)* are well distributed. The Shingra (*Cynometra ramiflora*) and Amur (*Amoora cucullata*) grow in more saturated sites as under storey and the Goran in drier sites. Golpata is widespread along the newly formed mudflats along the drainage creeks and riverbanks.

In the south close to the sea with obviously the greatest seasonal variation in salinity levels, Gewa is the dominant woody species. It is often mixed with the Sundri in the backswamps, which receives frequent inundation by the tidal water twice a day. It is also commonly associated with dense understorey of the Goran and sometimes the Passur. In the newly accreted mudflats, the Keora forms pure patches. The Baen (*Avicennia marina*) either grows in mixed patches with Keora or in pure patches in the islands near the sea. The *Rhizophora mucronata*, *Rhizophora conjugata* and the Golpata are common along the creeks.

In western part with more salinity sparse Gewa and dense growth of the Goran is the key vegetation form, with discontinuous patches of the Hantal (*Phonix paludosa*) which grow on the drier ground and riverbanks. Sundri and Passur are found but smaller in size and diameter. As usual in other zones, Keora, and the Golpata are widespread along the drainage creeks and riverbanks. A species assemblage map is provided in Figure 3.30.

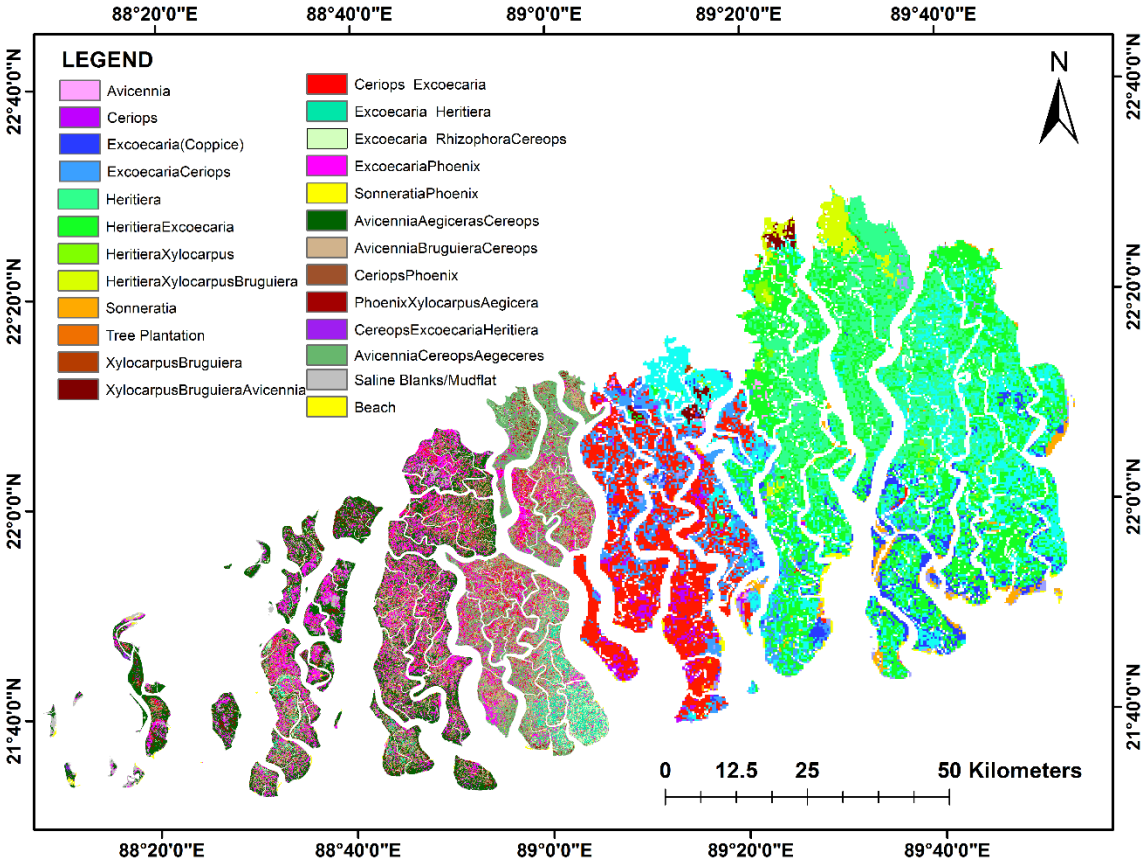


Figure3.30: A species assemblage map of the Sundarban

All plant species show seasonality in leaf, flower or fruit production and Sundarban is no exception to this. The lean period of freshwater is coincidental with the increase in salinity and also negative precipitation and evapotranspiration values. The dominant plant Sundri and members of Rhizophoraceae are evergreen trees while Gewa and Passur are deciduous trees. Sometime large part of the Sundarban is suffused to red or pink. This is due to the colour change of the leaves of Gewa which turn red at the time of shedding. Some plants were found to shed their leaves twice a year, once during October-November and again during May-July. Passur shed their leaves during the month of March. However, the same species may not shed its leaves in all areas at the same time. This is due to the strength of the stimulus which triggers leaf fall.

Table 3.10. Sundarbans mangroves: estimated incidence by salinity interval

Salinity (ppt)	Baen	Gewa	Gewa Goran	Gewa Sundri	Goran	Goran Gewa	Keora	Passur Kankra	Passur Kankra Baen	Sundri	Sundri Gewa	Sundri Passur	Sundri Passur Kankra
2							**0.01**						
3	**0**	**0**	0	0.23	**0**	0	**0.37**	0	0	**0.90**	0.22	0	0
4	**0**	**0**	0	0.98	**0**	0	**0.02**	0	0	**1.33**	0.69	0	0

Salinity (ppt)	Baen	Gewa	Gewa Goran	Gewa Sundri	Goran	Goran Gewa	Keora	Passur Kankra	Passur Kankra Baen	Sundri	Sundri Gewa	Sundri Passur	Sundri Passur Kankra
5	**0**	**0**	0	1.66	**0**	0	**0.48**	0	0	**1.03**	0.72	0	0
6	**0**	**3.07**	0	1.61	**0**	0	**1.23**	0	0	**1.03**	0.92	0	0
7	**0**	**2.46**	0	1.72	**0**	0	**0.72**	0	0	**0.58**	0.91	0	0
8	**0**	**1.40**	0	2.77	**0**	0	**0.72**	0	0	**0.99**	1.07	0	0
9	**1.12**	**0.52**	0	5.60	**0**	0	**4.37**	0	0	**3.80**	3.79	0.20	0
10	**0.53**	**0.93**	0	8.52	**0**	0	**2.37**	5.44	0	**7.89**	3.53	0.83	0
11	**0.17**	**1.22**	0	6.72	**0**	0	**2.77**	0	0	**9.80**	2.96	1.54	3.18
12	**12.34**	**1.65**	0	4.36	**0**	0	**3.54**	9.07	0	**9.11**	3.88	3.43	6.45
13	**25.59**	**3.30**	0.19	5.05	**0**	0	**3.60**	11.68	0	**6.40**	5.09	0.84	41.22
14	**16.13**	**10.42**	0.24	6.94	**0**	0	**8.07**	6.46	0.49	**10.05**	13.39	1.82	21.29
15	**5.61**	**15.16**	2.25	9.23	**1.05**	0.32	**8.21**	1.81	44.75	**11.53**	17.62	10.21	5.26
16	**2.06**	**14.47**	0.63	4.62	**0.09**	0.49	**12.56**	19.39	17.57	**12.76**	11.41	64.95	16.79
17	**1.59**	**6.45**	0.89	5.46	**1.66**	0.37	**5.06**	0	0	**14.83**	9.69	3.00	0
18	**5.58**	**5.42**	3.24	5.66	**1.89**	0.84	**7.34**	0	0	**0**	7.39	2.02	0
19	**8.54**	**6.55**	5.37	6.54	**0.38**	0.65	**4.03**	1.81	0	**0**	5.74	3.99	0
20	**9.61**	**4.79**	5.88	5.97	**0.69**	0.77	**3.89**	41.5	4.38	**0**	3.20	0	0
21	**2.43**	**5.19**	6.73	5.75	**0.68**	1.41	**4.82**	0	8.74	**0**	0	0	0
22	**0**	**5.92**	7.21	4.70	**0.62**	1.48	**6.77**	0	7.61	**0**	0	0	0
23	**0**	**5.14**	8.66	0	**0.54**	3.34	**4.48**	0	11.37	**0**	0	0	0
24	**0**	**0**	10.52	0	**2.36**	6.83	**2.56**	0	0	**0**	0	0	0
25	**0**	**0**	9.25	0	**10.33**	10.02	**3.93**	0	0	**0**	0	0	0
26	**0**	**0**	12.35	0	**3.45**	8.99	**0**	0	0	**0**	0	0	0
27	**0**	**0**	15.53	0	**29.91**	31.69	**0**	0	0	**0**	0	0	0
28	**0**	**0**	11.06	0	**46.36**	32.79	**0**	0	0	**0**	0	0	0

Source: World Bank: Policy Research Working Paper 7736.

Most of the trees in the Sundarban flower during pre-monsoon in the months of March and April, although not variation among individuals does exist within a single population. Fruits are produced after the flowering in the early part of the monsoon. However some species such as Gura (*Kandelia Kandel*) and *Bruguiera gymnorrhiza* may flower more than once a year. Sundri trees, in general, fruit heavily in alternate years. It was also observed that many mangrove species flower sporadically during any month of the year and this irregular behavior tends to obscure the existence of a single regular flowering and fruiting season.

Table 3.11: Phenology of some important mangrove species

Local	Scientific name	J	F	M	A	M	J	J	A	S	O
Sundri	*Heritiera fomes*										
Gewa	*Excoecaria agallocha*										
Amur	*Amoora cucullata*										
Golpata	*Nypa fruticans*										
Kankra	*Bruguiera gymnorrhiza*										
Keora	*Sonneratia apetala*										
Passur	*Xylocarpus mekhongensis*										
Baen	*Avicennia officinalis*										
Goran	*Ceriops decandra*										

Flowering time ; Fruit ripening time

Members of the family Rhizophoraceae shows viviparous germination and shed their fruits mostly from July to August and may continue up to September to October. Fruit shedding in Baen is completed within a very short period during the month of August. Fruit shedding of Sundri varies from area to area but tends to complete within July and August.

4.1.1. Structure and physiognomy

Evergreen species both trees and shrubs dominate the Sundarban. However, the vegetation composition is highly mixed and it is rare to find communities that are homogenous in structure and composition over large areas. Apart from certain communities in the degraded conditions, the forest is generally closed in structure and stratification is distinct. Even above 70% canopy closure is not uncommon in healthy condition. Some of the best developed forest is found in the moderate to relatively freshwater areas in the northeast. Under ideal growing conditions, Sundarban can support lofty evergreen trees of 25-30 m in height.

Trees are found to occur as mixed vegetation and sometimes found to form monospecific vegetation types. There is a great variation of vegetation, varying from multi-storeyed forest forming closed canopies to scrubby bushes with widely dispersed stunted trees. It is frequently the case that trees in the upper canopy have spreading branches while tree crowns in the lower strata are mostly slender. Species which are light demanders usually form pure stands such as *Avicennia* and *Sonneratia* (Hussain & Acharya, 1994).

Often the emergent stratum is occupied by only Sundri. The canopy is usually irregular and trees are without a single central trunk. Under this the second stratum either consists of pure Sundri or a mixture of Gewa and/or *Kankra*. In this stratum, tree crowns of the canopy are usually tall and narrow and form a continuous layer. The third stratum consists of saplings of the canopy trees and medium sized trees of Amur and Shingra.

In particular areas, this pattern could differ with complete absence of undergrowth in a dense Sundri forest dominated backswamp. But, in other areas, predominantly in low lying areas or along the riverbank, there is an undergrowth of varying densities, sometimes thick and almost impenetrable with Kewa (*Pandanus* sp.), Bhola (*Hibiscus tiliaceous*), Tiger fern and Hantal.

4.1.2. Micro-organisms

The diversity of micro-organisms such as bacteria, fungi and lichen in the Sundarban has not been examined in detail, although some recent studies and research documents focus on various microorganisms in the soils and on decomposing floral litter as well as aquatic and terrestrial animal remains, studies and research is still very uncommon, mostly based on short term isolated surveys, as a result there are many gaps in the knowledge and literature of micro-organisms of the Sundarban (Gopal and Chauhan, 2006).

Algae: Available information suggests that there is a highly diverse population of floral algea, comprised of both both benthic and planktonic forms ranging from the freshwater to marine environments. Islam (1973) reported 34 species of planktonic and benthic algae in Bangladesh while, Sen et al. (1999) recorded 80 species of algae (32 Cyanophyceae and 27 Chlorophyceae) from different parts of the Indian Sundarban. More recently, Naskar et al. (2004), identified 150 species including, 15 species of Rhodophyceae and 2 species of Phaeophyceae.

Lichen: The lichens are unique group of terrestrial autotrophs which grow in any stable substratum and the occurance of lichens in mangrove forests is dependant on the temperature, mean number of annual rain days and seepage of water from the land surface. Worldwide, 13,000 species of lichens are recognized and this number rises to 20,000 if the orphaned species are also considered. Ram (2006) documents 165 species of lichen of which 9 are new to science and 24 were not recorded in South Asia. This study also docemnts 28 endemic lichen species, this shows a clear evidence of lichen uniqueness in the Sundarban.

4.1.3. Forest Types

Forest types are classified predominantly through floristic assemblage based on dominant or co-dominant species. Sundarban forests have been variously classified by different authors. These include: Prain (1903) divided the entire Sundarban into three zones, namely (i) southern coastal strip and south - western part consisting of mangrove species; (ii) central zones of *Heritiera fomes*; and (iii) north - eastern part of Savannah type vegetation (completely gone due to land conversion).
Curtis (1933) also divided the Sundarban into three mangrove forest types, these being i) freshwater forest; ii) moderately salt water forest; and iii) salt water forest. Champion (1936) classified the tidal forests under primary seral type of moist tropical seral formations and did not regard the mangrove as a climax or pre16 climax forest types. He divided the forests of the Sundarban region into mangrove forests consisting of i) low mangrove forest; ii) salt water *Heritiera fomes* and iii) freshwater *Heritiera fomes* forest. Presently, Indian part of the Sundarban falls under categories (i) and (ii) while the Sundarban forest in Bangladesh are at large considered to be representative of category (iii).

Champion and Seth (1968) made one of the most comprehensive assessments of the vegetation

communities of the Indian Sundarban. They divided the forest into categories based on broad characteristics of physiognomy and structure. These communities were defined irrespective of physiographic, edaphic or biotic factors.

Champion and Seth (1968) were of the opinion that some communities were clearly associated with a definite site factor, which differed appreciably from the surrounding areas. Champion and Seth's classification sub-group 4B (Tidal Swamp forests) with sub-divisions is mentioned in Table 3.12

Table 3.12 Classification of Sundarban Mangroves according to Champion and Seth

i	**Mangrove scrub**	4B/TS1	*Ceriops, Avicennia alba, Aegialitis rotundifolia, Excoecaria agalllocha, Phoenix paludosa* (drier ground). Found along the edge of tidal water ways and sheltered muddy coast. Dense forest with average height 3-6 m. Few species are markedly gregarious, all evergreen with leathery leaves. Vivipary seen. Common in western Sundarban.
ii	**Mangrove forest**	4B/TS2	Rhizophora, Kandelia candel, Avicennia alba, Excoecaria agallocha, Ceriops decandra, Ceriops tagal, Bruguiera spp., Xylocarpus granatum, Sonneratia apetala. Found on mud banks of delta streams and near sea face where accretion is in progress. An evergreen forest of moderate height. Tidal mud flats permanently wet with salt water and submerged with every tide. Stilt roots and vivipary seen.
iii	**Salt water mixed forest**	4B/TS3	*Heritiera fomes*, *Excoecaria agallocha*, *Ceriops decandra*, *Xylocarpus mekongenesis*, *Avicennia officinalis*, *Aegialitis rotundifolia* (near sea face). *Nypa fruticans* is relatively uncommon. Fairly dense forest, more than the fresh water type but not as high. Rarely over 20 m. Trees do not attain girth. Ground flooded in every tide with brackish water. Less silt deposition than fresh water type. Less humus, soil stiffer, clayey liable to crack extensively when exposed. Bigger river deltas.
iv	**Brackish water mixed forest**	4B/TS4	*Heritiera fomes*, *Sonneratia apetala*, *Acanthus ilicifolius*, *Xylocarpus mekongenesis*, *Bruguiera sp*, *Sonneratia caseolaris*, *Excoecaria agallocha*, *Ceriops decandra, Phoenix paludosa* (high land), *Acanthus ilicifolius, Hibiscus tiliaceus, Nypa fruticans* (fringing banks). In the larger deltas, notably of High forests over 33 m., stilt roots rarely met but pneumatophores present. Forest is flooded for some portion each day, the water is never very salty and very fresh during rainy season or slightly brackish. Good amounts of fresh silt deposition.

v	**Palm swamp type**	4B/E1	*Phoenix paludosa* seen on drier areas within salt water mangrove scrub or forest. Forest area is partly flooded for some part of the day.

Naskar and Guha Bakshi (1982) grouped this forest into five major zones as i) sea face of beach forest; ii) formative island flora; iii) flora of reclaimed land and low lying area; iv) flora of river banks; and v) swamp forest. The first category is dominated by xerophytic plants due to the dryness of the soil and numerous sand dunes. The flora of the formative islands consists mainly of *Porteresia coarctata, Salicornia brachiata, Suaeda maritima, S. nudiflora*, *Phragmites karka, Acanthus ilicifolius* and a few tree species such as *Avicennia* sp., *Sonneratia* sp. and *Excoecaria agallocha*. The reclaimed land and low lying areas are dominated by mesophytic flora while the last two zones are dominated by halophytic mangrove species.

Estuarine Mangrove formation

All the estuarine regions of the Sundarban Biosphere Reserve (SBR) having less than 3-4 m elevation with maximum influence of water salinity, tidal inundation, silt and sand along with high wind speed. Vegetation in this zone is usually dominated by Avicennia marina associated with Sonneratia griffithii, Bruguiera cylindrica, B. parviflora, Ceriops tagal, Aegialitis rotundifolia, Phoenix paludosa and Excoecaria agallocha are also found commonly exposed under eroded conditions of the river banks. However, extensive plantation of Avicennia alba in mudflats have somewhat relegated rest of the species in a secondary position. Presence of salt excretory glands in the leaves and petioles of Avicennia marina and water storage mechanism in the leaves of the species of Sonneratia, Ceriops and Aegialitis are the adaptive mechanism for withstanding high salinity conditions. All the above plants are found especially along the forest block of Chulkati, Chotohardi, Mayadwip, Baghmara and Gona, river mouths.

Riverine Mangrove formation

Best developments of mangroves are found in the inner estuarine or riverine mangrove habitat and flora becomes rich and diverse due to sheltered situation and availability of more fresh water. Distribution of mangrove species exhibits three distinct habitats such as True or Typical Mangrove habitat, Semi or less pronounced mangrove habitat and Transitional or hinterland mangrove habitat.

True or Typical Mangrove habitat:

This zone covers the lowermost part of the river system, just away from the estuarine mouth where tidal flats are associated with maximum numbers of creeks and channels. Here the salinity is lower than the river mouth but tidal velocity is higher as the flow enters into the creeks. Vegetation is mainly dominated by Rhizophora apiculata, R. mucronata, Kandelia candle, and Aegiceras corniculatum. Common associate in this type are: Excoecaria agallocha, Bruguiera gymnorrhiza, Xylocarpus granatum, X. mekongensis, Avicennia officinalis, A. alba, Ceriops decandra, Dalbergia spinosa and Phoenix paludosa. Finlaysonia obovata, Derris scandens, Tylophora tenuis, Sarcolobus globosus and Hoya parasitica are found as common climbers in this zone. Most of the species in this typical mangrove formation are adapted by formation of stilt roots and vivipary for survival and easy regeneration. All the above-mentioned plants are associated in Dhulibhasani, Ajmalmari, Matla, Netidhopani, Chamta, Chandkhali, Panchamukhani and other forest blocks.

Semi or less pronounced mangrove habitat:

This habitat occurs in the middle part of the riverine system which is slightly elevated from the former type and is associated with less number of tidal creeks. As this part is further away from the sea and nearer to the fresh water source, the salinity is less and sticky, muddy condition of the soil becomes very prominent. This habitat is mainly dominated with Sonneratia apetala, Heritiera fomes, Nypa fruticans, Excoecaria agallocha in association with Brownlowia tersa, Sonneratiua caseolaris, Xylocarpus mekongensis, Bruguiera gymnorrhiza, Avicennia officinalis, Aglaia cuculata, Cerbera manghas, Intsia bijuga, Cynometra iripa (occasionally found), and Phoenix paludosa. Some common shrubs, climbers, grasses and sedges in this formation are Acanthus ilicifolius, Clerodendrum inerme, Caesalpinia bonduc, Sarcolobus carinatus, Derris trifoliate, Pentatropis capensis, Solanum trilobatum, Flagellaria indica, Myrostachia wightiana, Porteresia coarctata, Crinum asiaticum, Cyperus exaltatus, Fimbristylis ferruginea, Scirpus articulatus etc. Most of the tree species in this zone produce knee roots, pneumatophores, peg-like woody root suckers and buttresses to withstand the less aerated condition of the muddy soils and to support their massive boles. These adaptive features give a distinct stamp to the overlying topography, distinguishing this zone as less pronounced or semi mangrove formation from the previous zone. All the above-mentioned plants are found in Harinbhanga, Pirkhali, Khatuajhuri, Arbesi and other forest blocks.

Transitional or hinterland mangrove habitat

This habitat lies towards the hinter part of the river system where tidal flats are more elevated and creeks and channels are suddenly shut off due to formation of natural sand bars. These areas are usually devoid of regular tidal flow. This zone is mostly dominated by Clerodendrum inerme, Avicennia officinalis, Derris scandens, Thespesia populnea, Pongamia pinnata, Acanthus ilicifolius and Acrostichum aureum. Further increase in elevation, deposition of sand and accumulation of more organic matter towards the high limit are found associated with fresh water elements like, Syzygium rusifolium, Carissa spinarum, Ochna obtusata, Manilkara hexandra, Diospyros cordifolia, D. buxifolia, Trewia nudiflora, Salacia chinensis, Aristolochia indica etc. Most of the species in this habitat do not show any adaptive features like stilt roots, pneumatophores and vivipary. This formation may transit successfully towards non-saline zone. The plants are associated towards the most inner part of the islands and found in Basanti, Canning, Gosaba, Marichjhapi, Sajnakhali and other forest blocks.

Salt Marsh forest

Some areas within the mangrove forest blocks become dried up and slightly elevated along its margins due to deposition of sands and other debris. Owing to these microtopographic changes, the rate of outflow of saline tidewater decreases gradually and eventually the outflow comes to a halt on the shallower places. Accumulation of saline water and high evaporation rate on these areas render the soil hypersaline in comparison to the adjacent mangrove swamps. Thus the areas suffer from regular tidal inundation and remain physiologically dry with high concentration of salts.

Common plant species growing on this habitat are Sesuvium portulacastrum, Heliotropium currasavicum, Suaeda maritima, Suaeda nudiflora, Suaeda monoica, Salicorria brachiata, Arthroenemum indicum, Tamarix troupii, Aleuropus logopoides, Scirpus littoralis and other halophytes.

4.1.4. Vegetation of the sea shore

Open beach forest

Open beach forests are mainly divided into two major types that are areas under the influence of regular inter-tidal sea waves and areas above the influence of regular sea waves. Inter-tidal areas of the open beaches are devoid of any vegetation due to unstable nature of sandy beaches. In the supra-tidal regions where the areas are more or less semi-stabilized or stabilized with loose sandy grains, the following sand binders are common such as: Ipomoea pes-caprae, Hemathria compressa, Canavalia gladiata, Vigna marina, Cyperus arenarius, Aristolochia indica, Fimbristylis dichotoma, Gisekia pharmacoides, Hybanthus cnneasperma, Imperata cylindrical, Launaea sarmentosa, Rivea hypocrateriformis, Rothia indica, Oldenlandia biflora, Saccharum spontaneum, Vetiveria zizanoides, Wedellion biflora and others.

Sandy dunes/back dunes/ sandbar vegetation

Just behind the open and flat sand beaches in the supra-tidal habitat there are formation of small sand dunes. Only a few plant species can tolerate the stresses of a dune environment, particularly frontal dune sites. Only a few plant species can tolerate the stresses of a dune environment, particularly frontal dune sites. Foredune plants must be able to survive being buried by blowing sand, sand blasting, salt spray, salt water flooding, drought, heat, and low nutrient supply. In these areas, perennial herbs and grasses such as *Alternanthera paronychiodes, Alysocarpus vaginalis,* and others exist.

Plantation on beach and dunes

For protection of seashore wind following species are planted along the open cast sands: Casuarina equisetifolia, Prosopis chilensis, Thespesia populnea, Acacia auriculaeformis, Eucalyptus tereticornis, Lannea coromandelica and others.

Whittaker, (1962) and Karim, (1988), proposed a simplified classification of mangrove vegetation, based on dominance of a single species. Although classified as a mono-dominant forest types, these categories of forest vary in their floral assemblage and proportions of species depending on the site condition. The categories are listed below.

1. Grass type: Dhani ghas (*Porteresia coarctata*) and Nol khagra (*Phragmitis karka*) are the dominant in this vegetation type. They are abundant and occur in the newly accreting mud as a distinct zone or may be associated with Keora, Bean, Golpata. Wetlands within the Sundarban possess both Nol khagra and Hogla (*Typha elephantine),* which form extensive patches of marsh vegetation surrounded by dense forest vegetation.
2. Golpata type: This palm occurs along river banks and creeks. A zone of grass, Keora or Bean trees may occasionally be found in front of this zone, along the banks of larger water courses.
3. Bean dominance type: The genus *Avicennia* is represented by three species in the Sundarban of which only *Avicennia marina* was found to cover reasonable sized patches in pure composition in the south with high saline zones. Sometimes it forms mixed vegetation with *Aegicerus corniculatum* and *Aegialitis*

rotundifolia. The other two species (*Avicennia alba* and *Avicennia officinalis*) generally don't exist as a dominant species and found along the river banks and occur in association with other mangrove plants in relatively low saline regions.

4. Keora dominance type: Always on the newly accreting mudflats as pioneer species, this species generally forms monospecific stands of a few trees to a patch of several hundred meters. *Golpata*, *Avicennia marina* and Khulshi (*Aeigicerus corniculatum*) are the common associates of this dominance type. Regeneration of Gewa was found to occur under the mature trees of Keora.

5. Gewa dominance type: They occupy a very large part of the Sundarban, and are found in a verity of saline regime. The associate of this dominance type varies from pioneering trees like Keora to late seral species such as Sundri and even *Tamarix indica*. However, Goran is the most common associate of the Gewa in the Sundarban. Hental forms a distinct belt of forest either in pure patches or in association with Gewa in elevated river ridges.

6. Sundri dominance type: Similar to Gewa, Sundri is also found throughout Bangladesh Sundarban, often occurs as mixed vegetation associated with Gewa, Passur, Amur, Shingra, Bean and Goran and is sometimes found as monospecific types in the back-swamps.

7. Kankra dominance type: This type represents one of the most luxuriant attractive vegetation in the Sundarban but is restricted to small north-central part of the Sundarban. The dominant tree, Kankra (*Bruguiera gymnorhiza*), and its umbrella like structure, form an unbroken canopy along with the major associate Sundri and is often form as monospecific stands. The other tree species associated with this type are Gewa, Passur and Bean.

8. Goran dominance type: Goran can form an impenetrable scrubby thicket. It occurs as undergrowth associated with scattered Gewa or Sundri in the eastern part of the forest.

4.1.5. Geomorphology, sedimentation & Topography

Fluvial surfaces are response units to the interaction of stream erosion, accretion and vegetation. Each of them provides a unique habitat representing a potential niche for vegetation development. Geological and tectonic activity, together with past and present drainage patterns has been instrumental in defining the present geomorphology of the Sundarban. Here, at least four morphometric categories could be discernible, i.e., river or stream creeks, mudflats, ridges and back swamps, one grading into the other and responding to the changes in the fluvial process. While the geomorphic process largely determines the development of mangroves in a region, they are important mainly in producing certain substrate or soil condition and regulating the inundation time and frequency. Analysis of vegetation along the gradient of landform reveal that species assemblage pattern changes with the changing pattern of landform and its position in relation to the elevation from the sea level (Figure. 3.31). Thus, hydrological factors (sedimentation, drainage density etc) that change the morphometric pattern of the landscape have bearings on the vegetation development in the Sundarban. The Sundarban are low elevated isolated (like islands) landmasses under strong tidal influence. Plants have special adaptation to survive in saline condition using pneumatophores. There are variations of vegetation composition within the Sundarban due to the variation of physical factors: topography, salinity, soil condition and tidal variation. Different ecological niches of the Sundarban and occurring plants are shown in Table3.13.

Plants and animals occurring to particular niches are important bio-indicators to identify habitats and

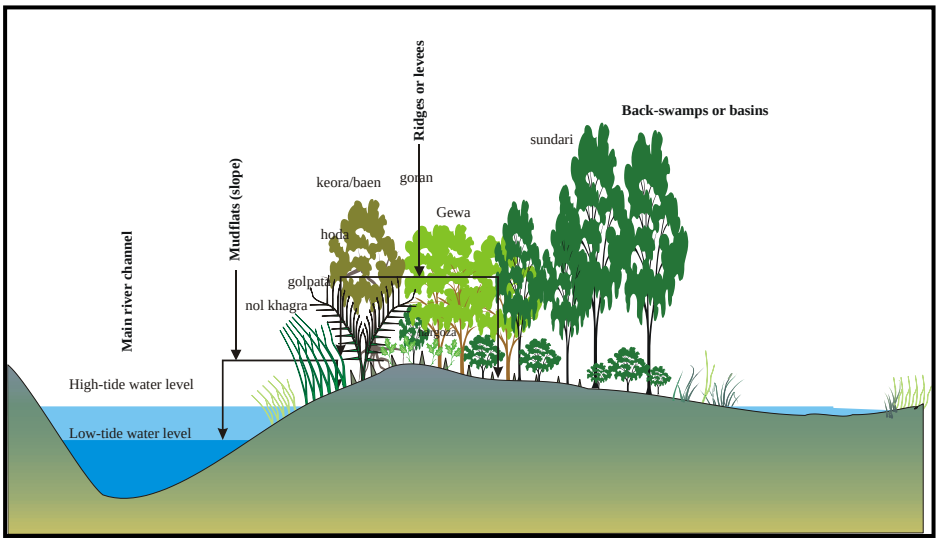


Figure 3.31. Profile of vegetation along the geomorphic gradient (after: CEGIS 2001)

monitoring changes due to climate change and destruction of habitats from climatic and anthropogenic causes. These niches are also breeding grounds for particular animals like Gangetic dolphins and Irrwaddy dolphins. Destruction of these habitats will cause damage to niche plants and animals. These bio-indicators and ecological niches should be taken into considerations while developing a SRF conservation and management plan.

Table3.13. Profile of vegetation along the geomorphic gradient

Ecological Niche	Occurring Plants
Mudflats (slope)	Hoda (*Acrostichum aureum*), Nol-khagra (*Phragmties karka*), Dhanshi (*Myriostachya wightiana*), Golpata (*Nypa fruticans*) and Hargoza (*Acanthus ilicifolius*)
Ridges or levees	Hargoza (*Acrostichum aureum*), Golpata (*Nypa fruticans*), Hantal (*Phoenix paludosa*), Baen (*Avicennia officinalis*), Kakra (*Bruguiera gymnorrhiza*), Keya katta (*Pandonus foetides*), Keora (*Sonneratia apetala*) and Dhundul (*Xylocarpus mekongensis*) and Keora (*Sonneratia apetala*)
Back-swamps or basins	Sundri (*Heritiera fomes*), Dhundal (*Xylocarpus mekongensis*), Gewa, (*Excoecaria agallocha*) Passur (*Xylocarpus mekongensis*), Kakra (*Bruguiera gymnorrhiza*) , Amoor (*Amoora cuculata*), Singra (*Cynometra ramiflora*) and Keya (*Pandonus foetides*)
Main river channel	Golpata (Nypa fruticans)
Tidal creeks	Chanda lota (*Dalbergia spinosa*), Gila (*Derris trifoliata*), Abeta (*Flagellaria indica*), Bowali lata (*Sarcolobus globisus*)
Bay or sandy shore	*Ipomoea pes-caprae, Paspalum sp., Suaeda maritime, Cynodon dactylon*

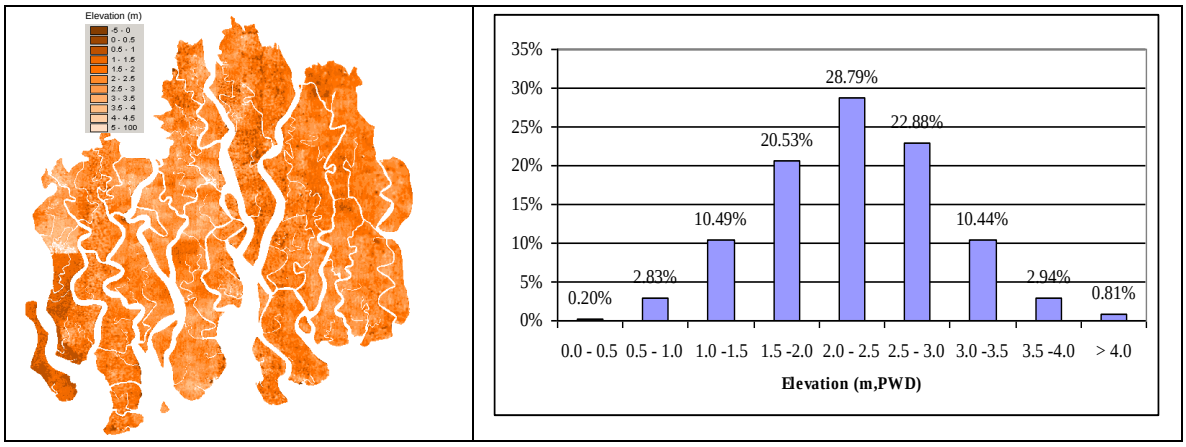


Figure 3.32. Topography of Sundarban; Source: CEGIS 2006

The topographical distribution of Sundarban varies from 0.5 meter to 4.0 meter with respect to mean sea level as shown in Figure 3.32. Inside the Sundarban the tidal fluctuation ranges from 1.5 to 2.5 meter. Approximately seventy percent of the land lies between 1.5 to 3.0 meter elevation, which goes under water in regular tidal flooding twice a day. But almost 85% of the land goes under water during high tide in the monsoon season.

4.1.6. Historical changes in vegetation

Geological evidences suggest that the Bengal Basin tilted eastward during the 12th Century because of the neo-tectonic movement. The rising of the western part of the delta separated the ancient branches of the river Ganges from the area, which today comprises the Indian and western part of Bangladesh. This alteration in the course of the main river resulted in a reduction of freshwater flowing into the western part of the delta. This in turn, led to accretion at the river mouth and an increase in saline water intruding into the western part of the delta. The lack of freshwater to the western part has had significant effects on the floristic composition of the forests. For instance, according to some studies of fossil pollen, *Sundri* was a dominant arborescent species in the Kolkata region about 5,000 years ago. However, the Indian Sundarban as well as the western part of the Bangladesh Sundarban no longer supports a healthy population of this species, which requires fresh or slightly saline water. Presently, it is dominant only in the eastern part of the Bangladesh Sundarban. On the other hand, more saline tolerant species become dominant in the western part of the Sundarban forest.

4.1.7. Change of vegetation in between 1985 and 1997

The pattern of vegetation succession in the Sundarbans depends upon the development stages of the land building process under particular sets of the fluvial regime. Salinity gradients, which in turn depends on the quantity of freshwater flushing from the upstream, also play an important role in shaping the vegetation development. The Sundarbans vegetation consists of recurrent patches of vegetation types. Overall, the mosaic formed by these patches represents the equilibrium for the whole

ecosystem. It is however argued that the mosaic of forest types represents the serial stages towards an equilibrium condition of vegetation development (Karim, 1988). Depending on the stresses, both biotic and abiotic including management conditions there are a number of self-maintaining terminal stage of vegetation development which differ from the traditional concept of climax. The most favourable development of vegetation occurs in the freshwater dominating area where the Sundari is the dominant plant. Another extreme condition under the high salinity terminal community is dominated by the Goran, which is a thicket of scrub. In both cases, grasses and/or trees dominate the initiating and pioneer stage of vegetation development.

The floristic composition of different successions depends upon the species niche and the physical conditions of each specific site. At the present level of information, potential changes in hydrology due to the changing flow of freshwater from upstream could best be understood by a comparison of salinity of the eastern region with that of the western region and its significance on the structural characteristics of vegetation. An attempt is made here to detect the changes in the floristic composition occurring between 1985 and 1997, when the freshwater flow into the Sundarbans was gradually decreasing. The data source for calculation was obtained from the forest department as two vegetation maps depicting polygons of different dominant plant communities. The vegetation class codes are presented in Table 3.13 and the changes, detected by overlying the two maps, are provided in Table 3.14 and Figure3.34. Table 3.15 provides the comparison matrix between the years 1985 and 1995.

During this period, major changes have occurred in the Sundari and Gewa dominated areas, as Gewa is gradually replacing Sundari as the dominant tree species. Pure Sundari dominated areas reduced by about 86 km^2 or about 11 percent of their previous extent, most of which are converted into the Sundari-Gewa and Sundari-Passur-Kankra community. The Sundari-Gewa community also followed a decreasing trend, as it lost 146 km^2 or more than 10 percent of its land to the Gewa-Sundari and Gewa-Mathal community. So the overall shift is from Sundari to Gewa and from Gewa to other more saline tolerant species. A similar trend is also visible even in the higher saline zone where the high saline loving Goran is replacing the Gewa and Sundari. Keora dominated areas have also increased from 37 km^2 to 79 km^2 resulting in an expansion of 43 km^2 or 110 percent. Grass and Bare Ground areas have also increased by about 15 km^2.

The general trend during this ten-year period indicate the reduction of commercially valuable species like the Sundari and Gewa and increase of less valued smaller tree species. From the map (Figur3.33) it is evident that the changes that occurred during this period are mostly concentrated in the eastern part of the Sundarbans. This might be because of the changed scenario of the salinity regime in the eastern belt due to decreasing freshwater influx from the Gorai River. The vegetation community in the western region seems to be more stable as the hydrological regime in this area remained stable during the period.

Table 3.13: Vegetation class codes

Class code	Description
0	Water
1	Sundari

2	Sundari-Gewa
3	Sundari-Passur
4	Sundari-Passur-Kankra
5	Gewa and Gewa-Mathal (Coppice)
6	Gewa-Goran
7	Gewa-Sundari
8	Goran
9	Goran-Gewa
10	Passur-Kankra
11	Passur-Kankra-Baen
12	Baen
13	Keora
14	Grass and Bare Ground
15	Tree Plantation
20	Sandbar

Table 3.14: Comparison matrix of area change between 1985 and 1997 in different vegetation composition classes

Year	Year 1997																
1985	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	20
0																	
1		608	134	4	11	3	1	70					2	1	3		
2	2	111	806	3	3	29	13	221		1	1	1	4	7	5		1
3		2	2	17				1									
4		4	1		57							3			1		
5		1	22		1	108	7	28	1	4				12	7		1
6			10			25	275	14	3	37				3	4		1
7	1	22	78	1		40	13	421		4		2	2	8	4		1
8							3		56	18				2	5		
9			1			4	35	4	22	497		1		1	7		1
10								1			1	5			1		
11			1		1			1		1		13					
12									1				3	2	2		
13			1			1	1	1						28	2		1
14		1	5			2	1	2		1				13	17		2
15		1	1												1	1	
20														2	1		1

Note: Area in km^2; numbers in highlighted diagonal line remained unchanged during this period

Table 3.15: Change of area from 1985 to 1997

Vegetation communities	1995	1987	Difference	% area of 85 remaining	% area of 97 remaining unchanged

				unchanged in 97	from 85
Water	4.46		4.46		
Sundari	750.30	836.50	-86.20	72.70	81.05
Sundari-Gewa	1061.70	1208.29	-146.59	66.70	75.91
Sundari-Passur	24.71	21.84	2.88	77.40	68.39
Sundari-Passur-Kankra	73.94	67.32	6.63	85.18	77.54
Gewa and Gewa-Mathal (Coppice)	213.86	193.40	20.46	56.05	50.69
Gewa-Goran	348.96	373.70	-24.74	73.52	78.74
Gewa-Sundari	764.83	597.97	166.86	70.44	55.07
Goran	83.34	85.50	-2.16	65.35	67.04
Goran-Gewa	563.70	571.87	-8.17	86.87	88.13
Passur-Kankra	2.86	9.55	-6.70	15.65	52.36
Passur-Kankra-Baen	25.85	16.77	9.08	78.29	50.80
Baen	11.47	9.28	2.19	32.48	26.28
Keora	79.32	36.61	42.71	75.62	34.91
Grass and Bare Ground	58.91	43.68	15.23	38.63	28.64
Tree Plantation	2.10	3.52	-1.42	31.20	52.26
Sandbar	9.45	3.97	5.49	26.54	11.14

Source: Forestry Department

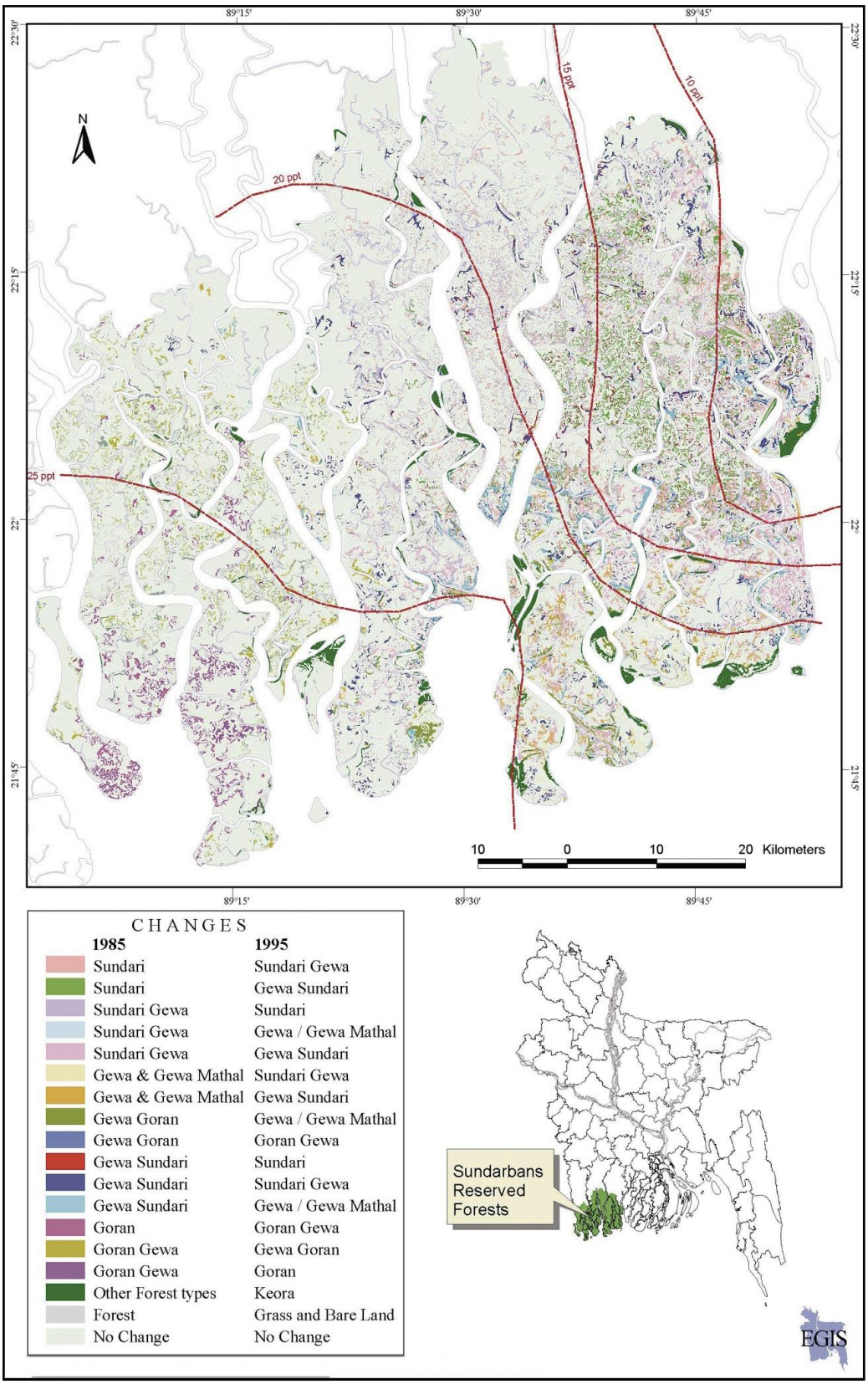


Figure 3.33: Change of floristic composition between 1985 and 1997

Table 3.16: Changes of species assemblages of Mangroves in Indian Sundarbans from 1999 to 2015

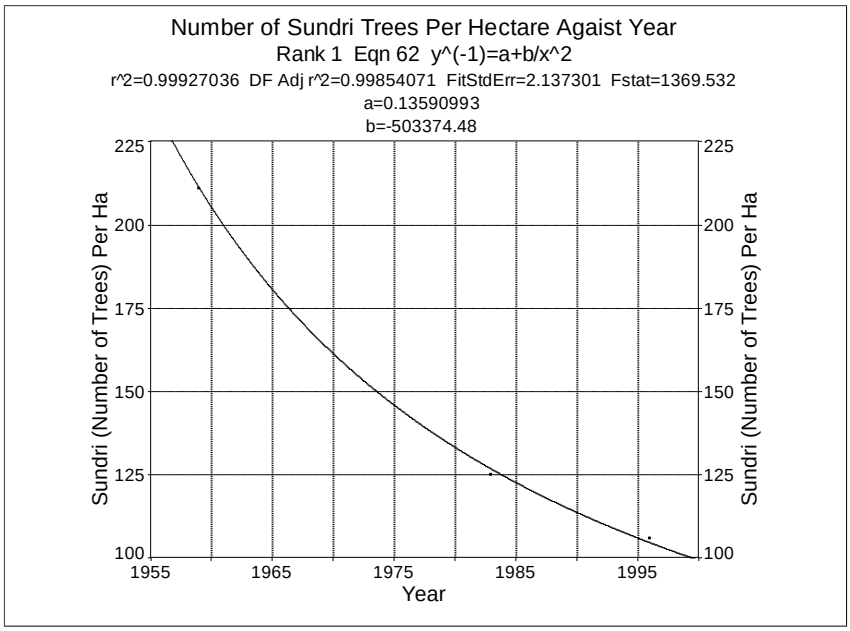
Species Assemblages	**1999 Area (Ha)**	**2015 Area in (Ha)**	**Change**
Ceriops Excoecaria	8,922	4,901	(4,022)
Excoecaria Heritiera	6,627	212	(6,416)
Excoecaria Rhizophora Cereops	5,183	23,774	18,591
Excoecaria Phoenix	39,510	59,400	19,889
Aonneratia Phoenix	4,266	6,588	2,323
Avicennia Aegiceras Cereops	48,646	45,440	(3,206)
Avicennia Bruguiera Cereops	38,973	19,830	(19,143)
Avicennia Cereops Aegiceras	27,470	32,659	5,189
Ceriops Phoenix	17,599	6,326	(11,273)
Phoenix Xylocarpus Aegiceras	5,922	3,268	(2,655)
Cereops Excoecaria Heritiera	203	419	216
Saline Blanks/Mudflat	10,509	4,631	(5,878)
Beach	435	245	(190)

The last inventory of Sundarbans was done in 1995-96 from FRMP. The gist of these three inventories is as under.

Growing Stock of Sundarbans at Different Inventory Time

Sl No	Inventory done by	Year of publication of Inventory Results	Sundri (Number of Trees per Hectare, having DBH 15Cm and above)	Gewa (Number of Trees per Hectare)	All Tree Species (Number of Trees per Hectare)
1	Forestal and Forestal Engineering, Vancouver, Canada.	1959	211	61	296
2	Overseas Development Authority, UK.	1983	125	35	180
3	Forest Resource Management Project (FRMP) Forest Department, Government of Bangladesh	1996	106	20	144

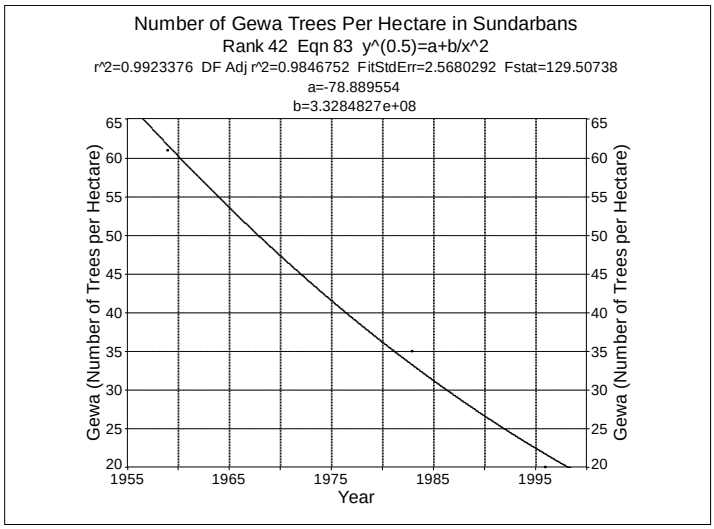
Analyses of these data resulted the following.



Based on this model the number of Sundri trees per hectare in certain years will be as under.

Sl No	Year	Number of Sundri Trees Per Hectare	95 Pred -	95 Pred +
1	1990	114	87	141
2	2000	99	72	126
3	2010	88	61	116
4	2020	**80**	53	107

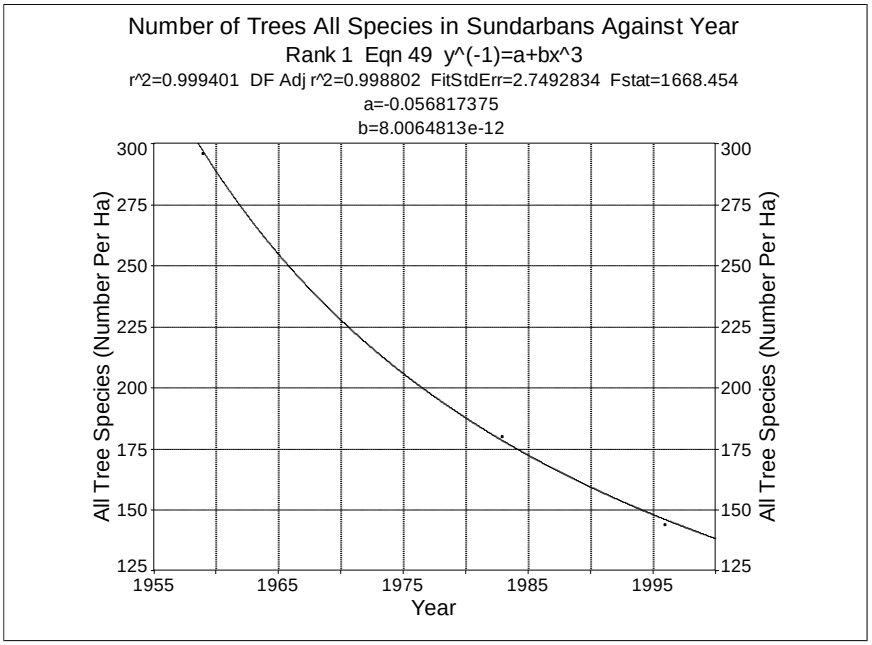
The analyses and projection of the number of Gewa stems based on these inventories resulted the following.



Based on this model, the number of Gewa trees per hectare in certain years will be as under.

Sl No	Year	No Of Gewa Trees/Ha in Sundarbans	95 Pred -	95 Pred +
1	1990	27	-6	60
2	2000	19	-15	52
3	2010	12	-21	46
4	2020	**7**	-27	41

Similar modelling using the total number of stems resulted the following.



Based on this model the total number of trees per hectare in certain years will be as under.

Sl No	Year	Total Number of Trees Per Hectare in Sundarbans	95 Pred -	95 Pred +
1	1990	159	124	194
2	2000	138	103	173
3	2010	122	87	157
4	2020	**109**	74	144

If this trend continues in the year 2020 the number of Sundri trees with DBH 15 Cm & above will decline to 80 per hectare, the number of Gewa trees per hectare will decline to 7 and the total number of trees per hectare will decline to 109.

4.2. Wildlife and fisheries of the Sundarban

Wildlife literally means the life forms (animals and plants) living in the wild, i.e. the life forms living independently of humans. The literal meanig is very broad, so different countries use different definitions for wildlife, but always focusses on higer taxa. The Wildlife (Conservation and Security) Act 2012 of Bangladesh defines wildlife as 'different varieties and species of animals and different stages of their life cycle having wild origins.' Rich plant and invertebrate aggregation ensures diverse habitats and food for wide range of vertebrate wildlife. One reason for the species richness, particularly of birds (Khan 2005), is that the Sundarban is a forest as well as a wetland with mudflats, sandflats and sea beaches. That is why it can harbour both forest species and wetland species. As many as 447 species of vertebrate wildlife (amphibians, reptiles, birds and mammals) are known to occur in the Sundarban, including some charismatic and/or globally threatened species. The fauna of the Sundarban has attracted much attention because of the huge economic importance of many species.

4.2.1. Different types of wildlife and their habitat

The Sundarban ecosystem thrives in a very delicate balance between the freshwater and saline water, and between the high tide and low tide. The wildlife of this ecosystem is adapted accordingly. Therefore, any imbalance will lead to an impact to the wildlife community and adversely affect the wildlife community. The rivers, canals and wetlands as well as the islands of mangrove forests provide a unique ecosystem for wildlife, but the Sundarban also has some huge grassland pockets and extensive and diverse aquatic and semi-aquatic habitats. The mangroves are habitats for a wide variety of wildlife, but some of them are mangrove specialists and occur only in mangroves. The Sundarban also support many unique species, like the Bengal Tiger (Panthera tigris), the Sundarban is the only mangrove forest with a species of the tiger. Most of the wildlife, particularly the megafauna, of the Sundarban prefer diverse habitat like grassland-forest mosaic.

This type of area is ideal for the Spotted Deer, because it can feed in relatively open grasslands and 'keora' (*Sonneratia apetala*) dominated areas, and can take shelter in forests. Therefore, the southern areas of the Sundarban with grassland-forest mosaic are known to support healthy population of the Spotted Deer. Healthy population of the Spotted Deer means higher carrying capacity for the Tiger, because as much as 80percent of the Tigers diet (in the form of biomass) comes from only one species - Spotted Deer (Khan 2008b, 2012). According to Schaller (1967), Sunquist (1981), and Johnsingh (1983), tigers do not normally kill prey in open habitats including short grass. Therefore, grassland-forest mosaic is ideal for the Tiger as well, because it offers enough cover for stalking.

The Tiger's main requirements are a sufficient supply of large prey, enough cover for stalking and access to water (Sunquist and Sunquist 2002), which are available in the Sundarban, particularly in the southern Sundarban. Tigers are not tied to a particular habitat type or temperature regime and they have a few ecological constraints that relate to specific habitat requirements (Miquelle *et al.* 1996). While tigers survive in a variety of habitat types, they live at higher densities in areas with high prey biomass (Sunquist *et al.* 1999, Sunquist and Sunquist, 2002). According to Smith *et al.* (1998), good quality habitat is important for the tiger's existence: when the good quality habitat drops below 50percent, tigers no longer breed successfully; when it drops below 30percent, tigers no longer occur in an area.

Both male and female Tigers use scratching to mark their territories (Smith *et al.* 1989). This action perhaps also sharpens the claws by peeling off any thin, loose or desquamated strips of laminae from the surface that are ready to flake off, either on the top of the claw or along the sides and thickened margins (Wyne-Edwards 1962, Kotwal and Mishra 1995). Trees with soft bark having a good amount of sap were more frequently scratched than those having rough bark, though the latter were more abundant (Khan and Chivers 2007). Although the tiger is known to be a habitat generalist (Nowell and Jackson 1996), its preference for soft-barked trees is just one example that how different components of a diversified habitat can be useful for its daily life. This again emphasizes the importance of conserving the entire landscape for the conservation of the tiger.

The aquatic habitat of the Sundarban, i.e., rivers and estuaries, are used by the Estuarine Crocodile (*Crocodylus porosus*). It uses rivers and estuaries for foraging and hunting fish, and uses the riverbanks for basking and egg-laying. A total of four species of dolphins occur in the Sundarban rivers and estuaries, viz. Ganges River Dolphin (*Platanista gangetica*), Irrawaddy Dolphin (*Orcaella brevirostris*), Finless Porpoise (*Neophocaena phocaenoides*) and Indo-Pacific Hump-backed Dolphin (*Sotalia chinensis*) (Khan 2008a, Smith *et al*. 2008). There are reports of natural immigration and colonization of non-mangrove species of flora and fauna along the eastern and northern boundaries of the Sundarban. In most of the cases these species cannot establish to the mangorves permanently. The wildlife from the surrounding village groves occasionally visit the Sundarban in search of food, but they return to the village groves after foraging in the Sundarban, because there are competitors and the mangrove habitat is not necessarily suitable for permanent colonization of those species.

4.2.2. Faunal diversity of the Sundarban

The 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 Sundarban, leading to both floral and faunal diversity in this mangrove forest. The faunal diversity of the Sundarban is discussed below:

Terrestrial Mammals

The Tiger is the supreme flagship species of the Sundarban. This large carnivore is at the top of the ecological pyramid of the mangrove ecosystem, and the conservation of theTiger will lead to the conservation of the unique biodiversity of the Sundarban. It is a globally Endangered (IUCN 2012) and nationally (in Bangladesh) Critically Endangered species (IUCN-Bangladesh 2000).

Three species of large mammals; i.e. Spotted Deer, Wild Boar and Rhesus Macaque (*Macaca mulatta*); together comprise 95percent of the biomass consumed by Tigers in the Sundarban (Khan 2008b). Therefore, the Tiger cannot survive in the Sundarban without these three species, particularly the Spotted Deer that alone contributes 80percent of the biomass consumed by tigers (Khan 2008b). The Spotted Deer is the dominant and most gregarious prey species in the Sundarban, which is very important speceis in a sense that it is the main prey base of the Tiger. It is also a tourist attraction since it has beautiful coat and, unlike the Tiger, it is easily seen by tourists. It is primarily a grazer (Mishra

1982) and one possible reason for its abundance is that after the extirpation of Javan Rhinoceros and Wild Water Buffalo it is virtually the only grazing ungulate there. The Spotted Deer population has been variously estimated from 80,000 (Tamang 1993) to 83,000 (Dey 2007). The highest density of the Spotted Deer was in grassland-forest mosaic in the southern part of the Sundarban. The Barking Deer population in the Sundarban is low (2,150 according to Dey 2007), because it is selective feeder that feeds on rich but scarce food items such as shoots and fruits (Karanth and Sunquist 1992). The Fishing Cat is very difficult to see, but it occurs throughout the Sundarban. The Wild Boar population in the Sundarban has been variously estimated from 20,000 (Tamang 1993,) to 28,000 (Dey 2007). The Rhesus Macaque population in the Sundarban has been variously estimated from 40,000 (Tamang 1993) to 51,000 (Dey 2007).

Aquatic Mammals

Other than the Tiger, many important species of mammals occur in the Sundarban, of which four species are aquatic mammals, viz. Ganges River Dolphin (*Platanista gangetica*), Irrawaddy Dolphin (*Orcaella brevirostris*), Finless Porpoise (*Neophocaena phocaenoides*) and Indo-Pacific Hump-backed Dolphin (*Sotalia chinensis*) (Khan 2008a, Smith *et al.* 2008). The first two species are common and year-round residents in the Sundarban, but the other two mainly occur in winter. The Sundarban supports healthy populations of two species of otters, viz. Oriental Small-clawed Otter (*Amblonyx cinereus*) and Smooth-coated Otter (*Lutrogale perspicillata*). They occur in small family parties, especially when foraging and feeding along the creeks. The population of the Oriental Small-clawed Otter in the Sundarban is about 20,000 individuals (Tamang 1993).

Fish

The Sundarban is exceptionally rich in fish species diversity, which has made the region an important commercial fishing ground. The Sundarban supports 53 species of pelagic fish in 27 families and 124 demersal fish in 49 families (Hussain and Acharya 1994). The mean fish biomass is 39 kg/ha, which is comparable to the Rhizophora-dominated forests of Malaysia (Huque, 2007). Of these, over 120 species of fish are reported to be commonly caught by commercial fishermen in the Sundarban. The fish diversity is directly related to the salinity gradients in different parts of the Sundarban. 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. The *Hilsa Ilisa* is the most economically important fish in the region.

The official production figures show sharp fluctuations from year to year, thus there is a need for systematic and collaborative fisheries stock assessment.

Reptiles and amphibia

Another flagship species in the Sundarban is the Estuarine Crocodile (*Crocodylus porosus*), which has been identified as a Critically Endangered species in Bangladesh (IUCN-Bangladesh 2000). The total population of the Estuarine Crocodile is thought to be around 200 (Khan 1982). A decline of crocodile population has been observed in the Sundarban, possibly due to indiscriminate killing (Hussain and Acharya1994, UNDP and FAO 1998). A number of interesting amphibians occur in the Sundarban, viz. Green Frog (*Euphlyctis hexadactylus*) and Crab-eating Frog (*Fejervarya cf. cancrivora*). Of the 17 species of snakes found in the Bangladesh Sundarban, 10 are sea snakes (Sarker and Sarker 1988). There are 4

species of marine turtles recorded in the Bangladesh Sundarban, of which Olive Ridley Turtle (*Lepidochelys olivacea*) is the most common (Khan 2008a). The River Terrapin is very rarely found in the rivers of the Sundarban, but Olive Ridley Turtle is occasionally found along the Sundarban coast. They lay eggs in the sandy shores of the Sundarban.

Birds

The total bird species that number 339, including 130 winter visitor species, recorded in the Sundarban is nearly half of the total bird species recorded in Bangladesh, while of the 12 species of kingfishers found in Bangladesh, 8 are found in the Sundarban (Hussain and Acharya 1994, Khan 2005). A few species of birds that can be cited as example are Mangrove Pitta (*Pitta megarhyncha*), Mangrove Whistler (*Pachycephala grisola*), Brown-winged Kingfisher (*Halcyon amauroptera*) and Collared Kingfisher (*Todiramphus chloris*) (Khan 2005). Others that prefer mangroves, but are not mangrove specialists include Oriental Small-clawed Otter (*Amblonyx cinereus*), Masked Finfoot (*Heliopais personata*), Lesser Adjutant (*Leptoptilos javanicus*), Water Monitor (*Varanus salvator*), Dog-faced Water Snake (*Cerberus rynchops*), Glossy Marsh Snake (*Gerardia prevostiana*) and File Snake (*Acrochordus granulatus*). Many species of the Sundarban are known to prefer grasslands, viz. Blue-breasted Quail (*Coturnix chinensis*), Red-wattled Lapwing (*Vanellus indicus*), Paddyfield Pipit (*Anthus rufulus*), Zitting Cisticola (*Cisticola juncidis*), Bengal Bushlark (*Mirafra assamica*), Grey Wagtail (*Motacilla cinerea*) (Khan 2005). Moreover, Spotted Deer (*Axis axis*), Wild Boar (*Sus scrofa*), Himalayan Crestless Porcupine (*Hystrix brachyura*), Burmese Python (*Python molurus*) are largely dependant on grasslands for food. Some directly feed on sungrass (*Imperata cylindrica*), others prey on organisms that occur in grasslands.

Invertebrates:

Crustacea account for by far the largest proportion of animal biomass, with an estimated 40 million kilograms of fiddler crabs and 100 million kilograms of mud crabs. The nutrient-rich waters of the Sundarbans also yield a considerable harvest of shrimps, prawns and lobsters. The area supports a varied insect population including large numbers of honey-bees, honey and beeswax being among the economically important products. The insect life of the Sundarbans has been little studied. Zafar and Mahmood (1989) recorded the zooplankton belonging to 13 taxa, such as Copepoda, Amphipoda, Mysidacea, Chaetognatha, Polychaeta, Lucifera, Hydromedusae, aceters, shrimp larvae, finfish larvae, crab larvae, squilla larvae and horse-shoe crab larvae. In the Sundarban a total of 32 species of butterflies have been recorded (Larsen 2004). Among the aquatic invertebrates, 24 species of shrimps in 5 families, 7 crabs in 3 families, 2 gastropods, 6 pelecypods and 8 locust-lobsters have been recorded from the (Hussain and Acharya 1994).

4.2.3. Status of Wildlife

Among the wildlife of the Sundarban, at least four species have become extinct since the beginning of the 20th century, which are Javan Rhinoceros (*Rhinoceros sondaicus*), Wild Water Buffalo (*Bubalus arnee*), Swamp Deer (*Cervus duvaucelii*) and Hog Deer (*Axis porcinus*) (Hendrichs 1975, Blower 1985, Tamang 1993, Hussain and Acharya1994, Khan 2008a). These species, except the Hog Deer (Khan 2008a), have also become extinct from whole Bangladesh. Baker (1887) had killed three rhinoceros in the Sundarban in 1881, and according to the Bengal District Gazetteer (1908) the rhinoceros became 'rare' as early as 1908 and was restricted in the southern Sundarban. There are three specimens of the

rhinoceros in the collection of the Indian Museum, Kolkata, and two of the specimens have recorded collecting sites: Chillichang creek and Mathabhanga river (Barisal district, now in Bangladesh) (Groves and Chakraborty 1983). The Bengal District Gazetteer (1908) mentioned that buffalo was 'fast disappearing' and was found only in the 'waste lands of the Backergunge portion of the Sundarban (eastern Sundarban)'. Groups of 8-10 buffalos were sighted in tall grass of the riverbanks in Sarankhola Range, Bangladesh Sundarban, until 1925-1930 (Khan 2004a). Jerdon (1874) mentioned the occurrence of the Swamp Deer for the eastern Sundarban. In 1914, the Bengal District Gazetteer mentioned that the Hog Deer is 'not uncommon', but being very shy, are seldom seen along the banks of streams in the northern Sundarban, while Curtis (1933) also noted the Hog Deer in the northern areas of the Sundarban. The Barking Deer (*Muntiacus muntjak*) is no longer seen in the Indian Sundarban (Sahgal *et al.* 2007), but it exists in the Bangladesh Sundarban where it is not rare, but difficult to see since it is not a grazer.

Some experts believed that Leopard (*Panthera pardus*) (Curtis 1933), Gaur (*Bos gaurus*)and Marsh Crocodile (*Crocodylus palustris*)(Blower 1985) were once found along the edge of the Sundarban. Since the names of these species did not appear widely in old documents, it is difficult to say whether they really had existed in the Sundarban, but originally the Sundarban had covered much wider area and the northern fringes of the forest was probably not typical mangroves. Therefore, the above mentioned wildlife could have occurred along the fringes, but not in the Sunderbans interior.

Tiger, Estuarine Crocodile, Spotted Deer and other wildlife that exist today existed earlier. All these megafauna had existed in greater numbers due to low level of poaching and anthropogenic disturbance. We do not have any record of population estimates of these species in the past, but earlier comments (Baker 1887, Bengal District Gazetteer 1908) clearly inticate that the megafauna that exist today were much more abundant in the past. As for instance, the Bengal District Gazetteer (1908) mentioned that 'tigers and crocodiles, however, are still as numerous as ever.' All the wildlife species of the Sundarban that have gone extince were megafauna. Since the Sundarban is still relatively intact as wildlife habitats, it can be concluded that overhunting by sport hunters and subsistence hunters is the main reason for the extinction of some wildlife. The Javan Rhinoceros was a prize game for sport hunters (both European and local elites) when it existed in the Sundarban. Subsistence hunting for meat was common in the Sundarban and the main targets were Wild Water Buffalo and different species of deer, since deer meat is considered a delicacy in the locality. Still today, Spotted Deer poaching for meat is a formidable threat to the species and to the Tiger that depends on it.

Other than the Tiger, the Sundarban tract provides extensive habitats for some globally threatened species. These are River Terrapin (*Batagur baska*), Olive Ridley Turtle, Masked Finfoot (*Heliopais personata*), Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*), White-rumped Vulture (*Gyps bengalensis*), Pallas's Fish Eagle (*Haliaeetus leucoryphus*), Greater Spotted Eagle (*Aquila clanga*), Lesser Adjutant (*Leptoptilos javanicus*), Fishing Cat (*Prionailurus viverrinus*), Smooth-coated Otter (*Lutrogale perspicillata*) and Ganges River Dolphin (IUCN 2012, BirdLife International 2001).

The Masked Finfoot is a rare breeding resident of the Sundarban that mainly occurs in the eastern half of the Sundarban. Its population appears to have declined after the two devastating cyclones - Sidr and

Ayla. There is no recent sighting of the Spoon-billed Sandpiper in the shore of the Sundarban, but there are old records. Both White-rumped Vulture and Pallas's Fish Eagle are rarely found in the northern Sundarban. The Greater Spotted Eagle is rarely found in the riverbanks or shores of the Sundarban. The Lesser Adjutant is a common breeding resident in the Sundarban.

Since the Tiger is at the top of the ecological pyramid of the Sundarban, it is ecologically the most important species. At the same time it is the most economically important species, mainly because it attracts large number of domestic and foreign tourists. The urge of watching the Tiger brings the tourists to the Sundarban that generates a significant amount (Tk ca. 16.7 million per year) of revenue to the Government (International Resources Group 2009). The Sundarban of Bangladesh and India is believed to hold one of the two largest Tiger populations globally (Seidensticker *et al.* 1999, WWF 1999; Khan 2002, 2004a). However, there have been few studies which have used robust and repeatable methods to estimate the densities of tigers and prey in the region. Based on the most recent estimates using the remote camera-traps the mean total population of Tigers in in the Bangladesh Sundarban is 106 and in the Indian Sundarban 76, giving the grand total population of about 182 in the entire Sundarban landscape (Jhala *et al.* 2015).

4.2.4. Threats to Wildlife

The Sundarban today is about half the size it was a few centuries ago (Curtis 1933, Choudhury 1968, Hussain and Acharya 1994). The mangrove ecosystem of the Sundarban has grown in a delicate balance between the terrestrial and the marine ecosystems. The water salinity plays an important role in maintaining this balance. The threats to the ecosystem and biodiversity, wildlife in particular, of the Sundarban are from different sources, some are anthropogenic and some are effects of climatologically and deltaic changes/evolution with the anthropogenic factors relatively easy to control. The threats are documented below,

- The Sundarban is the only mangrove habitat in the world where wild Tigers exist and this impenetrable swamp offers natural protection to healthy populations of Tigers and their prey. Yet, both the Tiger and the Spotted Deer are poached in the Sundarban by professional as well as opportunistic poachers. Research findings (e.g. Khan 2010, 2011; Mohsanin *et al.* 2012) have indicated that the decline of Spotted Deer due to poaching is the principal limiting factor for Tiger population in the Sundarban. Other species of wildlife like Wild Boar, Estuarine Crocodile and Red Junglefowl (*Gallus gallus*) are poached rarely. Spotted Deer poaching is common and widespread in the Sundarban, because it is commonly found and relatively easy to catch by loop-traps or easy to shoot, but Tiger poaching is not common, because it is difficult to locate the tiger in a dense forest where it is thinly distributed. Other than poaching, retribution killing of Tigers is common in the villages along the border of the Sundarban. The retribution killing of Tigers could have a sizable impact on the long-term viability of the Tiger population (Chapron et al. 2008, Goodrich et al. 2008). Officially, on an average, a total of 3 Tigers are killed by people and 17 people are killed by Tigers every year in the Sundarban of Bangladesh, but the actual average figures are 5 and 27, respectively (Khan 2011). Moreover, tigers kill a total of about 80 livestock every year along the boundary of the Sundarban (Rahman et al. 2009).

- Overexploitation of the natural resources to meet the requirements of the growing population is a major threat to the wildlife habitats in the Sundarban. There is no permanent human settlement inside the Sundarban in Bangladesh, but other than the coast in the south, the entire forest is surrounded by densely populated villages. The people of these villages mainly depend on the natural resources of the Sundarban. More than 30 products are harvested from the Sundarban (Khan 2011).
- Studies suggest that coverage and density of larger diameter trees, canopy closure and diversity have declined over the last 100 years or so (Canonizado and Hossain 1998, Iftekhar and Islam 2004, Iftekhar and Saenger 2007). The ODA (Overseas Development Authority, UK, 1985) inventory documented overexploitation in the Bangladesh Sundarban due to excessive harvesting (legal and illegal). It was reported that two economically important species of trees, *Heritiera fomes* and *Excoecaria agallocha*, had been depleted by 40percent and 45percent, respectively, since the 1959 inventory. The legal harvest of *Heritiera fomes* has been suspended since 1990 due to declining stock, but some illegal felling continues (Canonizado and Hossain 1998). Moreover, patches of *Heritiera fomes* died, or in the process of dying, due to 'top-dying', which caused the dying of trees from the top. The scattered mangroves in the private lands around the Sundarban once used to serve as buffer, but these lands have been entirely converted for prawn culture (Khan 2002).
- The effect of shrimp culture is not only restricted to the buffer zones. The local people collect Tiger Prawn (*Penaeous monodon*) fry from the Sundarban, when more than hundred times of non-target fish and crustacean fry are destroyed. As many as 10,000 fishermen catch at least 10 metric tonnes of fish every day and in the process they destroy the fry and discard the bodies of 100 metric tonnes more of fish that are not considered edible. Fishing with poison (e.g., Sembush, Ripcord, Dhalai, etc.), i.e. by poisoning the creek water to catch poisoned fish easily and quickly, in recent years is a formidable threat to aquatic organisms as well as the whole ecosystem of the Sundarban. According to the local fishermen, the fish catch in the Sundarban has been reduced by 50percent over the last 10 years. Following the decline of fish and other aquatic organisms in the Sundarban, many of the aquatic wildlife like Estuarine Crocodile, dolphins, otters and aquatic birds and reptiles are declining rapidly.
- Changes in water salinity due to alteration of freshwater flow affect the mangrove communities, which could change vegetation pattern as well as status and distribution of wildlife. This reduction of freshwater flow is due to the construction of dams (mainly Farakka dam in West Bengal, India) and embankments, and overall increase of the upstream water use for agriculture and other purposes.
- The sea level rise due to global warming is a serious threat to the Sundarban and its wildlilfe in the long-term. Loucks et al. (2010) estimated that with a 28 cm rise of sea-level, which is likely to occur in the next 50-90 years, remaining Tiger habitats in the Bangladesh Sundarban would decline by 96percent and the number of breeding individuals would be reduced to less than 20. Serious erosion and land loss is evident in the western part of the Bangladesh Sundarban, particularly in Mandarbaria and Katka. In the Indian Sundarban at least four islands (Bedford, Lohachara, Kabasgadi and Suparibhanga) have already disappeared due to sea level rise and scientists predict that 25percent of the terrestial wildlife habitable area will be lost by 2020 (Sahgal et al. 2007).

- Pollution is a growing threat to the Sundarban ecosystem and wildlife, with at least 20 insecticides, 18 fungicides and 2 rodenticides, together with different types of fertilizers being used in the upstream of the Sundarban. These agro-chemicals are carried downstream in the Sundarban and incorporated into the food chain with biological magnification at higher trophic levels (Hussain and Acharya1994). Industrial waste is indiscriminately thrown into the river in the upstream of the Sundarban. Oil spills from ships cause instant mortality of mangrove seedlings, grasses, fish, shrimps and many other organisms. Two major oil spills occurred in 1994 and 2015 in the Bangladesh Sundarban, causing a lot of instant damage to the ecosystem and biodiversity, and long-term impacts have remained largely unknown. Mega-establishments in the vicinity of the Sundarban will not only increase the pollution risk, but will also stimulate urbanization and influx of people along the boundary of the Sundarban.
- Natural disaster like cyclones also cause a lot of damage to the vegetation and wildlife of the Sundarban, which are beyond human control, with about one-tenth of global tropical cyclones occurring in the Bay of Bengal (Grey 1968, Ali 1980), with approximately one strong cyclone per year (Islam and Peterson 2008).
- The Sundarban is the most popular tourist destination for both domestic and foreign tourists in Bangladesh. Majority of the tourists are not aware of conservation and they contribute to the pollution by littering a wide range of things and making a lot of noise. The sheer number of tourists, and the pollution and disturbance created by them is a growing concern for the wildlife of the Sundarban.

5. The socio-economic landscape

Conservation and management efforts in the Sundarban are mostly geared towards protection of biodiversity and habitat of animals and plants. While this is the case in most forest management activities around the world, there is growing recognition that natural resources play a key role in supporting the poor and are important in reducing their vulnerability to economic and environmental shocks. There is however, a tendency to underestimate the contribution of forest resources. For example, analysis of data from 17 countries found that 22 percent of household income for rural communities in forested regions comes from sources typically not included in national statistics, such as harvesting wild food, fuelwood, fodder, medicinal plants, and timber (Millennium Ecosystem Assessment, 2005). Thus, the role of forests in poverty reduction has so far not been reflected in any significant way in national level strategy in most countries, including Bangladesh and India. On the forestry side, reporting has typically been focused on the physical resource, its status and extent; yet data on socio-economic issues affecting forest change, dependency and interlinkages on forest resources are absent. In order to achieve sustainable management in Sundarban and reduce poverty of the dependent population both biophysical and socio-economic aspects need to be addressed.

The Sundarban region has been defined as the Sundarban Reserve Forests (SRF) and Ecologically Critical Area adjacent to the Sundarban (ECA) in Bangladesh and Sundarban Biosphere Reserve (SBR) in West Bengal, India (shown in Figure 1.1). The Sundarban region, thus defined not only represents the uninhabited mangrove forests but also adjacent inhabited areas that were historically forested and currently the populations living in the populated areas are directly dependant on the forest for their lives and livelihood. Analysis from different studies (IUCN 2014, CEGIS, 2013), however, show that the population which according to BBS (2011) is 2.5 million, residing in a 20 km wide radius surrounding the periphery are directly dependant on the Sundarban in Bangladesh, this 20 km area is often called the Sundarban Impact Zone (SIZ) (IUCN, 2014). Taking this information into account, the socio-cultural description of the narrative also includes the population of this corresponding area.

Five districts named Bagerhat, Satkhira, Khulna, Barguna and Pirojpur fall within the 20 km periphery. While the SBR covers 6 administrative blocks (Hingalganj, Hasnabad, Haroa, Sandeskhali –I,II, Minakhan) of North 24 Parganas district and 13 blocks (Canning - I,II, Basanti, Gosaba, Jaynagar – I,II, Mathurapur - I,II, Kultali, Patharpratima, Kakdwip, Namkhana and Sagar) in South 24 Parganas. Table 5.1 gives the demographic profile of the Sundarban in both countries.

Table 5.1: Demographic profile of India and Bangladesh Sundarban

Parameters	India Sundarban Biosphere Reserve (SBR) [a]	Bangladesh Sundarban Impact Zone (SIZ)[b]
	2011	***2011***
Total population	4,426,259	2,306,550
Male (%)	51.15	47.95
Female (%)	48.85	52.05
Density (per sq. km)	1089.2	560.3
Literacy rate	64.3	58.75

Source: *[a]Census 24 Paraganas (South) 2001,Census 24 Paraganas (north) 2001; Statistical Handbook of West Bengal 2010-2011; [b]Population & Housing Census 2001, Bangladesh Bureau of Statistics (BBS); Population & Housing Census 2011, Bangladesh Bureau of Statistics (BBS);*

The population suffers from several and similar dimensions of poverty in both the countries. The average per capita income in Indian part is about USD 0.5 per day while the corresponding figure for the Bangladesh part is about USD 0.9 per day. The data analysis in this chapter demonstrates how firmly forests underpin livelihoods, providing fuel, health, food and building materials. For example, in Bangladesh, the Sundarban provides employment for over 700,000 people people working as 'jaleys' or fishermen, 'bawalis' or woodcutters, 'mouals' or honey gatherers, shrimp fry collectors and nipa-leaf (*Nypa fruticans*) and thatching grass (*Imperata spp.)* collectors (Islam, 2010), and several million people benefit from these activities (Islam and Wahab 2005). Forest records that some 50,000 people from around the Sundarban enter the forest every day for their livelihood. In India, the livelihood of nearly 2 million people is linked with the Sundarban, which mainly include fishing, crab collection, honey and beeswax collection and allied activities (Singh et al, 2010). In both countries, with the moratorium on harvesting of timber, the livelihood opportunities are dominated by agriculture closely followed by fisheries. On the other hand modern services such as tourism and brackish water shrimp farming[19] have been gaining popularity since the late eighties.

However, the livelihood options of the population of the Sundarban are always constrained by the fragile ecology, climatic hazards and environmental degradation due to anthropogenic impacts. With the emergence of ecological, environmental and wildlife conservation perspectives, which are often exclusionary, some of the traditional as well as modern livelihood opportunities are also shrinking (Sen 2016; Allan et al, 2013; Kothari and Pathak 1998).

Interpreting the trend of the global sea level rise, scientists believe that a considerable land area in the Sundarban will be inundated in the coming decades. As such, precious land resources will further shrink and enhanced climatic hazards, following climate change, will further deteriorate and increase stress significantly. It is reported that inundated areas might increase up to 3 percent (2030) and 6 percent

[19] According FAO, in terms of aquaculture and farming, shrimp are marine creatures, while prawns live strictly in fresh water. In recent years cultivation of brackish water Bagda or tiger shrimp has increased considerably over golda or the freshwater prawn in Sundarban in both countries, so the term shrimp cultivation will be used in this chapter.

(2050) respectively, primarily in coastal low lying areas (0 – 30 cm, Khan et al., 2006, using upper estimates of sea level rise). Prolonged water logging and drainage congestion will result in permanent loss of agriculture land. The crop suitability in the Sundarban region will change significantly due to sea level rise induced salinity intrusion and tidal inundation.

The geo-climatic factors of Sundarban have considerable health effects also, including respiratory, gastrointestinal and musculoskeletal problems, as well as general weakness. Moreover, stagnation in infrastructural development such as road network, health care, education, water supply, sanitation, energy and communication facilities in the peripheral areas in Bangladesh has resulted in the decline of population in these areas over the last 10 years (Bangladesh Bureau of Statistics, 2011, shown in Table 4.2). In India, infrastructure development is slightly better, but still below the national or state average. The health and well being of the local population suffers due to environmental degradation coupled with inadequate infrastructure including communication, water supply, hygiene, and sanitation resulting in losses equivalent to around 5 percent of Sundarbans GDP in 2009 (World Bank, 2014).

Recent policy developments and activities in both countries indicate a growing awareness amongst the researchers and policy makers on the importance of mangroves and the multi-faceted consequences of their destruction (Singh et al 2010, IUCN, 2014). Nevertheless, programmes remain weak as information and basic understanding about the issues need more clarity and research and need further integrated planning for sustaining the livelihood of local communities. The people living around the Sundarban must be seen as part of the solution. It is important to bring the local communities into mainstream development processes, recognizing their different coping mechanisms, and including them in delineating risk management options. This implies that it is crucial to provide them access to education, skills, healthcare, information, and credit, which will increase their opportunity to share in societal wealth creation (Dercon 2010; Takasaki et al. 2004). With this perspective this chapter focuses on the socio-economic landscape and is detailed according to the following sections,

- Demography and migration
- Income level and poverty
- Forest dependant livelihoods
- Peripheral livelihoods
- Educational and public service facilities
- Transport and communication
- Inland navigation
- Sustainable tourism

5.1. Demography and migration

In the Sundarban, the co-existence of human settlements and reserve forest is unique, there is no human settlement within the reserve forest area, yet a large population depends directly or indirectly on the ecosystem.

In the Sundarban Biosphere Reserve of West Bengal, the human habitat and the forest are always separated by rivers. There are around 102 islands in SBR, 54 of them inhabited and the rest are within the reserve forest area with mangrove cover (World Bank 2014, Raha et al, 2014). In the SBR, along the north and western boundaries of the reserve forest, human settlements can be classified into two parts depending on their geographic location. Some of them are now parts of the mainlands which are connected by roads and having other infrastructural facilities typical of their rural counterparts in India. Under South 24 Parganas, the areas under the Administrative Blocks of Canning, Joynagar, Mathurapur, Kakdwip and Namkhana fall almost entirely in this category. The people living in these areas are not in close proximity with the forest and their living conditions and livelihood options are similar to that of other areas in the district. But the Blocks of Basanti, Gosaba, Kultali, Patharpratima and Sagar, together accounting for around 40 percent of total area in the district, call for a special understanding of the people, their livelihood and threat perceptions. They are almost entirely detached from the mainland and live under much different conditions unmatched in the rest of India. These people are living in islands on the fringes of reserve forest. The islands often face the forest on the other side of the separating river. Sundarban also covers 6 administrative blocks of the adjacent North 24 Parganas district, besides 13 blocks in South 24 Parganas (Development & Planning Department, Government of West Bengal, 2009).

Similarly, there are no settlements in Bangladesh Sundarban Reserve Forest (SRF). However, unlike Indian Sundarban, human settlement whose livelihood is linked to this forest is not defined. Recent studies have shown a 20-kilometer zone adjacent to the Sundarban demarcated as the Sundarban Impact Zone (SIZ) in Bangladesh. This is. This area comprises of parts of twenty Upazilas (sub-district) of five districts (Barguna, Pirojpur, Bagerhat, Khulna and Satkhira). The southern part of Satkhira, Khulna and Bagerhat and parts of Barguna and Patuakhali join together to form the Bangladesh part of the Sundarban. Table 5.2 shows the population trends in both countries.

Table 5.2: Demographic Profile of Sundarban in India and Bangladesh

Parameters	India Sundarban Biosphere Reserve (SBR) [a]		Bangladesh Sundarban Impact Zone (SIZ)[b]	
	2001	***2011***	***2001***	***2011***
Total population	3757356	4426259	2,337,448	2,306,550
Male (%)	51.3	51.15	51.54	47.95
Female (%)	48.57	48.85	48.46	52.05
Density (per sq. km)	925[c]	1089.2	537.33	560.3
Literacy rate	53.98	64.3	56.22	58.75

Source: *[a]Census 24 Paraganas (South) 2001,Census 24 Paraganas (north) 2001; Statistical Handbook of West Bengal 2010-2011; [b]Population & Housing Census 2001, Bangladesh Bureau of Statistics (BBS); Population & Housing Census 2011, Bangladesh Bureau of Statistics (BBS); [c] Danda et al.2011*

Population in the Indian part of the Sundarban has been rising. Table 4.2 and Figure 4.1 show that in 2011, the population was 4.43 million which comprises of about 1.78 percent rise per year since 2001.

The population growth rate is higher than the average West Bengal growth rate, this is due to high birth rates in the area and also migration inflows. According to local population, the migration inflows has occurred because of easy access to work, retreat of embankments, restoration of ecosystems and diversification of economic activities like tourism and aquaculture. On the other hand, there is also a lot of seasonal out-migration due to reduced agricultural production, depletion of natural fisheries resources and natural calamities. So population increase has occurred in urban areas of the SBR and rural population has decreased (Banerjee, 1998).

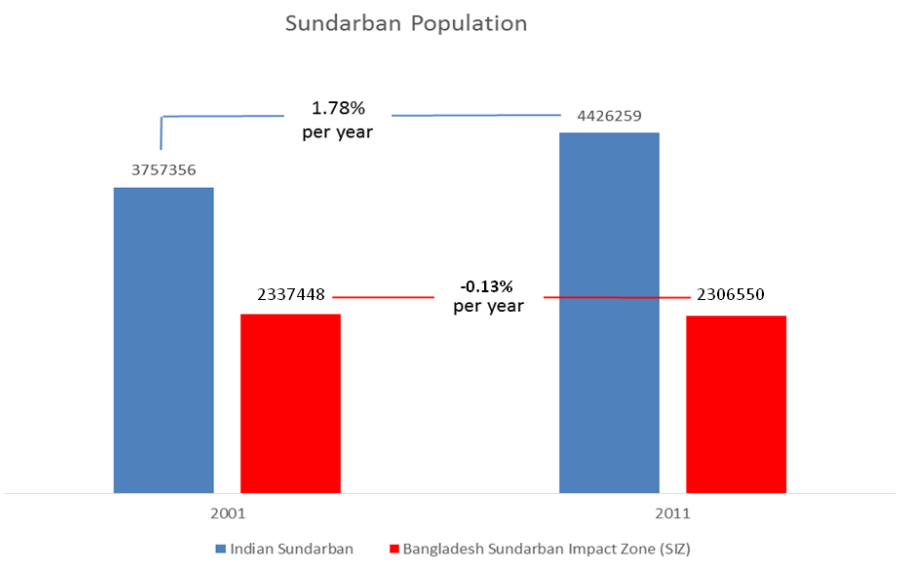


Figure4.1: Population in SIZ and Indian Sundarban

In Bangladesh, as of 2011 estimated population in the SIZ area is around 2.3 million. There is some variability in the population densities in the SIZ parts of the district that comprise Bangladesh Sundarban; Mongla area has the lowest (93 people per sq.km) and Bagerhat Sadar has the highest (977 people per sq.km) population densities, averaging an estimated 560 people per sq. km. in the Bangladesh SIZ area. Figure 4.1 shows the population in the SIZ area has dropped on an average of 0.13 percent per year since 2001, mainly due to out migration. Literature review, discussions with experts and local communities show the following reasons:

- Water salinity is increasing gradually because of global warming induced sea level rise and reduced upstream flow to flush out the saline water. The scarcity of fresh water has negative impacts on health of the surrounding population, agricultural production and the total health of the ecosystem. The population, especially, women and children have to collect water from distant parts of the region.
- Over the past 20 years, shrimp farming has become an important option for economic development in the coastal regions of Bangladesh. Shrimp farming has the potential to enhance small stakeholder's income and provide relatively well-paid employment opportunity at larger operations; however, politically and financially strong farmers exploit marginal and small farmers. Consequently, small and marginal farmers are diminishing from the agricultural sectors. A large number of small and marginal farmers have already migrated to other places due to change in traditional livelihood pattern, change in agricultural pattern, and increasing number of

landless, transfer of land, wealth and livelihood to local and national elites, poverty, food and social security and the marginalization of the rural poor. About 120,000 people were displaced from Satkhira district of Bangladesh since the initiation of shrimp farming (Didar-Ul Islam, S.M. S.M. & Bhuiyan, M.A.H.,2016)

- Frequent natural calamities are destroying property of the surrounding peoples and making them poorer.
- While collecting forest products, bandits take water and food supplies and demand ransom money from captured individuals. If the harvesters fail to pay the ransom money then the bandits take one or two people from the boat as hostages and demand extra ransom money from their family.
- During every harvesting season some harvesters are killed by tigers, crocodiles and other wild animals. There are no medical facilities nearby the forest to help injured forest product collectors. Even seriously injured people have to wait several days for proper medical treatment.
- Inadequate infrastructure and facilities like health care, education, transport and communication, life insurance for the forest harvesters and fishers in the Bangladesh part is causing people to search for better job opportunities by migrating to other parts of the country.

Table 5.1 shows that almost 50% of the population in the Sundarban in both countries is female. Women in this region face marginalisation as they live and work in rural, pastoral communities and are affected by chronic poverty, destitution, domestic violence, health problems and indifference of society to their problems (Kanjilal et al. 2010). The age-sex distribution of the household members shows a wide base and a narrow apex with a high proportion of children in the households, which matched with the pattern found in a typical developing region. Early marriage is very common, research shows that 37 percent of females aged 15-19 were married compared to 2 percent males of the same age group (Kanjilal et al. 2010).

5.2. Income Level and Poverty

Harsh hydro-climatic conditions and fragile natural resource base coupled with inadequate infrastructure, poor communication facilities, lack of access to clean drinking water, insufficient health and education services have contributed to a low level of development and high poverty incidence in the Sundarban region. The traditional livelihoods in this area are limited by the fragile ecology which mostly include forest-work, agricultural work and other community services. Simultaneously, climatic shock erodes the opportunities for maintaining livelihoods and triggers food insecurity, forcing people into chronic poverty, resulting in malnutrition and recurrent disease. As mentioned earlier, women are particularly underprivileged and marginalized, with minimum access to income, livelihood opportunities, education, and healthcare. It is generally believed that the populations are suffering from marginalization and inequality in income. Poverty status can be considered as a proxy to extent of marginalization.

As mentioned before, the average per capita income in Indian part is about USD 0.5 per day while the corresponding figure for the Bangladesh part is about USD 0.9 per day. Poverty in the Indian Sundarban

is slightly more acute with about 43 percent households lying below the poverty line. The national and West Bengal average are respectively 21.92 percent and 19.98 percent of households respectively below

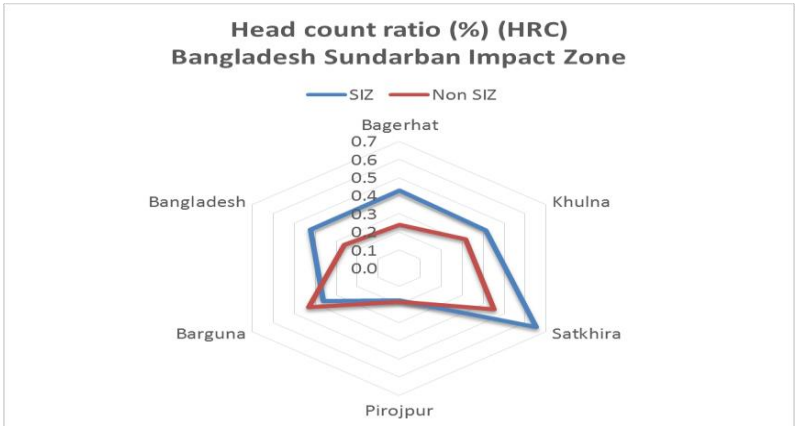
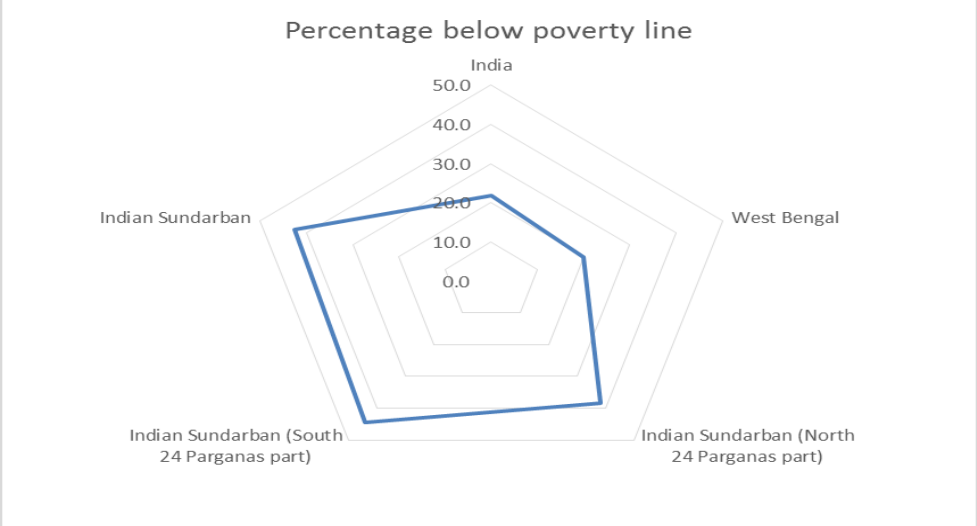


Figure 4.1: Head Count Ratio (%) Bangladesh Sundarban Impact

the poverty line. The part of Sundarban in the North 24 Parganas is slightly better in terms of poverty with about 38 percent households below the poverty line, this is due to proximity with Kolkata (World Bank, 2014).



4.2: Percentage of households below poverty line

Head Count Ratios (HCR) for the SIZ districts of Bangladesh are shown in Figure4.3. Here, comparative analysis is shown of the SIZ areas with those of non-SIZ areas, which shows a dismal picture. The extreme poverty levels of SIZ districts are at a considerably higher level (0.42) in almost all of the districts apart from Pirojpur, compared to non-SIZ upazilas in (0.26). Thus, the poverty situations in the SIZ appear to be extremely severe, which have immense policy implications (Islam, 2010). Large income inequality amongst different social groups is also present in the region. Incomes of the more affluent households are six times higher than those of the poorest groups. Land ownership is also skewed, only 51 percent of the population owns agricultural land (Islam and Chuenpagdee, 2013).

In Bangladesh most of the fishers and resource harvestors suffer from long term debt bondage and face exploitative relations with moneylenders. They generally have limited education, training and diverse professional skills, and have a muted voice in decision making. Infrastructure is poorly developed and access to markets is restricted. Moreover, there is no mobilization and organization of the Sunderban resource extractors in order for them to be recognized as stakeholders in the management of the Sunderban (Mitra 2000; Asian Development Bank 1998).

The poorest are also exposed to shocks which hamper livelihoods and often lead to increased poverty. The population living in the region in both countries perceive the following as the main challenge to lives and livelihoods,

1. Cyclones and other extreme climatic events
2. Physical accidents during fishing and collection of resources from the Sundarban
3. Tiger attacks
4. Attacks by criminal gangs
5. Illegal rent seeking (ransoms, bribes)
6. Food insecurity and drinking water crises
7. Illness and health problems
8. Legal procedures after breach of regulations

Reduced consumption is the first strategy to deal with crises induced no or insufficient income. Usually the head of family and income earner gets the first priority in terms of access to limited food, with women having the last priority. The proportion of cheaper vegetables increases with the reduction of rice in daily consumption during periods when prices increase (Islam and Chuenpagdee, 2013). As seen from previous section, these shocks also cause out migration in search of livelihoods and jobs, especially by men.

5.3. Forest Dependent Livelihoods in Sundarban

The Sundarban ecosystem is the basis for many of the livelihood activities that have traditionally formed the backbone of rural living in the region, and a significant number of households depend on the forest for their livelihood and sustenance through activities such as honey collection, fishing, and timber collection (World Bank, 2014; Singh et al 2010). Records from Forest Department in Bangladesh show that as many as 12 Non Timber Forest Products (NTFP) are harvested annually from the Sundarban (CEGIS, 2012). The different kinds of livelihoods as observed in the Sundarban can be classified into three broad groups: (i) Fishing, prawn seed and shrimp fry collection, (iii) NTFP collection and (iii) Wood collection (Datta, 2011).

5.3.1. Forest Dependent livelihood in Indian Sundarban Biosphere Reserve (SBR)

Fisheries and Aquatic Resources

The whole of Sundarban is characterized by a variety of fishing and aqua-cultural activities comprising coastal fisheries, brackish water aquaculture, estuarine and riverine fisheries, riverside prawn and shrimp seed collection, shrimp farming and several freshwater aquaculture variants. The state of West

Bengal is the largest fish producing state in India, the North and South 24 Parganas contribution is the highest to the state production. Production statistics for 2007–08 show that, West Bengal alone can be ranked 19th amongst fish producers in the world (World Bank, 2014). However, while the population numbers for the rural blocks of the Sundarban are available in the latest 2011 Census, there is nothing about fishers in the census categories. The census does not include fishing under cultivation, agricultural labour, or household industry.

Table 1.3: Inland fish production, 2006-07 (in tonnes)

Inland production	Fish	Prawn
24 Parganas North District	1,30,451	40,516
24 Parganas South District	1,80,815	9,900

Source: Department of Fisheries, Aquaculture and Aquatic Resources, Government of West Bengal, Annual Report 2006-07

Around 25% of the households are engaged in some kind of fishing activities (Singh et al, 2010). This percentage goes up to 60–70 percent in areas with easy access to rivers. A separate study found that the estimated total number of inland fisher families in South 24 Parganas and North 24 Parganas was 52,917 and 50,897, respectively. The main areas of traditional fishing are Sagar Island, Fraserganj, Bakkhali, and Kalisthan. The significant inland fish landing regions in the Sundarban include Canning, Hariabhanga, and Gosaba (World Bank, 2014). However, fishing is not allowed in the Sundarban core zone, fising boats with permits are allowed only in the buffer zone. Hilsa, bhetki, bhangon, and mullet are the most lucrative finfish species (Chatterjee 2011).

Estuarine and riverside shrimp fry collection engages most of the workforce of the Sundarban comprising of around 150,000 men, women and children. Increase in shrimp aquaculture over the last two decades, has created a large demand for shrimp-fry or prawn-seed collection. This is because the region does not have shrimp hatcheries and the aquaculture farms rely on fry collected from the wild. However, unsustainable practices in shrimp fry collection have caused biodiversity loss in Sundarban (Cook, 2010).

Crab harvesting is also practiced in Sundarban with at least five species being regularly caught. The estimated crab landing from this area is about 1200 to 1500 tonnes per year. Some parts of the population also collect snails, clams and giant oyster for lime, shrimp feed and chicken feed production (Haque, 2002).

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Non-Timber Forest Products (NTFPs) collection

Over 32,000 households in the Sundarban have at least one member exploit the forest regularly for various purposes, such as collecting fuel wood, sustenance, cash income (from the sale of honey), medicinal requirements, and harvesting timber for construction of houses and boats. Forest dependence is largely a result of low levels of education and skills, which prevents people from accessing better-paying jobs, and the lack of alternative income-generating opportunities available in the region. Agriculture has low income-earning potential in the region, and conversion of agricultural

land into prawn farms has forced many to turn to the forest for livelihood purposes (World Bank, 2014; Datta, 2010).

Considerable numbers of people in the forest-fringe areas of Sundarban earn their livelihood from honey and wax procurement as well as from other NTFPs collection. Honey, collected from both wild (*Apis indica)* and artificial captive boxes, is treated as a nutritious food and has high market demand. Similarly wax is also a valuable commodity. Every year, especially in the months of April-May, hundreds of people with or without valid permits issued by the Forest Department enter the reserved forests to collect honey and wax. On average, 200 quintals of honey, both from wild and bee-boxes as well as 1000 kg of wax are collected every year from the Sundarban. As the primary collectors are not associated with direct marketing of these products, the amount of money earned is meagre (Datta, 2011).

Golpata (*Nypa fruticans*) and Hental (*Phoenix paludosa*) leaves were once widely used for thatching of hut roofs, making ropes and handicrafts in the Sundarban. With the establishment of National Park and Biosphere Reserve, commercial harvesting of these plants from the wild is totally banned by law. However, these plants along with the Dhani grass variety found around the embankments and riversides as well as Hogla (*Typha elephantina*) found in more inland areas are still being used for small scale handicraft, straw, plate, rope and mat making industries.

In addition, various resources such as tannin, gum, resin, wild fruits, leaves and tree parts as primary medicines are collected by the marginal forest dependent people mainly for subsistence and to sell in the local markets. However, the creation of National Park and Wildlife Sanctuaries in the Sunderban has drastically reduced the scope of legal procurement and harvest of these products compelling many people to switch to prawn seed collection or engaged themselves as agricultural labours.

Wood collection

Government restrictions mean scope of direct livelihood earning from legal timber harvesting is nil for the population living in the Sundarban Biosphere Reserve. However, a relatively small number of people, mostly indigenous populations, are still engaged in wood collection for fuel and other uses. Though, plantations raised under Social Forestry do have the provisions for timber harvesting from Eucalyptus (Eucalyptus grandis) and Akashmani (Accacia auriculiformis) trees (Datta, 2010).

5.3.2. Forest Dependent livelihood in Bangladesh SIZ

About 28 percent of the population of this zone are dependent on the Sundarban forest for their livelihoods, such as fishing, collection of golpata, honey, fuel wood etc. A value chain analysis of the resources extracted from Sundarban shows that about 740,000 people, including collectors and traders, are directly involved in forest resources extraction, of which 80 percent are 'collectors'. About 95 percent of the collectors work for others. With regard to the distribution of the total number of collectors across the districts, Khulna occupies the highest position (48.7 percent) and Satkhira the lowest (4.1 percent). On an average each collector is engaged in collecting 1.8 products in a year. The

largest number of persons is engaged in galda prawn fry (24.3 percent) collection, followed by collection of bagda shrimp fry. Most of the actors (59 percent) were local, while some come from elsewhere (Islam, 2010).

A profile of the working months and days in the Sundarban related activities (including collection, trade and other ancillary activities) showed that peak months range from 3 to 6 months, except for grass and hental collection, which is in the range of 9 months. Workers are engaged in collection in the Sundarban, in maximum numbers, during the months of December to March or during the Bengali calendar months of Poush to Chaitra (Islam, 2010).

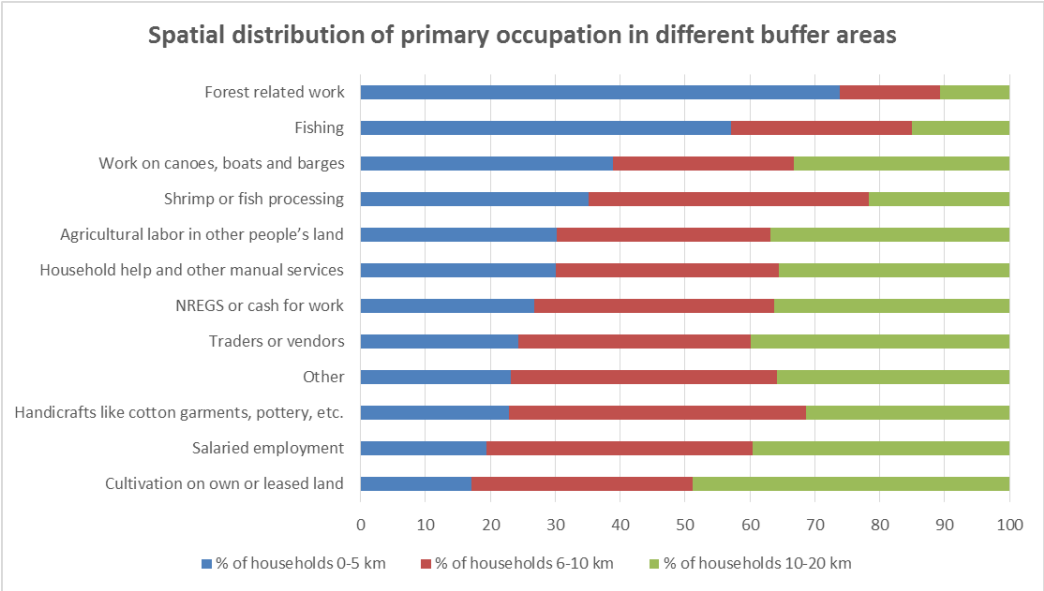

Figure 4.4: Spatial distribution of primary occupation in different buffer areas (Source: CEGIS, 2012)

According to a survey among 2144 households, the households residing in the SIZ areas were mostly engaged (primary occupation) in agriculture, daily labor, fishing, forest related work, petty trade, salaried employment, cash for work, handicrafts (cotton garments, pottery, etc.) shrimp or fish processing, work on canoes boats and barges, household help and other manual services. The spatial distribution of primary occupation varied with the difference in proximity from the SRF. For example, the percentage of households, mostly engaged in agricultural activity, was larger in the 10 to 20 km buffer zone than that of the 0 to 5 km buffer zone (Figure). On the other hand, households (70 percent) located in the vicinity of the SRF were mostly dependent on fishing and forest related activities than the distant households. About 56 percent of fishing took place within the 0 to 5 km zone (CEGIS, 2012).

Fisheries and Aquatic Resources

Bangladesh is the fourth largest inland fisheries producing nation in the world and 2.7 percent of this fish is produced in the Sundarban. Inshore, estuarine and coastal fisheries of Sundarban provide a major source of food and employment for about 900,000 of the population, most of which are fish labourers (Islam, 2010). Any sort of fishing or collection of aquatic resources within the Sundarban is controlled by

issuing permits and collecting revenue at the forest stations, and the collectors are not allowed to enter the forest more than three times per month.

Similar to India, a large number of people are involved in collecting shrimp fry. An estimated 423,000 people are engaged in collecting shrimp fry, 40% of whom are women and children. Yearly earnings from shrimp fry collection can be as much as USD 375, which is 16 percent higher than the yearly wage of a day labour (Islam, 2010).

Other than collecting shrimp fry, a large number of fishermen are involved in Hilsa fisheries and also other fish such as Rupchanda, Pungus, Poa, Koral, and Bhetki. Out of an annual total of 200,000 MT produced in the country, nearly 400 MT come from the Sundarban. Although this is a small part of the national production, the second largest income of fishers in Sundarban comes from Hilsa (Hoq, 2003). Due to ban on wood collection, many former wood collectors are entering into fisheries, thereby increasing pressure on the fisheries resources. Fishermen work as labour or on profit share schemes without ownership of fishing gears and craft and land; Houses are small with thatched roofs; Frequently take loans (dadon) for buying food or for other daily expenses (Islam M. M and Chuenpagdee R, 2013). Again about 20-22 thousand people are involved in dry fish processing. About 20 to 23 types of fish were used for dry fish production in the Sundarban. It is estimated that about 20% of the total marine catch is dried round the year with the substantial production during October to April and, marketed both in domestic and international markets (Ahmed et al, undated).

In most cases, poor fisher communities collect crabs, mollusc and shells in the Sundarban area. There is usually a ban on crab collection in specific months of the year but the ban is often not adhered to. In the off season, poor crab collectors have few livelihood opportunities but some of them manage to switch to fishing, shrimp fry collection or agricultural wage earning. Some of them get involved in collecting mollusc, shells and oysters (CEGIS, 2012).

Non-Timber Forest Products (NTFPs) collection

As mentioned earlier, Bangladesh Forest Department collected revenue from permit issuance for around 12 NTFPs including fisheries and aquatic resources, tourism as well as harvesting of golpata, honey, wax, oyster, hental, nal khagra, ulu ghas and maila ghas in 2012 (CEGIS, 2012, World Bank 2012).

The Sundarban is the major producer of honey in the country and accounts for about 20 per cent of the total honey production of Bangladesh and brings in the largest revenue collection amongst NTFPs. These are mostly unifloral honey of goran-type and golpata-type. The other unifloral honey of the Sundarbans is khalshi-type which is very high priced due to its high quality. Every year over two hundred tons of honey is collected from the wild beehives of Sundarban, but since it is a reserve forest, the collection is regulated by government permits. The honey hunting season officially opens on April 1.

Golpata is popularly known as “CI (corrugated iron) sheet for the poor population” as it is widely used in house roofing in the coastal region of Bangladesh. Normally it takes around 32 days to collect one boat of golpata. Golpata contributes to low cost house maintenance, and is a cash earner for the population as it is sold for housing, fuel, fence-making, medicine, cigarette wrapping, molasses, wine, fishing etc.

Wood collection

Timber harvesting in the Sundarban is illegal due to a ban imposed by the Government after 1986. However, Figure 5 shows that government does earn limited revenue from timber products. This revenue comes from the auctioning of illegal timber seized by the competent authorities. Additionally a small amount of timber is used for fuel and other accessories for supporting fishermen, honey collectors and other forest users permitted to enter the Sundarban for livelihood purposes (Bangladesh Forest Department, 2012).

5.4. Peripheral Livelihoods

The people living around the Sundarban in both countries are mostly dependant on agriculture, however, over the last two decades, brackish water aquaculture, especially Bagda shrimp (Penaeus monodon) culture started to become a dominant landuse. Conversion of forest tracts to wet-rice cultivation had started as far back as 1200 AD. But the agricultural activities practiced in the Sundarban are complex, diverse as well as risk prone (Saha, 1999). In addition to agricultural crops and shrimp aquaculture, livestock and poultry play an important role. The economic significance of the shrimp sector is large in terms of export earnings, around USD 3,105 million in India for the 2013-14 fiscal year (Sea Food Source, 2015) and around USD 380 million in Bangladesh in 2005 (Sen, 2010). However, shrimp production is highly criticized in the public discourse for its environmental impact, especially its effect on the soil salinity. Through the construction of canals and the flooding of the former rice fields with salt water, the soil quality is affected. Some people even equate these regions to 'deserts', because of the high levels of salinity. The Bangladesh Soil Research Institute describes the growth in saline areas and the rise of areas with high salinity as "truly alarming". It affects mainly the coastal areas, where 30% of Bangladesh's cultivable land is situated.

Livestock provides significant draft power for ploughing of the land and threshing and crushing of oil seeds, but a shortage of grazing area throughout the year causes a severe shortage of animal feed. However, the production of livestock and poultry is constrained due to lack of fodder storage, veterinary doctors and facilities. Livestock/poultry are also affected by floods, cyclones, epidemics, snake bite etc., mainly during monsoon season between July and October.

5.4.1. Peripheral Livelihoods in Indian Sundarban Biosphere Reserve

Agriculture and aquaculture are the primary economic activities in the peripheral areas of the National Park or Reserve forest. There is substantial conflict between these two livelihoods as indiscriminate aquaculture which is mainly shrimp-farming has caused salinization of paddy fileds and freshwater sources.

Agriculture

Agriculture is an important source of livelihood in the Sundarban economy. Nearly 60 percent of the total working population depends on agriculture as a primary occupation, either as cultivators (23.6 percent) or as agricultural labourers (36.1 percent). More than 80 percent of total farmers in the region farm in marginal areas. The average landholding among farmers is just 0.36 ha. More than 75 percent of the inhabited portions of the Sundarban are used for agriculture (World Bank, 2014). However, studies show that the available agricultural land has reduced from 2149 km^2 to 1691 km^2 during the period 2001-2008 mostly due to increase in population (Hazra, 2010).

Table 4.4: Rural Working Population of Sundarban Blocks of the 24 Parganas

	Total	Male	Female
Cultivator			
Main	200,536	186,824	13,712
Marginal (3-6 months)	54,812	37,385	17,427
Marginal (0-3 months)	20,745	11,829	8,916
Agricultural Laborer			
Main	320,361	292,574	27,787
Marginal (3-6 months)	264,682	183,293	81,389
Marginal (0-3 months)	99,293	57,338	41,955
Household Industry			
Main	44,364	25,999	18,365
Marginal (3-6 months)	44,977	13,183	31,794
Marginal (0-3 months)	19,200	4,732	14,468
Other Work			
Main	352,375	296,242	56,133
Marginal (3-6 months)	114,227	68,462	45,765
Marginal (0-3 months)	33,868	17,755	16,113

Source: Census 2011, Government of India

Paddy monoculture dominates the entire landscape along with small pockets of seasonal vegetables (e.g., watermelon) and oilseeds. The cropping intensity is 41.1 percent in North 24 Parganas and 31.3 percent in South 24 Parganas – low compared to the state of West Bengal as a whole (77 percent). Although, the paddy yield in the Sundarbans is higher than that of the country as a whole. The average yield roughly 16 percent of the net cropped area is irrigated in the Sundarban, compared to 41 percent in North and South 24 Parganas districts (Figure A9.3). Sources of irrigation in the Sundarban are primarily tanks (71 percent) and shallow tube-wells (13 percent), with the former method being the preferred choice (World Bank, 2014).

Aquaculture

Aquaculture in Sundarban includes both freshwater and brackish water species. Almost every household possesses excavated areas, which, in the monsoon season, store rain water; these are used for freshwater aquaculture (Chand et al, 2012).

In the past two decades, driven by the high profitability, shrimp aquaculture has experienced rapid growth in the inhabited areas of the Sundarban Biosphere Reserve. SBR is the top producer of fish and prawn, producing roughly 31% of the total inland fish/prawn production of West Bengal. South 24 Parganas alone produced 30% of the total marine fish/prawn production of West Bengal in 2007-08 (Mandal and Dubey, 2015).

Mostly low intensity traditional shrimp farming is practiced in the Sundarban. Usually in traditional farming system, no supplementary feed is used and shrimp grow on the natural productivity. Annual production of shrimp from these bheris or traditional fields is very low (200-350 kg/ha). This farming is normally practised in low-lying areas and shallow water bodies, influenced by tidal water especially during lunar phases. Brackish water from the adjacent water body e.g. river, creek, backwater, lake, lagoons etc. is let into by gravity flow to a large and shallow area of 10 to 100 ha, enclosed by constructed earthen bunds on its periphery. Depending upon salinity variation in the water body, these areas are used exclusively for shrimp farming or together with other fish species. In areas experiencing higher salinity in the range of 10-35 ppt during the year, mostly shrimp monoculture is practiced. In such areas, farming starts during January / February months and harvesting is completed by October / November. Usually in traditional aquaculture, no supplementary feed is given and algae and other aquatic micro / macrophytes in the bheris provide an excellent natural environment for the growth of shrimp. However, in few cases farmers use supplementary feed and other inputs for higher production. The dominant species under culture is *Peneaus monodon* or tiger shrimp due to its uniques taste, high unit value realisation and over expanding export demand. Estimated production of shrimp through aquaculture in West Bengal increased from 12,500 Metric tonnes during the year 1990-91 to 33,685 metric tonnes in 2009-10. (Chand et al, 2012).

Among the substantial environmental and social problems aquaculture also results in water pollution, salinization of drinking-water wells, destruction of fry of wild fish and crustacean species and various social conflicts related to land conversion - a critical outcome has been the conversion of mangroves to shrimp farms. As a of result, protests from local villagers in the major shrimp producing states of India, supported by various social and environmental NGOs, culminated in the 1996 Supreme Court judgement and the 1997 Aquaculture Bill which established a regulatory framework for shrimp aquaculture in India.

5.4.2. Peripheral Livelihoods in Bangladesh Sundarban Impact Zone

Agriculture

Agriculture, similar to the rest of the country, is the dominant livelihood in the Sundarban Impact Zone (SIZ), where over 80 percent of the gross area is being used for cultivation. In the area over 90 percent of cultivated land is medium high land (30-90 cm flood inundation) and is suitable for multiple cropping. The cropping intensity was found to be 149 percent (in FY 2008-09) in the region, which is below the national level (189 percent). The major agricultural production in the region comes from rice crops. Transplanted Aman (Local) and Boro (HYV) contributes a major share of rice production. Major non-rice crops include jute, wheat, oilseeds, spices, vegetables and watermelons (CEGIS, 2012).

Predictions show that the crop suitability in the Sundarban region will change significantly due to sea level rise induced salinity intrusion and tidal inundation. Based on the IPCC projections of sea level rise in Bangladesh, it could be estimated that the suitable area for transplanted Aman will be reduced to 60 percent by 2050 with a sea level rise of 32cm. Moreover, based on the same projection, only 12 percent suitable area will be available for transplanted Aman by 2100 with a sea level rise of 88cm (IPCC, 2001; CGEIS, 2006). Similar forecast was given for other crops such as Boro, Pulse, Bagda and Golda, to name a few.

Some of the problems which impact agricultural productivity are:

- Scarcity of fresh water during dry season for Boro (HYV) cultivation;
- Regulators were not functioning properly and there were social conflicts over water sharing especially for fish culture;
- Increasing siltation in the rivers and khals near the structures/regulators;
- Scarcity of sweet groundwater for irrigation during the dry season;
- Scarcity of capital for growing agriculture crops;
- Practice of wetland rice in monsoon season due to soil salinity;
- Unfavorable nature of heavy clayey soil texture for growing dryland crops in Rabi season etc. b) Problems outside embankment
- High soil and water salinity throughout the year;
- Drainage congestion during dry season creating problems for tillage operation over dryland /upland crops;
- Regular intrusion of saline water during high tide in the absence of any embankment;
- Siltation of rivers, khals and creeks;
- Scarcity of fresh water during dry season;
- Insecurity of farmers with regard to growing crops;
- Poor marketing facilities, etc

Aquaculture

From late 1970s, the brackish water aquaculture, especially Bagda shrimp became one of the main occupations for the local people and currently employs over 1.2 million. The area for shrimp cultivation has doubled in the last 20 years. After the initial modest beginning the shrimp farming rapidly gained popularity and by early 2000 reaches its peak, covering about 200,000 ha of Satkhira, Khulna and Bagerhat districts in 2005. This brackish water farming started as filler for a second crop after the harvest of monsoon rice, but rapidly gained popularity to replace the rice farming completely. Production rates are about 170,000 million tons of shrimp per year, saltwater shrimp or Bagda accounts for approximately half the production, while freshwater shrimp, golda accounts for 30%.

Social problems such as conflicts over control of land, water and natural resources, landlessness, unequal distribution of the benefits of shrimp farming, human right violations and gender inequality have been created due to shrimp farming expansion. Most of the social problems were created by a small wealthy class in the shrimp growing regions that led them to migrate due to poverty of the rural areas. Unplanned and rapid expansion of shrimp farming in Bangladesh has caused some environmental problems and ecological changes. Soil salinity, water salinity in canals and ponds, scarcity of drinking water, loss of agricultural land and grazing land and consequent reduction of livestock, destruction of mangroves, over exploitation of wild post larvae of shrimp, reduction of aquatic resources and bio-diversity, loss of trees and plants and adverse effects on cropping intensity, cropping pattern and crop diversity were identified as some of the important environmental problems (Rahman and Hossain, 2005).

5.5. Public Service Facilities

Access to public services and facilities such as water supply, sanitation, energy, education and health facilities has remained low in the Sundarban both countries compared to national averages. This poor performance is mainly due to technological failures, a piecemeal approach and poor governance and alos the challeng of embedding a techno-centric approach in socio-cultural and institutional settings. People, who live in the remote areas of the Sundarban – that is the villages adjacent to the forest area or the Bay of Bengal face much harder problems compared to those who live in the northern peripheral areas. It undoubtedly explains the region's relative impoverishment and also points out the priorities towards which any planned effort towards the region's development should be directed to.

5.5.1. Public Service Facilities in Indian Sundarban Biosphere Reserve

The insufficient infrastructure development in Sundarban region makes the region more vulnerable to poverty and natural calamities. In the 4,500 sq.km of inhabited area, there are only 42 km of railway line and about 300 km. of metalled road network. Almost all the islands are devoid of any conventional electricity supply. Due to remoteness of many villages most are unlikely to get electricity in near future unless the nonconventional energy sources are tapped. Governmental effort to provide solar energy systems at subsidized rate has also not been much successful because of the very little purchasing power of the islanders (World Bank, 2014).

In North 24 Parganas, at least five of the thirteen Sundarban blocks are entirely or mostly constituted by islands which do not have a direct road link with the mainland. For these blocks the only means of communication with the mainland as well as with other islands is through long journeys through river channels. Such transport is not well-organized and people have to depend on the private mechanized boats which are often overloaded while negotiating treacherous waters. Few islands have pucca/well-maintained jetties. Few islands have inland transport in the form of cycle-van, while others do not have any mode of transport at all.

The relative disparity in infrastructural provisions in Sundarban can be amply seen from **Table 4.5** which directly compares the island blocks with the rest of Sundarban and with the rest of the district in terms of four basic indicators of infrastructure. It shows the sharp deficit in infrastructural provisions in Sundarban region and even across blocks within it.

Table 4.5: North 24 Parganas – Infrastructural Provisions

Infrastructural Provision	Island-blocks around forest boundary	Other Sundarban Blocks	Rest of North 24 Parganas
% of HH with access to Electricity	0.7	9.18	29.34
Length of surfaced road (in Km) per sq per area	0.36	0.95	2.59
No of Bank Branches per 10000 population	0.26	0.3	0.49
Irrigated area as % of net area under cultivation	21.13	15.99	48.42

Source: (Development and Planning Department, Government of West Bengal , 2009)

Table 4.6 shows the infrastructural situation in Sundarban region.

Table4. 2: South 24 Parganas – Infrastructural Provisions

Blocks	Percentage of villages with Electricity for Domestic Use	Percentage of villages with Paved approach roads	Percentage of villages having Primary Schools	Percentage of villages having Maternity and Child welfare center	Percentage of villages having availability of Drinking Water
Haroa	62.22	83.33	67.78	30	100
Minakhan	27.03	40.54	70.27	4.05	98.65
Sandeshkhali-I	43.33	63.33	100	0	100
Sandeshkhali-II	20.83	62.5	100	91.67	100
Hasnabad	65.75	89.04	87.67	4.11	100
Hingalganj	25	63.64	90.91	15.91	100

Source: (Development and Planning Department, Government of West Bengal, 2010)

Water Supply

Table 4.7 summarizes household water supply in the Sundarban. Over 90 percent of households used public tube wells and, of those, over 25 percent spent more than 30 minutes per day collecting water. In general, in islands on which there are no water sources for drinking or irrigation, women travel longer distances (taking up to three to four hours daily) to collect drinking and cooking water for their family (The World Bank, 2014).

Table 4.7: Household Water Supply in the Sundarban

Water Source	Percentage of Households Surveyed
Public tubewell	91.5
Pond	6.4
Other	2.1

However, Arsenic remains an issue in many areas in this region. According to the Central Ground Water Board of West Bengal (CGWB) and West Bengal Public Health and Engineering Department (WBPHED), the Arsenic level ranges from 0.12-0.96 in several blocks of North 24 Paraganas like Sandeskhali, Haroa and Hasnabad which exceeds the WHO standards. Arsenic levels are comparatively lower in South 24 Paraganas (WBPHED, undated).

Energy for Cooking

About 90 percent of the population in the Sundarban uses wood and biomass (straw, shrubs, and grass, agricultural crop residues, and animal dung) as the primary cooking fuel. About 70 percent of this population cooks primarily indoors and 30 percent cooks primarily outdoors.

Electricity: Existing Supply

According to official records, all villages in the SBR have access to electricity, of this, approximately 17 percent of the population has access to grid electricity. Even when grid electricity is available, around 85 percent of electrified households face power cuts of four to nine hours per day, and the remaining households face power cuts of between nine and 14 hours per day. It is extremely difficult, if not impossible, to extend high-tension transmission lines to these areas as most of the places are separated from the mainland and from each other by wide rivers and creeks.

The 83 percent of households without access to grid depend largely on solar photovoltaic panels, but maintenance costs for these are substantial. The Sundarban has more than 20 percent of the share of the total off-grid capacity in India through off-grid solar energy, energy storage and mini-grids. Households without access to grid electricity, located in remote areas, are connected to renewable energy plants (consisting of 16 solar photovoltaics, two wind, and three biomass gasifiers), which provide four to six hours of daily power supply. About 20,000 solar home systems have been distributed to households through government schemes or by NGOs. Over 110 small-scale diesel sets (less than 25 kilowatts capacity) are operated by independent power producers to meet the needs of small markets and selected commercial users (The World Bank, 2014).

Sanitation

Only 66 percent of the population has access to a toilet facility in rural South 24 Parganas, compared to 90 percent in rural North 24 Parganas (Mohan 2011). The Total Sanitation Campaign (now called Nirmal Bharat Abhiyan) has been implemented in all blocks of the Sundarban to promote construction of household toilets, school toilets, community sanitary complexes, *anganwadi* toilets, and solid and liquid waste management facilities. Under this campaign, 156,413 below proverty line (BPL) households in North 24 Parganas and 281,649 in South 24 Parganas were provided with toilets, and implementation of the campaign has reduced the practice of open defecation (S.Boisson,2014).

Health

Environment-induced health hazards, including death and debility from natural disasters, animal bites and arsenic poisoning affect 60% of the population. Hospitals are too far away, and in emergencies, pregnant women have delivered on the way to the hospital. The crude death rate in the Sundarbans is 7.6 against 6.3 for West Bengal as a whole (Kanjilal et al 2010). The public health care system in the Sundarban, following the same pattern as in other parts of rural West Bengal, delivers preventive and curative services at multiple levels of institutions (or, facilities) and through outreach workers. The public facilities range from 2 sub-divisional hospitals with specialized physicians and inpatient services to about 800 small sub-centres (SC) at the village level staffed by trained multi-purpose workers (Table 4.8). Within this range there exist 19 block level facilities (9 Rural Hospitals (RH) and 10 Block Primary Health Centers (BPHCs)) and 47 Primary Health Centers (PHCs) – arranged in order of secondary to primary levels of care. The Block level facility (BPHC/RH), in addition to playing a role of a referral unit, acts as a hub of all primary health care activities within a block.

Table 4.8: Health Institutions in Indian Sundarban Biosphere

District	Type of Block Level Hospital*	Number of PHC	Number of SC	Population per PHC	Population per SC
North 24 Parganas Sundarban	BPHC,RH	14	203	76,056	5,245
South 24 ParganasSundarban	BPHC,RH,SDH	33	635	94,018	4,886
Total Sundarban		47	838	88668	4973

*BPHC=Block Level Primary Health Centre, RH=Rural Hospital, SDH=Sub-divisional Hospital, PHC=Primary Health Center, SC=Sub-center

As Table 4.8 shows, the sub-centers are adequate in number if one goes by the usual standard (5000 population per sub-centre). The number of PHCs, on the other hand, is evidently inadequate by the same standard (30,000 per PHC). The inadequacy is more prominent in South Sundarban especially in some blocks (Gosaba, Canning I and II, Patharpratima, and Kakdwip). Inadequate facilities in addition to poor environmental conditions are responsible for 3,800 premature deaths and 1.9 million cases of illness every year, mainly among young children and women (World Bank, 2014).

The health status of the children of the Sunderban is in a sorry state. About half of The children in the Sunderban (52%) were stunted (i.e., low height for age), or, in other words, were suffering from chronic malnutrition The proportion of chronically malnourished children is higher than both state (45%) and national average (48%) implying that in the Sunderban a comparatively higher proportion of the children are growing up with serious nutritional retardation. (Kanjilal B et al. 2010)

Education

As per 2011 census, literacy rate in the West Bengal is 76.26 percent, and the figure for the people living the in the Indian part of the Sundarban is 64.3 percent. Many children (5 years of age or older) go to school whereas only 5 percent of adult fishers (+30 years) have five years of schooling. The

government now gives monthly allowances to students in primary school. Particularly, the the school feeding programs, that provide nutritious biscuits to students, have positive impacts on school attendance.

5.5.2. Public Service Facilities: Bangladesh SIZ

A major concern is the growing settlements and urban areas in the SIZ due to population pressure. Unplanned settlement and urbanization is putting pressure on agricultural lands due to the absence of adequate legal provisions and plans at the local and national level (IUCN, 2014). Upazila HQs are connected to the main cities by road, but the gateway points of the Sundarban are not connected to each other. The port-connecting national highways of Dhaka- Aricha-Khulna-Mongla, Dhaka-Mawa-Gopalganj-Mongla, and Dhaka -Satkhira are considered to be in satisfactory condition.

Climate change will increase intensity and frequency of natural hazards, the vulnerability of the rural infrastructure will increase further. Housing, water supply and sanitation facilities are not well developed in this region. Majority of the households are of kachha and jhupri type made of wood, tin and golpata, although, some concrete houses can be found in the urban centres.

Education

Adequate educational opportunities in the SIZ are lacking, as infrastructures in the area are not well developed. Table 7 shows the number of schools in the SIZ area. There is one primary school in every 1.5 to 2.0 square kilometre and a secondary school in every 2-3.5 square kilometres (national level: one primary school in every 1.8 sq. km). Despite the inadequate educational facilities, the literacy rate in the associated districts is about 57 percent, ranging from 49 to 68 percent, which is higher than the national level figure of 51.8 percent as per the 2011 census (CEGIS, 2012, Islam K. M., 2010). This is attributable to a relatively large number of NGOs operating in both the formal and informal education sectors. While access to primary schooling facilities may exist in SIZ, concentrations of formal schools and higher educational institutes are much denser in the northern urban areas of the relevant districts (ADB, 1998). Thus the numbers create a false sense of adequacy. In reality, and the condition of the education infrastructure is comparatively deficient near to the Sundarban. Additionally, the present primary school drop-out rate in the SIZ is estimated at 40%, higher than the national average (IUCN, 2014).

Water Supply

There are different types of water supply systems in the area, such as pond water which is mostly used by the rural community. This is due to the fact that tube well water can contain salinity, iron and arsenic in many areas. The Department of Public Health Engineering (DPHE) has established piped water supply facility in several Upazila HQs and in rural areas, few NGOs (e.g. WaterAid) has also initiated small scale piped water supply in pilot level, the DPHE and and many other NGOs have established tube wells, Rain Water Harvesting (RWH) and Pond-Sand Filter (PSF) to ensure safe drinking water for the local people. However large percentages of households have no access to safe drinking water (23percent; BBS, 2012)

in these coastal districts. Although salinity is an issue in some pockets, the arsenic level in almost whole areas in SIZ of Bangladesh is negligible according to the WHO standard and BDS 1997 (CEGIS 2015). On the other hand, most of the households have access to sanitary toilet facilities due to special initiatives taken by both DPHE and international and local NGOs in the Aila and SIDR affected areas.

Electricity

The community's access to electricity is limited to only 30-40 percent of the households. Introduction of solar energy facilities have been initiated. For example, Banishanta union of Khulna district has been declared solar the first solar union because of solar electricity usage. The main source for cooking fuel is firewood although several NGOs are promoting bio-gas cooking facility and some NGOs are also selling fuel efficient stoves, which are becoming more popular in the area.

Solar lamps brightened their lives

School children of Binapani Govt Primary School in Dacope's West Khejuria village with their solar-powered lamps. They take the lamps to school, charge them with solar energy and carry them back home so that they can study at night.
For children in the villages bordering the Sundarbans mangrove forest, shadows should be especially long. Not only are there tiger tales to consider but forest darkness must hold a mystical, almost magical quality for a child's imagination to fear and celebrate. That same darkness is nothing but a nuisance, however, when it comes to completing homework. Mitali Barmon, a class-V student of West Khejuria village had the habit of visiting neighboring houses in search of a solar lamp in order to study of an evening. Her father Monoronjan is a day labourer who can neither afford costly kerosene for lamp nor provide for education expenses, including stationery and books.

Healthcare

The distribution of health infrastructure under the Ministry of Health and Family Welfare can be divided into different tiers, viz. national, divisional, district, upazila (sub-district), and union. According to the official website of the DGHS, SIZ districts have one Sadar Hospital except for Khulna district. Instead of a Sadar Hospital Khulna district has one public medical college which also performs as a medical hospital. Each upazila of these five districts has one Upazila Health Complex. At union-level there are mainly two types of hospitals: the Union Sub-Center and the Union Health and Family Welfare Complex.

Table 4.9: Number of different health institutions in Bangladesh SIZ

District	Number of Health Institution				
	Upzila Health Complex (UHC)	Union Sub Center (USC)	Union Family Welfare center (UFWC)	Community Clinic	
				Existing	Planned
Barguna	1	1	6	19	21
Pirojpur	1	2	7	35	35
Bagerhat	4	3	33	82	114
Khulna	3	7	24	65	90
Satkhira	2	0	22	64	73

According to government rules, there should be one union sub-center and one union family welfare center in each upazila. However, the institutional survey at upazila level showed a different picture

(Table). Four out of all eleven upazilas had no union sub-centers. On the other hand, all upazilas had a few union family welfare centers. An assessment showed that adolescent girls are unaware of reproductive health, and 50% of the pregnant women do not get proper health service. Hence, children are born with a low birth weight, making them susceptible to ill health. Many children also suffer from malnutrition.

5.6. Transport and communication

In both Bangladesh and India the lack of adequate transportation and communication, especially to the most remote areas of Sundarban, presents unique challenges and promising opportunities. Transport and communication infrastructure in the Sundarban Region are mainly based on roads and waterways. Over the past few decades there have been improvement in accessibility to road network facilities for the communities living in the Sundarban region. But still, navigation through the complex network of tidal waterways is the backbone of the transport system and plays a major role in the lives and livelihood of the people of the Sundarban.

5.6.1. Transport and communication in SBR

In the Sundarban Biosphere Reserve (SBR) the inhabited islands are connected with water based transport through improvised diesel operated mechanized boats. Major rivers include Hoogly, Muriganga, Shaptamukhi, Thakuran, Matla, Bidyadhari, Gosaba, Haribhanga and Raimangal. Concrete jetties have been constructed at almost all the ferry ghats, market places for boarding the vessels. These jetties facilitate commuters as well as for export and import of produces and supplies. During tourist season a large amount of boats carry hundreds of domestic and foreign tourists through the more accessible parts of Sundarban. In spite of this, service provision is inadequate and has been worsening as a result of increasing waterway siltation, neglect of the system, and shortfalls in service. Again many villages still cannot be reached by regular boat service and because of tides added to the remoteness passengers have to wait five or six hours before they can travel (World Bank, 2014).

People who live in the area commute to Kolkata and other cities in West Bengal for work, school, and other activities. Road transportation services are available from Kolkata to several urban centres Namkhana, Canning, Diamond Harbour, Bakkali and Jharkhali act as exit or entry points into the Sundarban. People travel from these places by river transport into the interior of Sundarban. Travel from Kolkata to any of these urban centres requires at least one-and-a-half hours, and travel to the furthest city, Namkhana requires at least three hours. Bus terminals are also important transport gateways. There are 14 bus terminals in the study area that can be considered as major hubs connecting the Sundarban: Bakkhali, Narayanpur, Kakdwip, Barpali Bazar, Raidighi, Ramganga, Jamtala, Jaynagar, Canning, Sonakhali, Dhamakhali, Haroa, Nazat, and Hasnabad. Presently the road network within the Sundarban consist of around 50 km of paved roads (bituminous concrete), 100 km of cement concrete roads, and 3,000 km of brick-paved roads, as well as around 30 small, medium, and large bridges in

various locations to improve connectivity. South 24 Parganas has significantly higher village road density (293 km per 100 km2) than North 24 Parganas (161 km per 100 km^2) (World Bank, 2014). However the road networks in the islands are mostly surfaced with brick pavements and concrete.

Railway connectivity in the Sundarban includes two railway routes that are under the jurisdiction of Indian Railways. There are at least nine blocks in the Sundarban located 10 km or more from the nearest railway station.

5.6.2. Transport and communication in SIZ

In Bangladesh, inland navigation is quite well developed with a high degree of penetration providing access to 25 percent of the rural households in the country. Similar trend also prevails in the Sundarban Impact Zone. The statistics from the Mongla Port Authority shows that navigation in the Sundarban waterways has increased 236 percent in last 7 years (Mangroves for the Future, 2015). The waterways in the region are mainly through large rivers such as the Passur, Raimangal Mongla, Baleshwar and Bishkhali in Bangladesh and Bangladesh Inland Water Transport Authority (IWTA) currently maintains navigability of only 14 rivers over a total length of about 326 km in SIZ. The BIWTA operates launch service at certain intervals through very limited routes of the area only during monsoon. (CEGIS, 2012). Along with commercial vessels, engine boats also operate via different local routes for transporting passengers and goods. However, private operators do not have any fixed schedule of operation. Since, there is no fixed time frame of operation of private boats and as all the waterway vessels operated in the study area are slow, people dependent on waterway transportation suffer greatly in reaching their destinations on time. Additionally, a few tourist boats also travel inside the Sundarban. Many of these remain inside Sundarban for 3-5 days and since there are no accommodation facilities the tourists stay on board during this period. Within the Sundarban Reserve Forest, navigation is very limited; during license issuance for fishermen, honey and other collectors, permission for country boats are also collected.

However, many vessels use the navigable routes of Sundarban to access Mongla Port which is situated inside the SIZ and floating sea terminal located at Akram Point near Mongla. The main route of travel for vessels reaching Mogla is the 31 km Mongla-Ghashiakhali navigation which started operation 1973. This route serves as a linkage between Mongla Sea Port, Khulna and other parts of the country. The navigability of the Mongla-Ghasiakhali route has rapidly decreased during the period 2010 to 2014 due to tidal asymmetry and increased sedimentation. As a result, the MoEF gave the environmental clearance for letting vessels ply an alternative route through the Sundarban as the regular Mongla-Ghoshiakhali route became unusable for ships due to its poor navigability since 2011. However, according to Bangladesh Forest Department more than 500 crafts, including large vessels and oil tankers, have been navigating inside the Sundarban (Mongla-Joimonir Gol- Harintana-Supoti canal to and from the Bay of Bengal) through the Shalle river illegally since 2011. In addition, the Mongla-Ghoshiakhali route is also a part of the international navigation route in the SIZ and is used by Indian and Bangladeshi water vessels under the Protocol on Inland Water Transit & Trade (PIWTT) between Bangladesh and India. This protocol will be further elaborated in Section 4.6.3.

There is of course no road connectivity within the Sundarban Reserve Forest. A few pucca roads and brick pathways exist at the different Forest Department office premises like Karamjal, Hiron point, Kochikhali. Within the inhabited areas of the SIZ, present road coverage is 4514.67 km. At present, less than twenty percent of the total internal roadway network maintained by LGED is paved and the rest is still earthen. On the other hand, there are two port-connecting national highways (Dhaka-Aricha-Khulna-Mongla and Dhaka-Mawa-Gopalganj- Mongla). After construction of the Padma Bridge, the overall roadway communication with the capital city is expected to become more efficient.

5.6.3. Transboundary Inland Navigation Protocol Routes

Under the Protocol on Inland Water Transit & Trade (PIWTT) between Bangladesh & India, all transit vessels travelling to and from Kolkata move through the Sundarban. Inland water transport trade between India and Bangladesh is presently passing through a very important phase, when the prospect looks brighter and more positive than at any time during recent decades. After formation of Bangladesh a trade agreement was signed between the two countries in 1972, which led in turn to the signing of the Indo-Bangladesh Protocol on Inland Water Transit and Trade, this was a big step in the revival of inland water transport in eastern and north-eastern India. From 1995 onwards, cement movement between India and Bangladesh under this protocol gained momentum. From 2001 onwards, movement of fly ash to Bangladesh started taking place, and today has reached a considerable volume. Although these are positive moves, and the volume of transit vessels has increased, there is a lot of room for improvement. Under the Indo-Bangladesh Protocol on Inland Water Transit and Trade, specific routes for the passage of inland vessels and ports of call within the Sundarban region for inter country trade have been clearly defined.

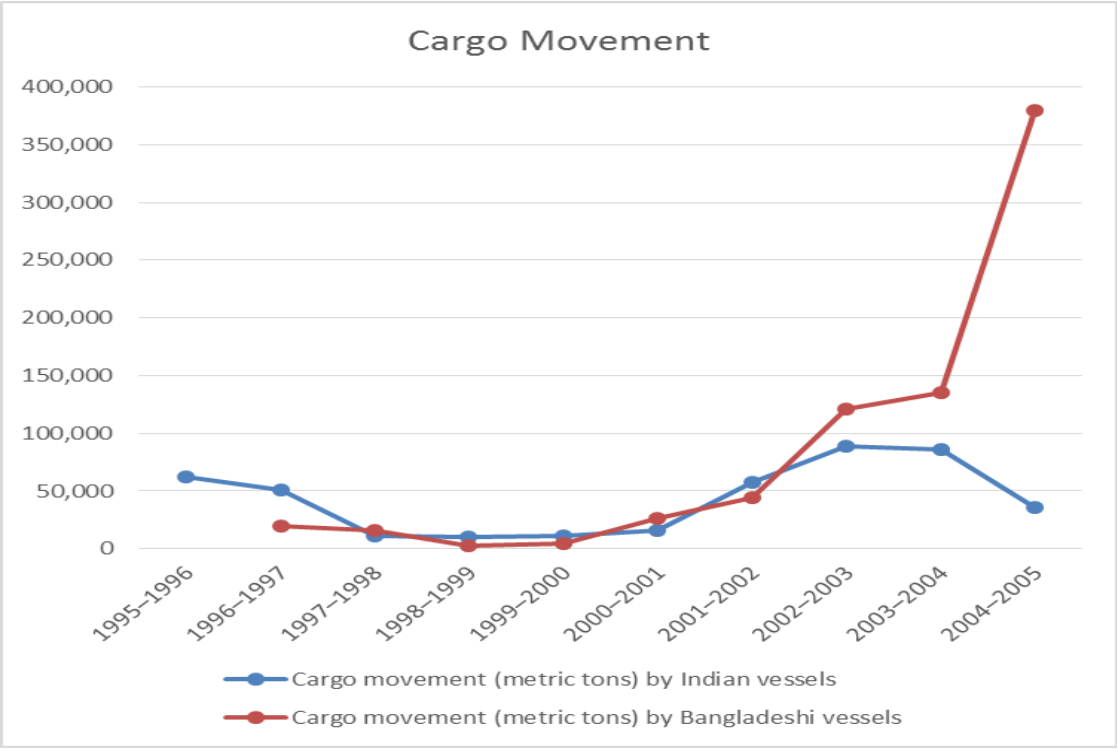

Figure 4.5: Cargo Movement by Inland Navigation

Protocol Routes

- Kolkata-Haldia-Raimongal-Chalna-Khulna-Mongla-Kaukhali-Barisal-Hizla-Chandpur-Narayanganj-Aricha-Sirajganj-Bahadurabad-Chilmari-Dhubri-Pandu
- Pandu-Dhubri-Chilmari-Bahadurabad-Sirajganj-Aricha-Narayanganj-Chandpur-Hizla-Barisal-Kaukhali-Mongla-Khulna-Chalna-Raimongal-Haldia- Kolkata
- Kolkata-Haldia-Raimongal-Mongla-Kaukhali-Barisal-Hizla-Chandpur-Narayanganj-Bhairab Bazar-Ajmiriganj-Markuli-Sherpur-Fenchuganj-Zakiganj- Karimganj
- Karimganj-Zakiganj-Fenchuganj-Sherpur-Markuli-Ajmiriganj-Bhairab Bazar-Narayanganj-Chandpur-Hizla-Barisal/ Kaukhali- Mongla-Raimongal-Haldia-Kolkata

Present inter country cargo transport

Cargoes that are exported to Bangladesh include fly ash, granulated slag, gypsum, clinker, cement, manganese ore, food grains, wheat, rice, sugar, project cargo, and dried fish. The imported cargo from Bangladesh includes crushed bone, hide, and return project cargo. The cargo moved during the year 2004–2005 along the protocol route was approximately 416,000 metric tons. Since April 2005 IWAI has been designated as the competent authority from the Indian side for operation of the provisions of the protocol; prior to that the Central Inland Water Transport Corporation held that responsibility.

Ports of Call

According to Article 11 of the Protocol some places of the respective countries are nominated as 'Ports of Call' (Table 4.2). A total of 10 ports of call, 5 on each side are designated for loading/unloading of inter country trade cargo. According to this provision vessels engaged in inter-country trade are allowed to load/ unload only at the nominated 'Port of Call'. If the cargo from Kolkata in India is destined for Barisal or Chandpur in Bangladesh, the vessel will have to run to Narayanganj and after customs formalities the vessel will have to come back again to the destination.

Table 4.10: List of Ports of Call in Bangladesh and India

Serial Number	Bangladesh	India
1	Narayanganj	Kolkata
2	Mongla	Haldia
3	Zokigonj	Karimganj
4	Sirajganj	Pandu
5	Ashuganj	Silghat

This is contrary to the scenario prevailing in road transport. Cargo destined for any place in Bangladesh comes to Benapole or to any road based land port and after customs formalities starts its journey to the destination. As such cross-border trade by inland navigation loses its competitiveness to the roads. This is because the 'Ports of Call' are far away from the entry/exit points.

Impact of increased Inland Navigation

Navigation Route through Sundarban area has become a burning issue for Tiger Conservation Landscape. Due to the siltation on the river bed of Mongla-Ghosiakhali Channel, majority of the water vessels now pass through the three Dolphin Wildlife Sanctuaries of Sundarbans from the North-East part upto the Baleshwar river. The vessels using the protocol routes range from ocean-going mother and feeder cargo ships, container carriers, tankers, lighterage ships, mid-size bulk cargo and tankers from inland waterways, and trans-boundary cargo ships between Bangladesh and India. Increased shipping multiplies risks from oil spill, the release of coal, chemical, fertilizer and fly ash by accident; in course of routine operation, vessels discharge ballast water, bilge water, and there is cargo tank washing too. A tanker containing 350,000 liters of heavy furnace oil sank in River Shella north of Chandpai Range, Sundarban on 9 December 2014, and a the thick carpet of oil spread at least 20 km up (including Mongla Port) and downstream. Fortunately, collection of oil through the joint effort of the community and Department of Forest reduced the intensive impact on biodiversity and livelihood (UNEP/OCHA Environment Unit, 2014).

Additionally, the impact of ship-induced waves on the mangrove ecosystem, disturbance to wildlife and the risk of international wildlife trafficking spreading widely with regular vessel based pollution. The moving and manoeuvring of vessels induce a variety of hydrodynamic changes and physical forces which have an impact on the surrounding flow, alluvial banks and sediments of the rivers. These impacts potentially harm the environment and can ultimately lead to environmental degradation. Without any sort of environmental management in place, this increasing navigation and shipping are multiplying the risk of accidents/spills and regular pollution in Sundarban.

5.7. Sustainable Tourism

Sustainable tourism is the practice of involving local community living around areas of tourist attraction on the management and conservation of tourist attraction sites and the surrounding natural environment. The natural beauty of the Sundarban has been attracting a steadily growing number of visitors in both countries.

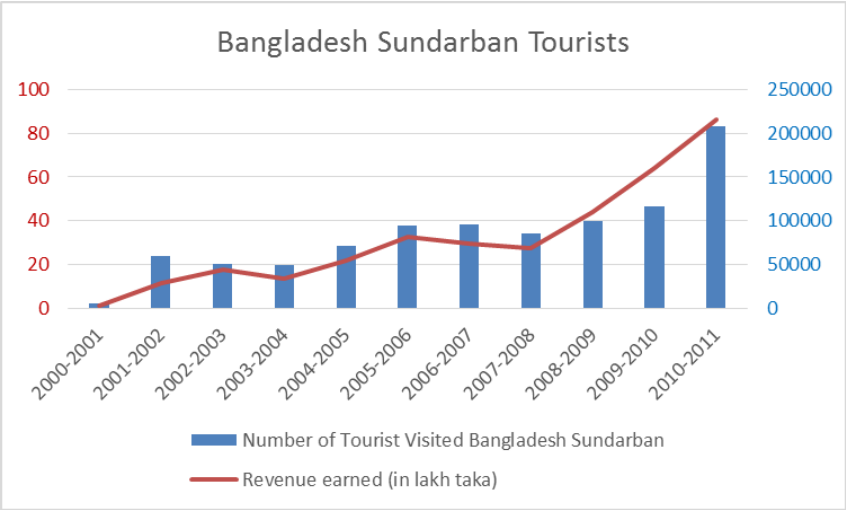

Figure 4.6: Bangladesh Sundarban Tourists

Figure 4.7: Number of Tourists visiting Sundarban India

Tourism facilities such as resorts, parks and transport facilities in the Indian SBR are more developed and available than the Bangladeshi side and as a result attract more domestic and international tourists. According to studies, it is possible to collect 300 percent more revenue from SBR, (Islam, 2016) through better planning. However, due to the remoteness of SIZ and lack of support from local tourism entreptrenaurs, sustainable tourism in the Bangladesh SIZ needs a well equiped approach to earn substantial revenue from this sector.

5.7.1. Tourism in Indian SBR

Wildlife and nature tourism is centric to Sundarban Tiger Reserve. The number of tourists visiting the Sundarban is around 1, 50,000 a year (TOI, October 31, 2012). Money from tourism makes its way to a number of different stakeholders including: the Sundarban Tiger Reserve via entrance fees; approximately 30 independent tour operators based from Canning, two private tour operators offering packages from Kolkata, public operators under the West Bengal Tourism Development Corporation, and a handful of site-based, individual operators who offer their services opportunistically; a mixture of private and government owned tourist lodges; and local people offering services and products to support operators and accommodation providers. The tourists entering the Sundarban in West Bengal are also mostly domestic, although the numbers of both domestic and foreign tourists have increased over the years (as shown in Figure 2).

The entry point to Sunderban Tiger Reserve is either Sonakhali via Canning, or Bagna via Dhamakhali. For visiting South 24 Parganas Forest Division, on the western part of river Matla, the entry points are Namkhana, Raidighi or Jharkhali via Canning/Basanti. Entry Permits are available at Canning, Sonakhali and Bagna for STR and at Canning, Namkhana and Raidighi for Western part of Sunderban Forest. Religious and pilgrimage tourism to Sagar Island in 24 Parganas (South) also contributes significantly to the local economy. The main point of attraction for beach tourism for visitors from Kolkata is Bakkhali on Namkhana Island. Two Mangrove Interpretation Centres are established at Sajnekhali and Bhagabatpore and a eco-museum is situated in Sudarikati to make the local people and tourists aware of the importance of conservation of nature in general and specially the mangrove ecosystems. Apart from viewing the wildlife from boat safaris, visitors also visit the Bhagatpur Crocodile Project, a crocodile breeding farm, Sagar Island, Jambudweep, Sudhanyakali watchtower, Buriidabri Tiger Project, Netidhopani Watchtower, Haliday Island, Kanak, and Sajnekhali Bird Sanctuary.

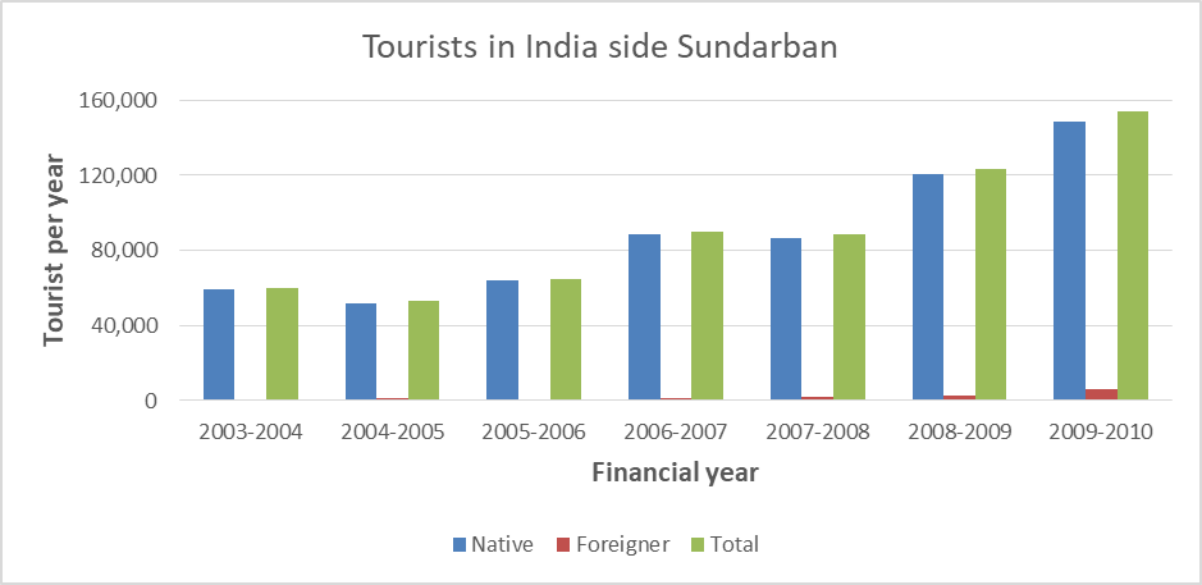

Figure 1: No of tourists in Sundarban, West Bengal, India

The National Tourism Policy, 2002 of India put a greater emphasis on ecotourism in order to reduce poverty and unemployment, improve the status of women, preserve cultural heritage, develop local crafts and finally will foster the growth of a more just society (NTP 2002, Ministry of Tourism). Following Government of India's thrust on ecotourism in the 1990s; several states of India including West Bengal also emphasized ecotourism as one of the tools in conservation and community development. In 2001-2010, West Bengal ranked among top ten tourist attracting states of India (West Bengal Tourism Department, 2010). However, there is hardly any clear guideline from the West Bengal Tourism Department regarding practicing ecotourism in the Sundarban. In 2012, The Ministry of Environment and Forest prepared a detailed guideline for ecotourism in protected areas of India which emphasizes 'community driven' ecotourism.

5.7.2. Tourism Statistics in Bangladesh SIZ

Sundarban is one of the most important destinations for tourists in Bangladesh and the tourism industry industry in Sundarban has grown over the last few decades. However a much more concerted and strategic intervention is required for the country to enter the global competitive arena. The number of tourists is mostly from the domestic sector with international tourists making up a small percentage.

Tourists are allowed formally to enter the Sundarban in Bangladesh on payment of a fixed entry fees, an important window of earning revenue for the government. The travel inside the Sundarban is boat based and travels start from Khulna, Mongla or Dhaka. The closest airport to Khulna or Mongla is at Jessore and it takes two hours by road to reach Khulna from the airport. At least 20 private companies operate tourism in Sundarban.

Some of the places of attraction in the Sundarban include Koramjol, Harbaria, Katka, Kochikhali, Dubla Island, Nilkamal, Sheikertek temple, Mandarbaia, Notabeki and Dobeki. Most of the places of attraction are located in the Sundarban East Division. At present visitors, are allowed to visit any part of the forest including the restricted protected areas.

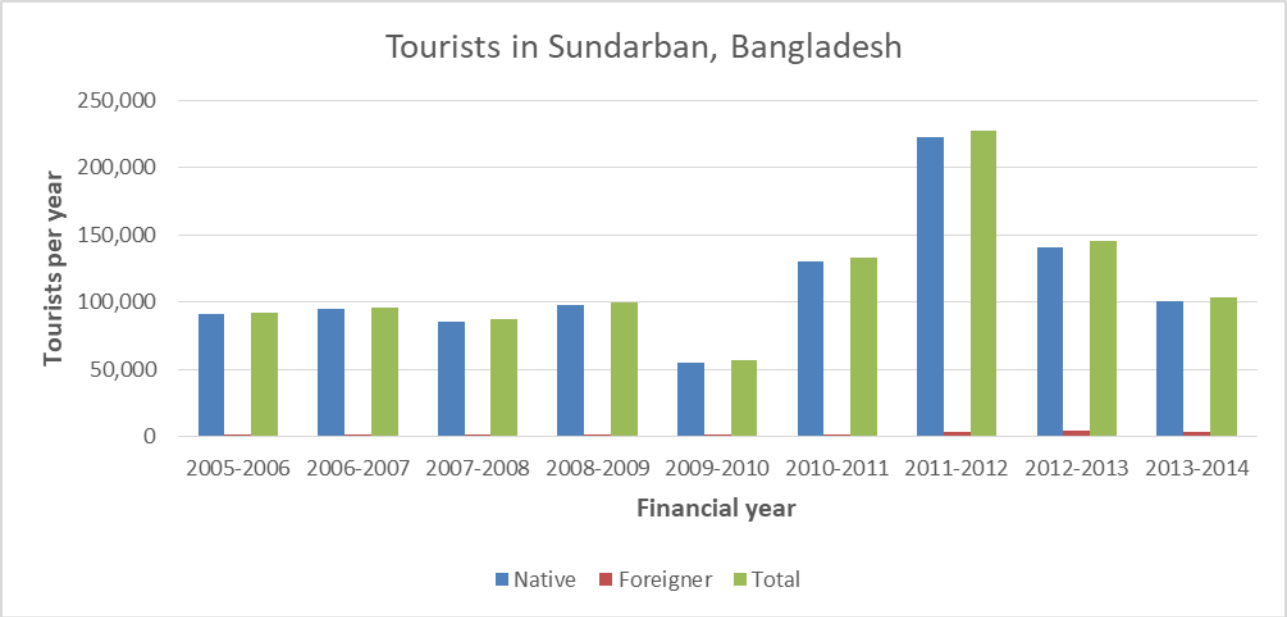

Figure 1: No of tourists in Sundarban, Bangladesh

The Government of Bangladesh has taken necessary measures to encourage private sectors to play a positive role in the development and diversification of tourism facilities; and to promote domestic and international tourism in the country. The Department of Forest (FD) developed several tourist spots within the Sundarban, allowing tourists inside the forest. In Bangladesh, the importance of ecotourism was first emphasized in the National Tourism Policy of 1992 as a means of low impact nature based outdoor recreation. Promotion of ecotourism considering the carrying capacity of nature was also emphasized in the National Forest Policy of 1994. The National Tourism Policy of 2009 has particularly addressed the development of ecotourism in the Sundarban, including specific development plans for Khulna, Mongla, Katka and Hiron Point.

More recently, a Strategic Master Plan of Tourism for the country has been prepared by the World Tourism Organization (WTO) in 2016. Ministry of Environment and Forest, Ministry of Shipping, Bangladesh Navy, Bangladesh Parjatan Corporation (BPC) and Bangladesh Economic Zones Authority (BEZA) submitted separate proposals for the roadmap for boosting tourism particularly in Sundarban to the Ministry of Civil Aviation and Tourism (MoCAT). The proposals recommend the introduction of tourist friendly ships, environment friendly motels in peripheral area, safari park fencing, bird viewing facilities, wildlife photography facilities, battery-run boat, angling spot and other facilities so tourist could enjoy their trip. Recommendations also include establishing cultural tourism sites in the neighbouring villages in Khulna and Satkhira and a visitor and interpretation center in Karamjal, where

there is already a mangrove arboretum, crocodile breeding centre and wildlife kept in captivity. As a part of its ecotourism activities, in 2016, the government has trained youths living in and around the forest as Eco-tour Guides.

5.8. The Cultural Landscape

The remoteness of the region, the water boundaries, the coexistence of human and the man-eaters or harshest mode of living generate thousands of legends and tales of the Sundarban. With all of her ethnicities, histories, myths, legends, beliefs, customs, rites and traditional knowledge Sundarban is a living museum, Sundarban peoples had improvised rich tradition of knowledge using their own lives as laboratories. This enriched cultural heritage is a common national wealth of Bangladesh and India, which cannot be dissected according to the political boundaries. Policy making towards conservation of the cultural heritage in Sundarban should be a common agendum for both the countries.

Above all, traditional rights of forest resource collection derived from indigenous knowledge, traditional cultural practices, beliefs, histories, philosophies and customary uses of forest resources ensure tolerable collection towards sustainable use of mangrove biodiversity resources (Moller et al, 2004; Berkes et el, 2000). This is the junction where cultural history meets the livelihood. Traditional knowledge and the social mechanisms behind traditional knowledge and practices can provide important insights into conservation and management of natural resources and thus this knowledge is to be comprehended, adopted and applied in natural resources management of the Sundarban.

The cultural history of Sundarban is a singular one comprising of Indian and Bangladeshi portions of Sundarban, so are the patterns of livelihood, essentially. There are very a few dissimilarities in traditional living patterns in these two parts that is within Indian SBR and people living within 20 km boundary of SRF in Bangladesh. The causes behind any of the deviation from the tradition are highly political, administrative and contemporary, which are, to some extent, region specific. Otherwise the populaces in both parts share common natural and cultural landscapes. The threats and challenges, the living and coping, the livelihood and fatality, the rites and rituals – all are so common that while in Sundarban it is tough for a first timer to determine that in which country he is travelling. The esential difference between the two parts then that is the coexistence of inhabited 46 villages/islands with the forests in India, while the whole part of human inhabitations are settled in the Upazillas in Bangladesh adjoining the forest. Naturally the human-animal conflicts are more common phenomenon in Indian part, which shaped up the forest or island villagers' living in a typical pattern, often absent in Bangladesh.

5.8.1. An overview of Ethno-cultural History of Sundarban

To understand the historical trends of socio-cultural conditions in the Sundarban, it is important to look into the demography of this region. There is quite a large number of dwelling ethnic groups (tribes/castes/sub-castes/clans/sub-clans) in Sundarban. Bagdi, Maal, Tiyaor, Kaibarta, Namahshudra, Bedia, Haari, Muchi, Dhopa, Munda, Turi, Kandra, Bhuina, Pod (Pundra) are the majorities to name with.

It is easier to observe the castes and clans in Indian part of Sundarban than in its Bangladeshi part due to the absence of Hinduite official caste system in Islam, who are predominant in the latter. According to Herbart Hope Risley in "…the three fisher castes, Kaibartta, Malo and Tiyor, are to be undoubtedly representatives of the prehistoric dwellers in the Gangetic delta."

Bagdis are indigenous people descended from people with Dravidian links, a hunter-gatherer tribe majorly living over the Raarh Bengal and the plateau of Chhotonagpur. Once known as a professional warrior clan they were often misrepresented as the criminals in the British records. In Sundarban, they emerged as one of the largest fisher communities. Tiyors or Tibars were also derived from the Dravidian communities, a large number of whom migrated to the plateau region, and gradually a considerable part of them, known as Rajbangshis migrated to Sundarban and another part to northern Bengal. Maalos, Maallaas or the Maals claim to fame as the expert mariners and the large boat builders (the term Maallaa represents the seamen). Kaibarttas or Keots are aboriginally fisher people, their ancestors were mentioned as 'Kirkat' in Rig-Veda and as 'Kharvat' in Aitareya Brahman. Like the Bagdis, the fisher Kaibarttas today are known as Jaaliya (jele-the fishermen).

It is popularly believed that the population in Sundarban is more or less evenly balanced between the two major religions, Hinduism and Islam from the very beginning, and all of the Muslims living by Sundarban are converted essentially from Hinduism, which is, factually a half truth. A part of the Hindu population living in and around the Sundarban also converted following the religious teachings of Jain Siddhacharyas and the Tantrayani Buddhist monks. A major populace of the coastal areas of Bengal thus came under the Buddhist (and partly Jain) fold before they became Hindu or Muslim (ref). Much of the population that converted to Islam abandoned their traditional practices, although some reflections still could be found in their daily life rituals e.g. nurturing a basil plant at home.

5.8.2. Deities, Divinities, Doctrines

The ancestry and the logic behind the beliefs, rites and rituals can be traced to some of the deities worshipped traditionally by the aforesaid ethnic groups. The deities of Sundarban region (jointly in India & Bangladesh) can be categorised into two –

- Primitive deities - More totemic, primordial and region-independent e.g. Makal Thakur (or Makhal-Makhali), Makal-Chaandi, Bura-Buri, Odor Bura-Sondor Buri, Ganga, Manasa, Sheetala, Jwarasur, Benaki, Bishalakshee etc.
- Folk deities - More human (often derived from real characters), comparatively younger and highly local e.g. Banbibi, Dakshin Roy, Kalu Roy, Bibi maa, Bandevi (Narayani), Ateswar Thakur, Manik Peer, Baro Khan Gazi, Bhangar Gazi etc.

Pagan or animist traditions come out of indigenous people's traditional modes of living, and their confronations and adaptations with nature. So as the people migrated to Sundarban at the different phases of history, they never tried to transform the landscape of this forested land. Rather the forests accommodated them and transformed them eventually. Fishing was originally the largest mode of

production, leaving agriculture or forest resource collection as the secondary ones. The destruction of the forests is a much later syndrome started in the British tenure only.

Primitive to Folk: Understanding Banbibi

Large land mass of Sundarban are divided, prevalently, between two parts – Abad and Bada – the inhabited, cultivated one and the forest. The story of Bada evolves keeping Banbibi and Dakshin Rai in the center and any socio-cultural account of Sundarban will be incomplete without Banbibi and Dakshin Rai. There are numerous numbers of tales involving two of them. In all of these tales Muslim Banbibi is the supreme deity of Sundarban and Hindu Dakshin Rai is the tiger god, and possessor of the forest produces (honey, bees-wax, wood and fish). Tales tell about how Banbibi once confronted to Dakshin Rai to protect a poor child called Dukhe and succeeded over him. Banbibi, can be associated with the Fakirs, Ghajis, Peers and Peeranis travelling through undivided Bengal in the late 13th-14th century. But the conflict between Banbibi and Dakshin Rai was not a religious conflict essentially. Dakshin Rai, or the King of the South, historically was a local feudal lord having a tight grip over the forest resources. Banbibi fought with him taking the side of the oppressed mass, irrespective of their religion

Figure5.1

Banbibi is an icon of religious tolerance beyond her own spiritual identity and is to be promoted as the face of faith leniency which becomes more and more indispensable in the present global scenario. This tolerance gave Sundarban people strength to live in a naturally, economically adverse land confronting all the odds collectively.

5.8.3. Traditional Knowledge & Livelihood

Native peoples' philosophy, traditional knowledge, science and technology has evolved through profound understanding of adversities in specific, and the nature at large. These traditional knowledge,

science and technology are applied in all the three major livelihood sources e.g. fishing, farming and gathering of forest resources – giving sustainability to every aspect of livelihood.

For an instance, honey and beeswax are among the lucrative treasure hunts in Sundarban. Moualis or the Mouals are the traditional honey-fetchers for centuries. The methods and technics they evolved over the ages are not tightly commercially focused but a proven one which stands for ecological balance. Cutting only a piece out of a beehive, not the whole, to ensure that the bees could make a return to their home, applying of wide smoke only, using Hental leaves, not petrol/kerosene, to lit up their bolens (fire torches) to make a smoke, or using green leaves in bolens outside and dry leaves inside – all are traditionally yet consciously manifested practices to ensure minimum impact on nature. Unlike commercial timber-cruisers, the traditional lumbermen of Sundarban always go for the feeble trees, an exemplary sustainable mode even by compromising on earning. The fisher folks of Sundarban use typical nets like behundi jaal (bag net) or char-paataa & khaal-paataa jaal (stake nets) - which were innovated and customized scientifically to befit Sundarban's unique and fragile waterscape.

Another interesting fishing technique which is almost on the verge of extinction is otter fishing. This peculiar traditional mode deserves distinct emphasis. Once practiced in many countries, this ancient technique is sustaining today marginally in Khulna and Narail districts of Bangladesh only and plays a vital role in conserving otters in Bangladesh.

5.8.4. Fables, Fictions, Films

Tigers persisted as the unchallenged icon of Sundarban over the centuries. The dignity and the power in a Sundarban tiger justify the prefix 'Royal Bengal' to its name. Tourists remain obsessed about the tigers, so did the tourist brochures and the websites. Tiger-sighting in Sundarban is mesmeric indeed. But far more interesting than the tigers themselves are that how they have become ingrained into a way of life for the people of Sundarban. In no other place in India, or probably in the world, a carnivorous, potential man-eater animal lives in such proximity with humans. As a result, there is a constant struggle of

survival between man and the beast. In many islands it is rare to find a family which hasn't lost at least one member to a tiger. The inhabitants of this area live in constant fear yet constantly challenge that fear without which they will not be able to survive, for their livelihood depend on the jungle, and for that they have to face the king of the jungle, sometimes even at the cost of their lives. This struggle, this conflict gets reflected in local beliefs, folklores, fables, rituals and even the language of the people. The locals rarely refer to a tiger by its generic term (which is *Baagh* in Bengali), but call it *"mama"*- maternal uncle – a colloquial stands for a not-too-close yet not-too-far of a daily relationship.

Palan Naiya: His profession is to earn from tiger victim's compensation

Palan Naiya is a resident of a small village of Indian Sundarban named Deulbari, is situated at the boundary of the mangrove forest. By profession, he is a Mouli (honey collector/ hunter). As consequences of this profession, he has remoulded his mind set and thoughts and adapted himself to a different kind of persona. At present time if any incidence of death has been taken place in Indian Sundarban, then Palan will earn the compensation from the Forest Department. This source of income is considered as the sole earning opportunity for Palan. Now forest department used to provide Rs 2.5 lakhs as compensation for death caused by tiger attack. He generally takes Rs. 1 lakh from intimate relatives of any dead person. The remaining amount of Rs. 1.5 lakh will be enjoyed by the relatives. He has learnt to earn through this awkward type of profession from the sufferings of this life. He had witnessed the incidence of tiger attack in the forest and 5 people including his wife and nephew were killed in this event.

Now from top to toe Palan has groomed himself as a modern Sundarban people. He knows every detail of deep forest of Sundarban as well as he also has good connectivity with the city. This dual role also has some reflection on his personality. Sometimes it seems that he is a very innocent person and sometimes very dodgy. Sometimes he uses a local dialect of Sundarban to express himself sometimes he talks in a very polished language of the metro city. He has enough local ecological knowledge. He understands how to find out a crab from its hole using a stick, on the other hand, he also deals with the complex personality of Alipur court for the repayment of money for death compensation. Palan is a good example of today's Sundarban folk; his lifestyle clearly depicts the socioeconomic structure of Indian Sundarban.

One fine evening author had interviewed Palan's 14 years old boy Panchugopal who has lost his mother due to man animal conflict. A few days ago he saw that his father had brought back the dead body of his mother, which was torn apart by tiger attack. Panchugopal had queried the author that "Tiger had eaten up my mother then what is the reason for tiger conservation!"

6. Management and conservation practices

Living in harmony with nature and nature conservation is reflected in a variety of traditional practices, religious beliefs, rituals, folklore, arts and crafts, and in the daily lives of the people in this region. An edict passed by Emperor Asoka during his reign from 269 BC to 232 BC for the protection of animals, fish and forests, can be considered the earliest documented case of formal forest conservation and management initiative in the South Asia region (Rahman, 2005). Later, during the Mughal period, the Emperor and local rulers preserved and protected forest areas for hunting as game reserves. Scientific management of the Sundarban mangrove forest was initiated much later (Choudhury and Ahmed, 1994). The first call to preserve the forests was made by Dr Brandis, the Conservator of Forests in Burma in 1862. Based on his recommendations, additional reclamation grants were stopped, but deforestation continued irrespectively. The rate of forest clearance had increased and forest wood was used for ship building and railway slippers. By 1873, almost 5,100 km^2 of forests had been converted into agricultural land and the Sundarban area forest cover had been effectively reduced to about 14,100 km^2. The Forest Act was formulated in 1855 but it is only post 1873-1874, when faced with dwindling forest produce; the colonial rulers started reviewing the policy of transformation of all available wetland forest to taxable agricultural land in the Sundarban. Under the Forest Act some parts of the Sundarban were declared as reserved forest in 1875-1876 and from then on the resource harvest became the subject of Government control. Fishing or collection of natural resources became subject of permits, and paying revenue to the Government through the Forest Department (Hussain and Acharya 1994). Entry without permit was prohibited from that time. The first working scheme, including prescriptions for wildlife and biodiversity conservation, came into force during 1893-1894.

The first 10 year working scheme came into operation in 1893-94, in which the forest was divided into two felling series and 10 annual coupes (Choudhury and Ahmed, 1994). During 1906-1912 a revised working scheme by the Forest Department raised the exploitable girth of *Heritera fomes*. Till 1912 Sundarban was managed under working schemes. This was followed by the first real working plan based on sceintific inventory of the Sundarban. F. Trafford wrote the first management plan for Sundarban for the period 1912-13 to 1931-32. He suggested two working circles as eastern working circle and western working circle. The eastern working circle had the richer growing stock. He prescribed selection system and suggested a 40 year felling cycle with an exploitable girth of 106.6 cm for *Heritierra fomes* and 122 cm for *Sonneratia apetala*. (Saenger, 2002).

By 1930s, the standing stocks of other trees were on the decline due to unregulated felling and a new plan was devised. The Curtis plan came into force on 1931 and was based on detailed scientific inventory. Volume functions were developed suggesting rotations, felling cycles and minimum exploitable girth for major species including 'yield calculations' and the forest was divided into management units called compartments. The maps and inventories were prepared based on detailed physical survey and are considered milestones, and are found to corroborate very closely with inventories using state of the art technologis at later times (MoEF, 2007). However the focus was still on scientific harvesting rather than conservation. 12 different diameters were prescribed for *Heritierra fomes*, 11 for *Excoecaria agallocha*, 7 for *Xylocarpus mekongensis*, 2 for *Xylocarpus granatum*, 4 for *Bruguiera gymnorhiza*, and so on. Curtis' plan was elaborate and needed professional skill to apply the precise prescriptions. The field staff was found to be incapable to cope with his prescriptions and thus this management plan was revised by S. Choudhury in 1937. Choudhury's plan was in force from April

1937 to 1947. The Curtis plan of 1931 remains the last coordinated assessment of the entire Sundarban as one forest, hereafter the relevant laws, policies and management plans are at the national level and focus on only the national part of the Sundarban.

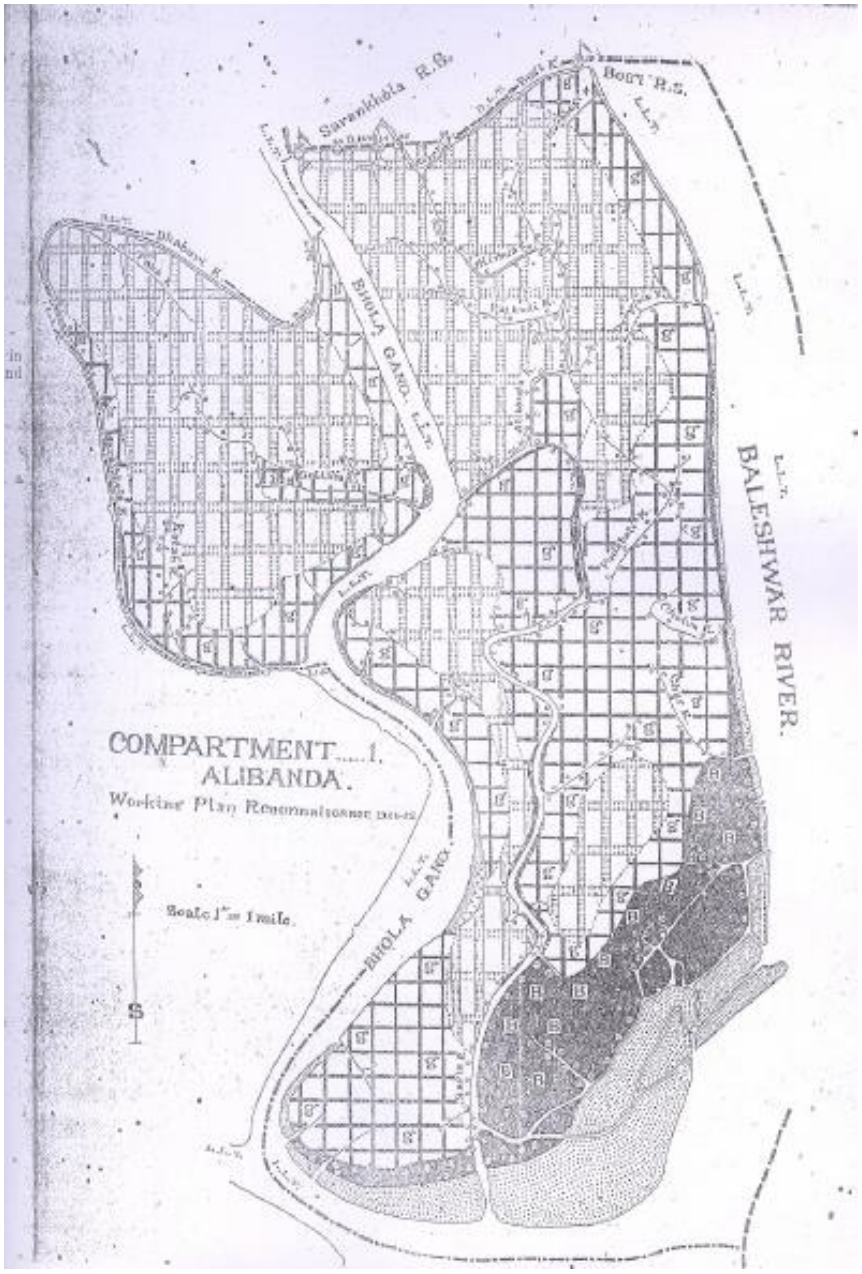

Figure 6.1: Curtis map for a compartment of the Sundarban

A separate forest department was created for Bengal in 1876 and the Sundarban Forest Division was created in 1879. Around 1927, forest management, for long time a central matter, became a provincial

responsibility under the revenue department. Soon after, the forest section became independent of the revenue department. The forest organization since then consists of a Chief Conservator of Forests located at the provincial/ central headquarters, and regional deputies called Deputy Conservators of Forests. Divisional Forest Officers are usually located at the district headquarters and Forest Rangers and Beat Officers at the block or sub-block levels. This organizational structure is still maintained in both countries. During the British era, the Forest Department divided the forest into 100 compartments for more efficient management and conservation. 45 of these compartments fell in the Sundarban Biosphere Reserve in West Bengal, India and the remaining 55 compartment are situated in the Sundarban Reserve Forest in Bangladesh. In Bangladesh, these compartments still remain as the forest management unit within the mangrove forest. Each compartment is assigned a Beat Officer in Bangladesh.

The Indian Forest Act, 1927, is responsible for declaration of 9,630 km^2 areas as Protected Forest within the Sunderbans. The 'protected' forest was again classified as Reserved Forest to prevent any further reclamation in 1943 (WWF, 2011). Although the rules framed under the Forest Act of 1927 still remain central to forest legislation in both countries. The thrust of the policy in both countries continues to be "command and control" where the forest is cordoned off as a reserve forest and then entry, exit, and economic activity are regulated through policing and licenses. Currently both countries have a moritorium of felling of tress within the reserve forest or national park areas, varying restrictions on harvesting of non-timber forest resources and ban on killing or capture of wildlife other than fish and some invertebrates. Conservation of Sundarban remains high on the agenda for both governments but also the mangrove forest has an iconic presence in the populations of both countries. Under at least three international conventions (Convention on Biological Diversity, Ramsar Convention, and Convention Concerning the Protection of World Cultural and Natural Heritage), to which Bangladesh and India are signatory, and under three national laws the Governments of Bangladesh and India are committed not to allow hydrocarbon exploration, unsustained resource exploitation and industrialization (source of pollution) in and around the Sundarban. As a result, in both countries, the areal extent of the Sundarban mangrove forest remained more or less stable since the 1960s.

Despite these similarities, there is considerable variation in the understanding, focus, direction and implementation in the relevant laws, acts and policies which include:

- Management boundaries differ between the two countries. In Bangladesh, while a 10-km wide band, was declared ecologically critical area (ECA), forest conservation essentially focuses on the reserve forest. There are a few uncoordinated activities by government and non-government agencies, no real initiative has been taken to manage and develop the surrounding areas which house the population dependant on the Sundarban so far. On the other hand, Sundarban Biosphere Reserve (SBR) in India consisting of uninhabited National Park as well as inhabited areas and there are quite a few programmes and initiatives by government, non-government and research agencies focussing on the entire SBR.
- As a result, in Bangladesh planning and management has typically been focused on the physical resource, its status and extent. In West Bengal, India, socio-economic issues affecting forest change, dependency and interlinkages on forest resources are better addressed.

- In Bangladesh only one agency, the Forest Department is solely responsible for the conservation of the Sundarban. While in India there are quite a few agencies at the state and national level involved in conservation activities. These include, West Bengal Forest Department, National Tiger Conservation Authority, Sundarban Biosphere Reserve Authority. There is often overlapping roles and responsibilities creating confusion.
- The geographic location of Sundarban in both countries mean that some of the issues are also different. The Sundarban is situated a 100km from Kolkata, the state capital, and is accesible by road and railway. This means more tourists have access to the mangrove forest. Tourism infrastructure are also more developed. Whereas, in Bangladesh, the Sundarban is quite remote and can be accessed only by rivers. This has restricted the number of tourists in Bangladesh, however, tourists are on te rise..
- Despite human habitations and economic exploitation of the forest, Sundarban retained a forest or canopy closure of about 70% (ODA, 1985). The forest-village interface in Bangladesh is limited to the northern boundary of the Sundarban, limiting human-wildlife interaction. In India, many human habitations share boundaries with forested areas, causing wildlife, especially tigers to stray into the habited areas. In order to prevent straying of tiger into villages, Nylon net as well as well as Goran fencing have been erected along the forest-village interface. Tranquilisation and capture of the straying animal and their subsequent release into the forest, is also frequently resorted to.

6.1. Legal status and current management of the Sundarban

Sundarban Reserve Forest, Bangladesh

The total area of Sundarban Reserve Forests in Bangladesh are approximately 6,01,7 km^2. In order to conserve the wildlife and biodiversity of the Sundarban, the Government of Bangladesh established three Wildlife Sanctuaries (Sundarban East, Sundarban South and Sundarban West) in 1977, under the Bangladesh Wildlife Act 1974, covering an area totalling 324 km^2, which was declared a World Heritage Site by UNESCO in December 1997. In 2012, three river areas (Chandpai, Dudhmukhi and Dhangmari) covering a total area of 10.7km^2 were declared as Wildlife Sanctuaries, mainly for the protection of dolphins. The rest of the Sundarban remained as Reserved Forest, which was declared in the colonial era. Since the Sundarban is also treated as a wetland of international importance, the entire Sundarban gets protection under the Ramsar Convention (which Bangladesh ratified in 1992).

From 1947 to 1959-60 Sundarban was managed on short-term schemes. Forestal Forestry and Engineering International Limited of Vencouber, Canada carried out detailed inventory of Sundarban in 1960. Based on the data and information generated, A. M. Choudhury prepared the management plan of Sundarban for the period 1960-61 to 1979-80. He recognized 3 quality classes and suggested 3 working circles. He suggested exploitable diameter limits for *Heritierra fomes* as 26.9 Cm, 21.9 Cm and 16.8 cm for site quality I, II and III respectively. For most of the other important species except *Avicennia* officinalis, he suggested same exploitable girths. He prescribed a 20 year cutting cycle for all important species. Choudhury's management plan laid emphasis on the production of industrial wood.

Immediately after liberation a ban on exploitation till 1978-79 was imposed. Operation restarted in 1979-80 under a revised felling scheme for the period 1979-80 to 1984-85. The second detailed

inventory of Sundarban was done by Overseas Development Administration (ODA) of U. K. during 1980 to 85. The report was published in 1985. E. G. Balemforth prepared a set of interim prescription in 1985. In 1990 a temporary moratorium on the harvest of timber was imposed. This moratorium though stopped the felling for sale to the members of the public, felling for the industries such as news print and hard board mill continued. In the mean time top dying of Heritierra fomes became conspicuous. ODA report indicated that about 0.45 million *Heritierra fomes* trees (114trees/ha) are affected by top dying. ODA report also indicated that there has been more than 40% depletion of the growing stock of Heritierra fomes and Excoecaria agallocha while the area under pure Heritierra fomes forest decreased from 31.6% to 21% and the mixed Excoecaria agallocha- Heritierra fomes increased from 24.4% to 29.7% between the Forestal and ODA inventories.

All the past forest inventories concentrated on tree resource only and thus total picture of its ecology is yet to be unveiled. A need of broader understanding; of the importance of the inter-relationships of the flora, fauna, aquatic resources and the edaphic conditions on which they occur, under mangrove ecosystems of Sundarban; is emerging with the passage of time and awareness with respect to the significance of biodiversity at global level. A benchmark needs to be established through a base line survey for future comparison. Thus it has been felt that a data set needs to be generated to indicate the status of the health and condition of the Sundarban forest, and recorded as such, to serve the purpose of a bench mark with respect to the flora and fauna of Sundarban for future monitoring.

Presently there is a moratorium on tree felling in the reserve forest, only Non Timber Forest Products (NTFPs) are being harvested, this harvest is based on seasonal licenses issued from the Forest Department. However studies show that at present, the Forest Department does not control permit licenses to reduce overharvesting of fish or shrimp fry and there is no monitoring or implementation of ban on harvesting of wild shrimp fry (Roy and Alam, 2012; Hoq, 2007).

The National Forest Policy (1994) advocates social forestry and agro-forestry concept to include the poor and interested community in the regeneration on the basis of a benefit-sharing arrangement. While community based forest managament have been quite successful in some areas of Bangladesh, in the Sundarban the Forest Department has yet to introduce effectice participatory forest management (IUCN, 2014; Roy and Alam, 2012). A gazette notification for implementing a co-management approach for managing the Sundarban involving key stakeholders stipulate the establishment of co-management councils and committees. Two Co-management Committees have been functioning in the Chandpai and Sarankhola Forest Ranges of the Sundarban East Division and two more are being formed (nishorgo).

In 1999, a 10 km area surrounding the forest (except the seaside) of the Sundarban was declared an Ecologically Critical Area (ECA) under the Bangladesh Environment Protection Act 1995, by the DoE. Though certain activities are prohibited with the declaration of the ECA, there is none in the field to enforce these. It was expected that declaration of ECA will ensure better protection of the Sundarban and its wildlife, but the visible impacts are almost nil. Forest Department has taken some small-scale captive breeding programmes for Estuarine Crocodile and Spotted Deer at Karamjal, northern Sundarban, while special measures have been taken to conserve the habitats of the Estuarine Crocodile in Mrigamari. Moreover, many Governmental and non-Governmental projects and programmes were implemented in the Sundarban landscape and its buffer areas. As a result of these initiatives, despite

human habitations and economic exploitation of the forest, Sundarban retained a forest closure of about 70% and the forest boundary has remained unchanged since 1960 (ODA, 1985).

Sundarban Biosphere Reserve, West Bengal, India

In 1970, the Ministry of Environment and Forests, Government of India (GoI) adopted the UNESCO (United Nations Educational, Scientific and Cultural Organization) Man and Biosphere programme and declared 9630 sq. km. of the Ganga delta in West Bengal as the Sundarban Biosphere Reserve in 1989. The main objectives of the biosphere reserve are to: 1) conserve diversity and integrity of plants, animals and micro-organisms; 2) promote research on ecological conservation and other environmental aspects; 3) provide facilities for education, awareness and training for effective participation of the people living around the Biosphere Reserve.

The northern territory of the SBR is demarcated by the Dampier Hodges line of 1829-1830 (World Bank, 2014, Danda et al 2011). This includes approximately 4,260 sq. km of reserve forests, of which around 40 percent has been declared protected areas, including about 1,330 sq. km as a national park, and around 406 sq. km as wildlife sanctuaries. This Reserve supports one of the largest single tiger populations in India. The wildlife is protected under the Wildlife Protection Act 1972. There are three Wildlife Sanctuaries (Sajnakhali, Lothian Island and Holiday Island) inside this Biosphere Reserve. Moreover, the National Park, one Wildlife Sanctuary (Sajnakhali) and some other areas are under the Project Tiger area.

With the declaration of the Sundarbans as a World Heritage Site in 1987, the primary objective was given to biodiversity conservation. The management is geared towards the following objectives:

- Restoration of unique mangrove ecosystem of Sundarban and conservation of its biodiversity
- Development of sustainable economic, social activities, population living in Sundarban;
- Facilitating research, monitoring, education and training.

This Biosphere Reserve has been divided into the following inter-related zones:

(1) The core zone is a compact block of Reserve Forest covering approximately 1700 km^2 lying in the eastern portion of Sundarban adjoining Bangladesh border and is bounded by Matla river in the west and into Bay of Bengal in the south. This fully protected area containing the Sundarban National Park is devoted to conservation of bio-diversity, including primitive area which has remained free from any external disturbances since a long time.

(2) Buffer zone comprises majority of mangrove areas including reserved forests areas adjoining area surrounding the above core zone and includes portion of the buffer zone of tiger reserve, Sajnakhali Wild Life Sanctuary. The buffer area, excluding the wildlife sanctuary, is the only area where subsistence activities such as fishing, crab collection, shell collection and prawn seed collection are allowed, with prior permission from the West Bengal forest department.

(3) Transition zone: Covers the balance of the Biosphere Reserve area, which contains mangrove areas mostly in non-forest areas and reclaimed areas with agriculture. The population of the Sundarban region reside in this zone.

The government attempted to introduce some livelihood alternatives in the late 1990s. The programs were organized through the Joint Forest Management Committees (JFMCs) at the village level and through the Forest Protection Councils (FPCs), but did not yield the desired livelihood outcomes. The main reason behind this was misalignment with local cultural preferences, as well as because of poor marketing structures and inequitable benefit sharing mechanisms between and amongst the state and the locals (Ghosh et al, 2015).

The park receives financial aid from the State Government as well as the Ministry of Environment and Forests under various plan and non-plan budgets. Additional funding is received under the Project Tiger from the Central Government. Current management practices geared towards human-tiger conflicts:

- Integrity of forest has been accorded highest priority and patrolling duties are performed by using boats and speed boats to cover various water channels and creeks in search of intruders. There exists over 35 land based and floating camps.
- A new concept "Floating Check posts" and "Floating Camps" have been established to prevent illegal entry of people in protected areas of Sundarban.
- 1600 Km^2 has been earmarked as the core zone of Sundarban Tiger Reserve where no human activity is permitted except that of research and forest protection. This zone is inviolate by law.
- Alternate livelihood is being accorded high priority in the 65 Joint Forest Management Committees formed.
- Sundarban Tiger Conservation Foundation trust (STCFT) has been established for intensification of management.
- Joint Patrolling with Border Security Force and Special Armed Police (SAP) are performed.
- Strict checks are performed for Fishing Permits (known as BLC or boat license certificates) and there number has been restricted to below 3500 as compared to 4800 about a decade back. Over 3000 offence cases are booked annually for violation of rules.
- In order to prevent tigers to stray out of forest, a newly designed "Nylon Net Fences" (NNF) have been raised along the forest – village interface since the year 2001. The Nylon Net Fences act both as a psychological and physical barrier. A total of about 150 km nylon net fence has been raised in Sundarban to prevent straying by tiger. The nylon net fence maintenance is a serious problem as the numerous creeks in mangrove forest with about 6 hours diurnal tidal cycle poses problems. A "NNF Maintenance Protocol" has been developed and actively followed.
- Forest Department has established five Immobilization Teams. These teams are equipped with speed boats and immobilization equipments. In addition, the trap and translocation cages are also used to deal with the situation. Regular trainings are organized for capacity building of staff.

- The Forest Department in Indian Sundarban provides compensation to the dependents of tiger victim and free medical treatment to the injured. This is provided only to those who enter the forest with valid permits. A large section of people mainly the crab-collectors, who enter in Sundarban without permit, do not come in the ambit of this facility. The current rate of compensation for death is Rs. 2,50,000 (approximately 4000 $).

The area has recognised as the World Heritage Site for its unique wilderness. Three Wildlife Sanctuaries are Sajnakhali, Lothian Island and Holiday Island. These were established in 1976 and the total area covered by these three sanctuaries is 406.35 km^2. The areas mainly serve as the refuge for the Tiger and its prey. In order to maintain healthy population of Estuarine Crocodile and Olive Ridley Turtle, the Government of West Bengal has taken extensive captive breeding and re-introduction programmes. Additionally, the government of India established a National Mangrove Committee within the Ministry of Environment and Forests in 1979, with the mandate to manage, protect, and re-afforest the areas. Consequently, despite the high population density, the areal extent of the Indian Sundarban mangrove forest remained more or less stable since the 1960s.

6.2. Relevant Laws, acts and policies

Sundarban Reserve Forest, Bangladesh

In Bangladesh, with the promulgation of the Wildlife (Preservation) Act in 1974, the Forest Policy in 1994 and the amendment of Forest Act in 2000 and the Social Forestry Rules in 2004 and 2010, the emphasis of forests management has gradually shifted from timber production to ecological requirements, conservation of biological diversity, meeting bonafide subsistence consumption needs of local people and climate change mitigation and adaptation functions and services of forests.

Parts of the Sundarbans were declared a Wildlife Sanctuary under Wildlife (Preservation) Act in 1974 to conserve animals as well as trees. Currently the wildlife of the entire Sundarban is protected under the Bangladesh Wildlife Act 2012, and hence wildlife should not be killed or captured. The use and export of the tiger and other threatened species of wildlife, or their body parts, is banned under the provisions of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; Bangladesh acceded in 1982). A moratorium on felling of the dominant Sundari tree was enacted in 1989, and UNESCO declared the Sundarbans to be a World Heritage Site in 1997. A 10km buffer area around the forest was declared an “Ecologically Critical Area” in 1999 under the Bangladesh Environment Protection Act 1995, and certain activities were banned in the ECA in order to ensure better protection of the Sundarban and its wildlife. Finally, after the devastation of Hurricane Aila in 2007, a ban on all forest extraction was put in place .

Sundarban Biosphere Reserve, West Bengal, India

Since the 1970s, the Indian Sundarban mangroves have been protected under various legal measures which were established primarily to protect and help increase the threatened tiger population. In 1984 a

(subordinate) protection of the forests came into law with the establishment of the 1330 km^2 Sundarbans National Park. No human interference is permitted in the National Park.

The Wild Life (Protection) Act, 1972, provides the basis for declaration of national Parks and sanctuaries within the reserve and prohibits hunting and poaching of wild animals. The Forest (Conservation) Act, 1980, restricts use of forestland for non-forest purposes. The Environment (Protection) Act, 1986, is an umbrella act and provides protection from all the different types of pollutants. The Coastal Regulation Zone Notification (CRZ), 1991, The West Bengal Marine Fishing Regulation Act, 1993 regulates shrimp culture and marine fishing respectively. But in spite of all these legal tools and machinery the illegal trespassing, hunting discharge of various types of pollutants and unsustainable fishing are still continuing. Ministry of Agriculture issued Guidelines for Sustainable Development and Management of Brackish Water Aquaculture (1995). The overall purpose of the Guidelines is to assist in formulating appropriate shrimp farming management practices and adopting measures for mitigating the environmental impact for management of shrimp pond wastes and utilisation of land/water resources in a judicious manner. In accordance with the Environment (Protection) Act, the Aquaculture Authority under the administrative control of the Ministry of Agriculture has been established Further to this, the Coastal Regulation Zone Notification (CRZ), 1991 under the Environment (Protection) Act, which puts a comprehensive construction embargo on the forest area, is also relevant. The CRZ Notification of 1991 had demarcated only the core mangrove forest area of 4,230 sq km as CRZ-I and kept the remaining 5,400 sq km of non-forest area inhabited by 4.1 million people outside the purview. But the latest notification has earmarked the entire biosphere reserve as CRZ-I.

Table 6.1: Relevant Laws, Act and Policies in Bangladesh and India

Sundarban Impact Zone,Bangladesh	Sundarban Biosphere Reserve,India
Forestry and Environment	***Forestry and Environment***
1. Charts of Indian Forest, 1855	1. Charts of Indian Forest, 1855
2. Indian Forest Act,1878	2. Indian Forest Act,1878
3. Drift Timber Rules for the Sundarbans Forest Division and for the Chittagong Hill Tracts Divisions and for Sylhet District, 1881.	3. Drift Timber Rules for the Sundarbans Forest Division and for the Chittagong Hill Tracts Divisions and for Sylhet District, 1881.
4. The Forest Policy,1894	4. The Forest Policy,1894
5. Indian Forest Act, 1927	5. Indian Forest Act, 1927
6. Forest Policy of Pakistan,1955	6. The Wild Life (Protection) Act, 1972
7. Hunting and Fishing Rules, 1959	7. The Forest (Conservation) Act, 1980
8. Wildlife (Preservation) Act in 1974	8. The Air (Prevention and Control of Pollution) Act, 1981
9. NationalForest Policy,1979	9. The Environment (Protection) Act, 1986
10. National Conservation Strategy, 1992	10. National Forest Policy, 1988
11. National Environmental Policy, 1992	11. Joint Forest Management Circular (1990-)
12. National Tourism Policy,1992	12. National Conservation Strategy and Policy Statement on Environment and Development (1992)
13. National Forest Policy in 1994	13. National Forestry Action Plan, 1999
14. National Environmental Management Action Plan (NEMAP), 1995	14. Joint Forest Management Resolution,2002
15. Environment Protection Act 1995	15. Biological Diversity Act, 2002
16. Bangladesh Environment Conservation Act (ECA), 1995	16. National Wildlife Action Plan,2002-2016
17. Bangladesh Environment Conservation Rules, 1997	17. National Environment Policy,2006
18. Wildlife Sanctuary Regulation,1999	18. Wetlands (Conservation and Management) Rules 2010
19. the amendment of Forest Act in 2000	19. PROCEDURAL LAWS
20. National Biodiversity Strategy and Plan,2004	a) Appellate Authorities & Environmental Tribunals
21. National Adaptation Programme of Action (NAPA),2005	b) Public Liability Insurance Act,1991
22. Bangladesh Environment Court Act, 2010	c) Provisions of Criminal Procedure Code
23. Environmental Policies, Strategies and Plans the Social Forestry Rules in 2004 and 2010	d) Provisions of Factories Act, 1948
24. Bangladesh Wildlife (Preservation and Security)Act 2012	***Water Resources Management***
25. Bangladesh Biological Diversity Act,2012	20. Embankment Management Act,1882
Water Resources Management	21. Embankment Management Act (Amended), 1967
26. Embankment Management Act,1882	22. The Water (Prevention and Control of Pollution) Act, 1974
27. Bangladesh Water Act,2013	23. Water (Prevention and Control of Pollution) Rules 1975
28. National Water Policy,1999	24. Territorial Water, Continental Shelf, Exclusive Economic Zone and other Marine Zones Act – 1976
29. National Water Management Plan,2001 (Approved 2004)	
Inland Navigation	
30. Inland Shipping Ordinance 1976	

31. ~~Draft Rules for Inland Ship Safety 1994~~ 32. Inland Water Transport Policy (IWTP), 2009	25. ~~Water (Prevention and Control of Pollution) Cess (Amendment) Act, 1991~~
33. National Shipping Policy,2000 ***Socio-Economic*** 34. Major Fisheries Regulation by Forest Department a) Khal Closure Regulation (1989) b) Collection and Export of Live Crab Regulation (1995) c) Closed Season Regulation (1995) 35. National Fisheries Policy, 1998 36. National Agriculture Policy,1999 37. National Rural Development Policy, 2001 38. National Landuse Policy,2001 ***Coastal Zone & Marine Resources Management*** 39. Coastal Zone Policy, 2005 40. Coastal Development Strategy, 2006 ***Climate Change*** 41. Bangladesh Climate Change Strategy and Action Plan (BCCSAP), 2009	26. National Water Policy, 2002 27. Water (Prevention and Control of Pollution) Cess (Amendment) Act, 2003. ***Coastal Zone & Marine Resources Management*** 28. The Coastal Regulation Zone Notification (CRZ), 1991 29. The West Bengal Marine Fishing Regulation Act, 1993 ***Socio-Economic*** 30. Guidelines for Sustainable Development and Management of Brackish Water Aquaculture (1995) 31. Aquaculture Authority notification (1997-) 32. The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006 33. Rural electrification policy 34. Integrated Energy Policy ***Inland Navigation*** 35. National Water Transport Policy, 1980 36. The Inland Vessels (Amendment) Act, 2007

Both countries are signatory to the following:

1. Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973-2013)
2. Convention Concerning the Protection of the World Cultural and Natural Heritage (1975)
3. International Plant Protection Convention
4. Plant Protection Agreement for the Asia and pacific Regions
5. Conventions on Climate Change on Bio Diversity
6. Convention Relative to the Preservation of Fauna and Flora in their Natural State,(London), 1933.
7. Convention for the Protection of Migratory Birds and Game Mammals, 1936.
8. Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere, (Washington), 1940.
9. International convention for the Protection of Birds,(Paris)
10. Agreement concerning co-operation in the Quarantine of plants and their protection against pests and Disease, (Sofia), 1959.
11. European Convention for the Protection of Animals during International Transport, (Paris), 1968.
12. The Ramsar Convention on Wetlands of International Importance (Ramsar, Iran) 1971.
13. Benelux Convention on the Hunting and Protection of Birds; (Brussels), 1972.
14. Convention on the Conservation of Migratory Species of Wild Animals (Bonn), 1979.

6.3. Past and current collaboration

Bonds of culture, a shared history and a common ecosystem, as well as neighborly proximity, and social and economic ties between Bangladesh and India are major building blocks for enhanced cooperation between the two countries. India and Bangladesh's geographical locations complement each other and present an opportunity for both to further develop their connectivity linkages and economies. Although some progress has been made, the two countries present one of the least integrated parts in the world with regard to policy, trade, and infrastructure. This lack of integration directly affects economic development and hampers management of shared natural resources, such as forests and cross-boundary river basins.

The first formal agreement between the two countries was the India-Bangladesh Treaty of Friendship, Cooperation and Peace was a 25-year treaty that was signed on March 19, 1972 forging close bilateral relations between India and the newly established state of Bangladesh. Thereafter, multi-dimensional relations between the two countries have come in to affect generating several levels of interaction. High-level exchanges, visits and meetings take place regularly alongside the wide ranging people-to-people interaction. The two countries have so far (until 2015) consented to a total of 87 agreements including treaties, MoUs and protocols. They are also common members of regional collaborations such as South Asian Association for Regional Cooperation (SAARC), Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC), Indian Ocean Rim Association (IORA) and Bangladesh, Bhutan, India, Nepal (BBIN) Initiative.

Some of the important institutional mechanisms that meet periodically to discuss bilateral issues include Joint Rivers Commission (JRC) and Joint Economic Commission (JEC) at Ministerial level, Foreign Office Consultations, Home, Commerce and Water Resources Secretary level talks, BSF-BDR DG-level border coordination conference, Joint Working Group on Security (JWG), Joint Boundary Working Group (JBWG), Joint Working Group on Trade (JWG), Joint Group of Customs Officials (JGC), Protocol Renewal Committee and Standing Committee to review implementation of Protocol on Inland Water Transit and Trade, and Inter- Governmental Railway Meeting (Rao, undated).

Time and again at various fora it has been expressed that the Sundarban across Bangladesh and India be visualized as a single biogeographical entity and that bilateral research cooperation be promoted to inform joint action for sustainable development and conservation of the landscape. In 2001, a grant of US$20,000 was received as a preparatory assistance for promotion between India and Bangladesh from the World Heritage Fund. Most importantly, in 2011 the Governments of Bangladesh and India have signed a 5-year Memorandum of Understanding (MoU) on conservation of the Sundarban, and a protocol on conservation of the Tiger in the Sundarban. Both countries have agreed that the biodiversity, particularly the Tiger, of the Sundarban must be conserved by joint actions and none of the two countries will do anything that might threaten the Sundarban. Under these two mutual agreements a number of strategic actions have been proposed to be done in collaboration such as joint research and monitoring (on Tiger, prey and other biodiversity), adoption of joint management, sharing of relevant information and technical knowledge (e.g. on tiger-human conflict) between the concerned officials of the two countries, execution of patrolling along the respective borders of the two countries to prevent

poaching and illegal trade, and capacity building by exchanging personnel for training and promotion of education.

A Joint Working Group on the Conservation of Sundarban comprising officials from India and has been set up to implement the activities under the MoU. The Joint Working Group has so far held one meeting on July 21, 2016 at New Delhi, India.

Table 6.2: Summary of the Agreements for joint management of the Sundarban Region:

Name of Agreement/ MOU	**Date of Signing**	**Salient features**	**Responsibility**
Framework Agreement on Cooperation for Development	September 06, 2011	Lays down the framework for enhancing mutually beneficial bilateral cooperation in a wide range of areas. These include promotion of trade, investment and economic cooperation; connectivity; water resources; *management of natural disasters*; generation, transmission and distribution of electricity, including from renewable or other sources; *promotion of scientific*, educational and cultural *cooperation*; people to people exchanges; *environmental protection and responding to challenges of climate change through adaptation*; sub regional cooperation in the power sector, *water resources management*, physical connectivity, *environment and sustainable development*; and enhancing cooperation in security.	A Joint Consultative Commission would be established to monitor effective and smooth implementation of the Agreement that shall meet annually.
MOU on *Conservation of the Sundarban*	September 06, 2011	Seeks to facilitate cooperation in the areas of *conservation of biodiversity, joint management of resources, livelihood generation for poverty alleviation and development, cataloguing of local flora and fauna and studying the impacts of climate change*.	A Joint Working Group has been set up to define activities, responsibilities, time, and resources involved, according to the activities established as per this Memorandum.
Protocol on conservation of the Royal Bengal Tiger of the Sundarban	September 06, 2011	Provides for bilateral cooperation in undertaking *scientific research, knowledge sharing and patrolling of the Sundarban waterways on their respective sides to prevent poaching or smuggling of derivatives from wildlife and bilateral initiatives to ensure survival and*	Forest Officers or Park Directors from both the countries will hold periodic meetings on either side of the Sundarban alternately High level Ministerial level meetings will be held to

Name of Agreement/ MOU	Date of Signing	Salient features	Responsibility
		conservation of the Royal Bengal Tiger in the unique ecosystem of the Sundarban. The Protocol also provides for cooperation to promote *understanding & knowledge of Royal Bengal Tigers*, exchange of personnel for training and promotion of education.	follow up all the recommended actions between the two countries.
MOU on cooperation in the field of fisheries	September 06, 2011	Seeks to promote development of cooperation in ***fisheries and aquaculture and allied activities*** between the two countries through joint activities, programmes, ***exchange of scientific materials, information and personnel***.	A Joint Working Group has been set up to facilitate cooperation under the MoU The Ministry of Agriculture of the Government of India and the Ministry of Fisheries and Livestock of the Government of Bangladesh would coordinate implementation of the MoU.

6.4. Current role of institutions

The associated statutory conservation and multiple socio-economic zones with varied development requirements of the Sundarban region has resulted in the presence of numerous agencies with diverse mandates and activities concerning matters ranging from conservation to coastal issues to centralized schemes for socioeconomic development. However, in both countries, the Forest Department is the main agency historically mandated for the management of the mangrove forest.

Sundarban Reserve Forest, Bangladesh

The Sundarban reserve forest including the rivers and khals are controlled by the government through the Forest Department. The Forest Department has two administrative divisions in the Sundarban, these are, Sundarban West Forest Division and Sundarban East Forest Division, with two range offices under each division. So the whole Sundarban has four range offices and the entire forest is managed as 55 ecological compartments. The Forest Department has also been maintaining the fisheries resources through implementation of certain rules and regulations. Range Offices, Forest Stations and Forest Camps are responsible for on-site conservation activities. Forest Camps are tasked with patrolling the forest while Range Offices and Forest Stations in addition to patrolling also monitor patrolling, collect revenue and carry out administrative activities. Wildlife and Nature Conservation Circle (WNCC) was formed in 2001, which established dedicated posts to safeguard wildlife, primarily in protected areas. The WNCC does not yet have sufficient institutional presence or resources to fully carry out its intended

role. In the Sundarban the territorial Division Forest Officers, rather than WNCC staff, currently administer both the reserved forest and the wildlife sanctuary areas.

Other than the Forest Department, Coast Guard, Border Guard of Bangladesh (BGB) and Navy camps are also present within the SRF. In the ECA, outside the boundaries of the SRF, numerous government agencies have jurisdiction in the different sectors. The names, roles and responsibilities of the agencies are given below:

Sundarban Biosphere Reserve, West Bengal, India

The Principal Chief Conservator of Forests (PCCF), Wildlife & Bio-Diversity & ex-officio Chief Wildlife Warden, West Bengal is the senior most executive officer looking over the administration of the National Park subsumed in Sundarban Tiger Reserve. The Chief Conservator of Forests (South) & Director, Sundarban Biosphere Tiger Reserve is the administrative head of the park at the local level and is assisted by a Deputy Field Director and an two Assistant Field Director The park area is divided into two ranges, overseen by range forest officers. Each range is further sub-divided into beats. The park also has floating watch stations and camps to protect the property from poachers.

The Department pf Sundarban Affairs focuses on socioeconomic development of the inhabited parts in the Sundarbans. In addition, other relevant departments, such as those with responsibility for forests, irrigation and waterways, health, and education, continued to independently plan and execute sectoral schemes in the Sundarban. DSA has a formal mandate and structure to plan, monitor, and evaluate activities conducted by other agencies in the region. While these functions are carried out periodically, they have no clear influence on the allocation of resources or the improvement of schemes. DSA has four divisions: agriculture, fisheries, social forestry, and engineering, with deputed staff from the respective departments (World Bank, 2014).

7. Issues and Shared challenges in the Sundarban

The Sundarban symbolizes a world of human poverty and vulnerability encircled with natural richness. In Bangladesh and India, despite national and international concern, political support and significant resource flows; a combination of exposure to disasters and natural stresses; increasing population pressure; unregulated drives towards commercialization of natural products; and insufficient institutional coordination and capacity has led to inadequate management of the Sundarban and continuous degradation of forest resources. Meanwhile, population stress, increased demand, unplanned development and climate change are predicted to exacerbate the situation. The preceding chapters have shown, while both countries face varying degrees of degradation and challenges for sustainable resource management of the Sundarban, political and administrative boundaries also have distinct impacts on the social perception and interaction with both the landscape and human residents. Literature suggests the following challenges are present in both countries in varying degrees,

- Poverty and human development
- Coastal erosion
- Climate change and sea level rise
- Environmental degradation
- Natural resources management
- Lack of data and information
- Inadequate capacity of governments and communities to meet the challenges

7.1 Poverty and human development of peripheral populations

Around 7.5 million people (nearly 5 million in SBR, India, about 2.5 million in 20 km periphery, Bangladesh) are directly dependant on the Sundarban and suffers from several and similar dimensions of poverty in both the countries. The average per capita income in Indian part is about USD 0.5 per day while the corresponding figure for the Bangladesh part is about USD 0.9 per day. Common factors highlighting this extreme poverty include poor health conditions, relatively low education levels, limited employment opportunities with far more limited enterprise, inadequate water supply and sanitation, absence of electricity in many places, difficult and primarily river-based transport, and very high risk of persistent cyclones, floods and embankment failures. The main economic activity is agriculture, yet, agricultural productivity remains low due to poor levels of cropping intensity, soil salinity, lack of fresh-water availability, fragmentation of landholdings, frequent disasters and lack of access to modern agricultural infrastructure and markets.

Studies show that, in both the countries, markets function poorly and social safety nets (such as the Vulnerable Group Feeding program), even though present for a few, are not able to guarantee support when needed (World Bank, 2014). The population usually have little or no savings to fall back on. Even for better off households, there is a risk of impoverishment, as they lose property and income during natural disasters and may to sell assets to survive high treatment costs from accidents and health related problems. To recover from risks and shocks, many of the locals resort to illegal fishing, as well as

illegal poaching, creating thus a vicious circle of overexploitation and corruption. When fines are given for illegal activities, they add another shock to household's income. Permits may be revoked and locals have to take frequent trips to the government departments to pursue legal procedures, all of which involve money and time, and increase exposure to bureaucratic processes (Roy and Alam, 2012)). Many socioeconomic and biophysical tipping points have already been exceeded; others rapidly approach.

Social services such as modifications to the industrial structure of the sector, with an emphasis on decentralization of service provision, in many cases to the municipal level. Many of the decentralizing reforms have left the sector with a highly fragmented and inefficient industrial structure. It is made up of numerous service providers, without real possibilities for achieving economies of scale or economic viability, and is the responsibility of local bodies that lack the necessary resources to deal effectively with the complexity of the processes involved in providing drinking water supply and sanitation services.

Poverty in the Sundarban region is cyclically entwined with the ecosystem; increasing economic stress makes people depend on natural resources which, in turn, leads to depletion of the traditional source of livelihood for the poor and builds more stress. According to World Bank (2014), the cost of environmental damage and health effects is as high as 10 percent of the Sundarban's gross domestic product (GDP) in 2009. This complex relationship between poverty, human development and the ecosystem is gradually being understood. Recent policy developments and activities in both countries indicate a growing awareness amongst the researchers and policy makers on the importance of mangroves and the multi-faceted consequences of their destruction (Singh et al 2010, IUCN, 2014). Nevertheless, programmes remain weak as information and basic understanding about the issues need more clarity and research and need further integrated planning for sustaining the livelihood of local communities.

Some of the key challenges to human development in both countries in this region are:

- Poverty
- Lack of access to education for children
- Poor economic conditions and low family incomes below the poverty line
- Poor healthcare and sanitation in the community
- Lack of good quality food sources
- Limited employment opportunities
- Lack of community based organistitions to provide support
- Shortage of housing and housing materials for the poor
- Lack of higher education opportunities especially for women

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7.2 Coastal erosion

The role of mangroves in protecting our coasts against natural hazards such as storms, tsunamis and coastal erosion has been widely acknowledged. However, a combination of sea level rise and tidal hydraulics often results in erosion in the sea face and estuary margins. This results in progressive reduction of land area in the islands and also shallowing of channel floor. The eroded material may be carried by tidal currents and can be redeposited in the tide sheltered' sections in the mangrove area.

Sundarban is part of the largest delta in the world, the numerous islands are still in the process of being formed and reformed by continuous siltation and erosion from powerful tidal currents. These changes can be ascribed to sediment reworking in a flood-tide dominated environment that is greatly intervened by reclamation efforts, initiated in 1770 (Rahman, 2012, Hazra et al, 2002).

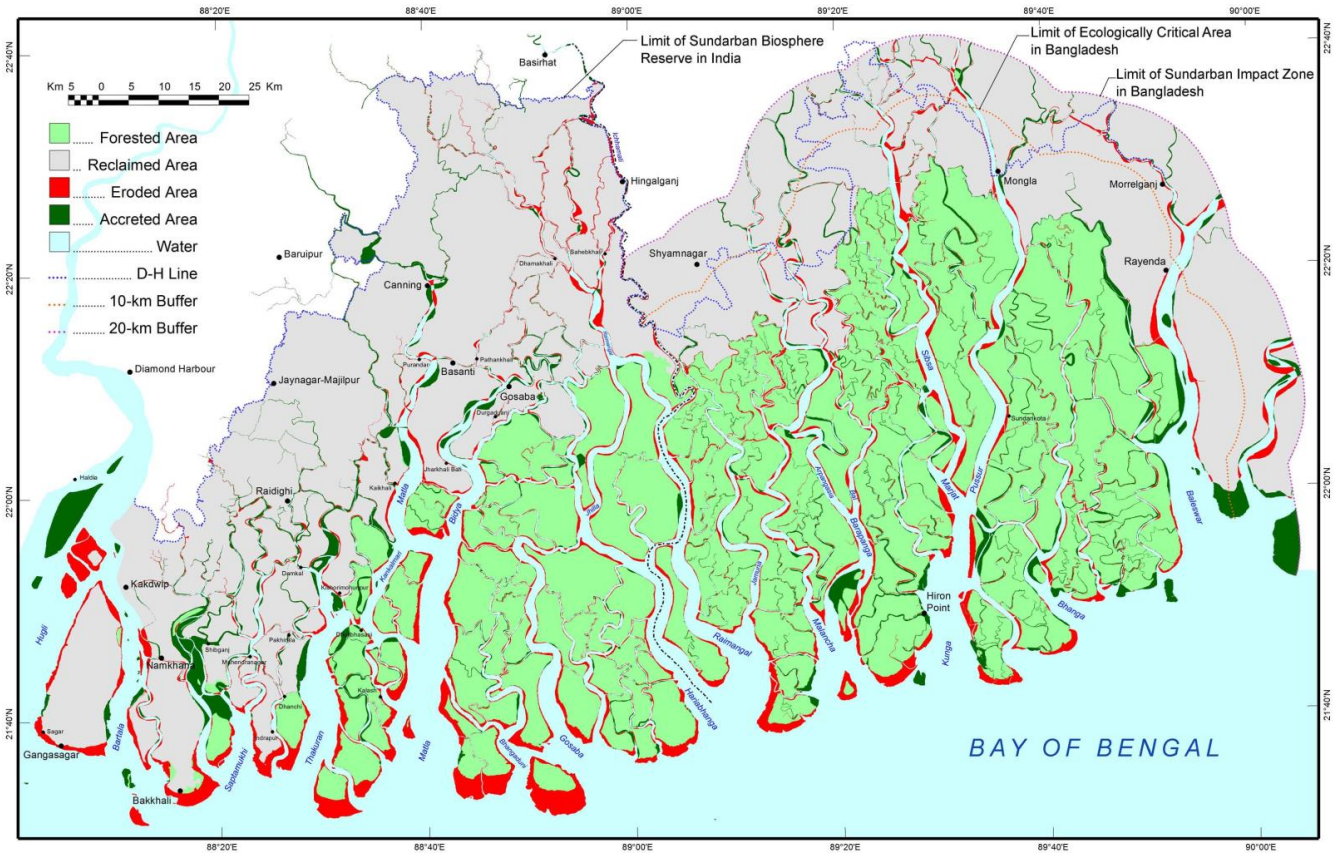

Figure 7.1: Composite map of the Sundarban showing erosion and accretion

The map shown in Figure 7.1 has been produced by overlaying Survey of India's 1901-23 topographic maps on recent satellite images and shows the erosion and sedimentation of the entire Sundarban. The figure shows over the past few decades nearly the entire southern face of the region is retreating, irrespective of forested or reclaimed portions. Rate of erosion is maximum at the west-central section between the Saptamukhi and the Gosaba estuaries, reaching up to 40 m per annum, and gradually reduces west- and eastward, almost to reach zero on the west bank of the Baleswar. Studies conducted by World Bank (2014) identified three main factors that have affected the size of tidal prisms and, therefore, discharge velocities and erosion or accretion of channel banks: (a) the sea level rise of 0.2–1.6 m that has taken place in the Sundarbans during the past 100–200 years; (b) the increasing prevalence of shrimp farming, which are periodically recharged by creating networks of channels that can deliver estuary water upstream so ponds can be recharged with saline water periodically; and (c) the creation of infrastructure on the upper reaches of the basin that restrict upstream estuarine flows.

Alternately, a number of interior creeks and estuaries are getting silted, mostly (partly) in the reclaimed western (northern) section. Outside this region, banks of most major estuaries are eroding; the situation is somewhat mixed for the smaller creeks of the forested islands. According to Hazra et al (2010), in the Indian part of Sundarban, total erosion over the last 30 years is estimated to be 162.879km^2. During the period 2001-2009, net loss of land has been 44.042km^2 after taking into account accretion of 20.120 km^2. Similar studies in Bangladesh show that the average rates of erosion for the eastern and western parts of the Sudarban Impact Zone are 14 m/year and 15 m/year (Rahman, 2012). The study reveals that the mangrove forests have been lost about 144 km^2 during 1973-2010 of which loss of land because of erosion was 233km^2.

Presently in both countries, the issue of coastal erosion in the Sundarban is missing in the planning and management. Future planning for the region must accept the transformations and physical trends that are brought into the system and strike a balance between the requirements of the nature and the needs of the people.

7.3 Climate change and sea level rise

According to the Global Climate Change Risk Index (2015), both Bangladesh and India have been amongst some of the worst impacted countries by climate climatic event like floods, droughts and cyclones in the last decade. Within both countries the Sundarban region is the most vulnerable to global climate change and sea-level rise in addition to other anthropogenic and natural causes.

Of all of the natural hazards, cyclones are the most severe and routine occurrences striking the Sundarban. Climate change scientists predict an increase in frequency and intensity of tropical cyclones that is projected for the North Indian Ocean (Webster et al. 2005; Elsner, Kossin, and Jagger 2008). For the north Indian ocean region, Fifth Assessment Report (AR5) of the Intergovernmental Panel for Climatic Change estimated that the frequency of tropical cyclones are likely to remain unchanged with rains getting more extreme near the centres of the storms (IPCC, 2013:1250). Specifically for the Sundarban, landfalling trend of cyclones indicates a decreasing tendency for the last few years. If the landfall events of the last 125 years are categorised into five 25-year intervals, the 1991–2015 period, with least number of recorded events, closely matches 1891–1915 at the start of the record. The 1941–1965 and 1966–1990 periods registered maximum number of landfalls of all storms, and maximum number landfalls of severe storms, respectively (IMD, 2012; http://www.rmcchennaieatlas.tn.nic.in) (Fig. 3.11). Operation of natural cycles in landfall frequency and harming potential of tropical cyclones is not uncommon (Coch, 1994). This, coupled with global warming-induced intensification of the storms (Webster, 2005), suggests that the probability of cyclone landfalls and consequent damages are likely to increase in the Sundarban even if their global frequency remains unchanged.

However slow onset changes from climate change are equally threatening, mangrove vegetation in the Sundarban is susceptible to coastal erosion, declined freshwater flow from the hinterland and the increased level of salinity. The fresh-water flow from the inland and the tidal waves from the sea play a crucial role in the formation and the dynamics of this fragile ecosystem. According to most climate

change scenarios there is general agreement across climate models on increased precipitation during the monsoon season in the Sundarban region (OECD, 2003). Higher rainfall and more snowmelt due to higher temperatures will lead to increased freshwater discharge in all the major distributaries of the Ganges supplying freshwater to the Sundarban – the Gorai, the Modhumati and Bhairab system on the Bangladesh side and the Hoogly on the Indian side. This increased flow regime in the river network feeding the Sundarban is expected to push the saline front seaward. Freshwater dominated hydrological condition during the monsoon would help freshwater loving species such as the Sundari to thrive. Simultaneously however, a rise in sea level would also occur under climate change which would cause increased backwater effect in the coastal rivers and tend to push the saline front further inland. The final location of the saline front during the monsoon is therefore hard to predict precisely.

The impacts of climate change on the Sundarban would be more critical during post monsoon, when the saline front starts propagating inland and the duration of the dry season. Climate models predict a decrease in precipitation during this period which might further reduce freshwater flows, which will encourage enhanced withdrawals upstream for irrigation. More importantly, the backwater effect due to sea level rise, would also push back the discharge of freshwater flow from the northern reaches of the tributaries of the Ganges. This means the saline front will move inland at an earlier time and remain for a longer duration. Studies on the effect of sea level rise on salinity ingress shows, considering about 23 cm of SLR, isohaline lines penetrate inland, significant penetration has been indicated for the threshold salinity of 1 ppt or higher for the rivers supplying freshwater in the western and central parts of the Sundarbans: Betna, upper Bhairab and Kobadak. Similar ingress of salinity is also expected on the Indian side of the Sundarban (OECD, 2003).

Additionally, backwater effect will impede drainage resulting in a relatively prolonged inundation of the forest land. Prolonged flooding episodes would increase the rate of sedimentation/siltation in the back swamps and creeks inside the forest area. Such a change would be relatively more pronounced in the Bangladesh side of the forest and may slightly offset permanent inundation of the forest floor due to continued increase in sea level rise. It is reported that inundated areas might increase up to 3percent (2030s) and 6percent (2050s) respectively, primarily in coastal low lying areas (0 – 30 cm, Khan et al., 2006, using upper estimates of sea level rise). Flooding from storm surge remains a significant hazard even when embankments are present, as natural disasters are capable of wiping out embankments. Given the relatively flat landscape, hazard mapping suggests that a 45-cm rise in sea level would destroy 75 percent of the Indian and Bangladeshi Sundarban.

The agricultural production in the Sundarban region is already exposed to natural hazards like storm surge, salinity, water logging/ drainage congestion, tidal flooding, river erosion, drought, etc., which will be further aggravated under climate change and sea level rise scenarios. The crop suitability in the Sundarban region will change significantly due to sea level rise induced salinity intrusion and tidal inundation. Increased salt water intrusion will also be a challenge in the provision of drinking water and will impact the health, livelihood and overall quality of life of the population.

Considering that the salinity regime inside the forest will significantly change as a consequence of climate change, it has been argued that increased salinity would have discernable adverse impacts on

forest regeneration and succession (Ahmed et al., 1998). The Sundari is projected to decline or disappear entirely under climate change and would be replaced by inferior quality tree or shrub species. Under such conditions vegetation canopy would become sparse and plant height would be reduced significantly. Mangrove systems themselves are inherently adaptable, however, land use change and other shifts in the habitat combined with climate change are placing even the normally resilient mangrove ecosystem at risk. It is clear from this brief summary, climate change and accelerated sea level rise due to global warming will have a potentially devastating effect on the integrity of the Sundarban ecosystem and its inhabitants.

7.4 Environmental degradation

An ever expanding population, dangerous levels of water pollution and water scarcity, massive land degradation, large scale deforestation, enlarged transportation networks, development of local economies and a variety of anthropogenic causes coupled with climate change and sea leve rise lead to an overall degradation of environment. As natural capital is being used up faster than it is being replenished, the degradation has reached alarming levels in the Sundarban region (Sen 2016; Aziz and Paul, 2015; World Bank, 2015; Allan et al 2013). According to World Bank (2015), the cost of environmental damage associated with ecosystem degradation and biodiversity loss is about Rs. 670 crore annually.

Water pollution and scarcity

Reduced flows via the Ganges during the dry season have increased tidal incursion, allowing saline water to penetrate inward threatening the ecological balance of the Sundarban. Climate change coupled with increased of diversion of water from upstream areas in the Ganges basin has resulted to around 60% reduction in dry season flows in the past 25 years. The reduced discharge from the north allows seawater intrusion deep inside the Sundarban and surrounding region increasing salinity of water and soil. This affects the growth of *Heritiera fomes* (sundri), the tallest (at over 15 m) and most commercially important plant and also affecting growth and distribution of other mangroves and biota Additionally, the surface water quality is affected by untreated industrial effluents, municipal waste water from nearby urban areas of Kolkata in West Bengal and Khulna-Mongla in Bangladesh, and run off from the surface of the agricultural lands treated with pesticides and chemical fertilizers.

Land degradation

Land degradation in the Sundarban region is mostly due to the nature of shrimp culture which requires letting in saline water into empoldered shrimp beds. Since 1980s shrimp has been a major part of aquaculture in this region and is considered as the major driving force of economic development in this area. Over the past two decades, the practices of shrimp farming have caused increased water and soil salinity, massive loss of crop production, loss of fruit, loss of indigenous floral species and fresh water crisis for drinking. The absence of national policy and strategy on sustainable shrimp aquaculture has been a fundamental problem of this sector (Kabir and Eva, 2014).

Additionally, increased shipping in the inland waterways of the Sundarban region and related activities also leads to multiplies risks from oil spill, the release of coal, chemicals, fertilizer and fly ash if adequate

safeguards are not on place. The moving and manoeuvring of vessels induce a variety of hydrodynamic changes and physical forces which have an impact on the surrounding flow, alluvial banks and sediments of the rivers. These impacts potentially harm the environment and can ultimately lead to environmental degradation.

Extent of bio-diversity

Forest inventories of the Sundarban reveal a decline in standing volume of the two main commercial mangrove species — Sundari (Heritiera fomes) and Gewa (Excoecaria Agallocha) by 40% and 45% respectively between 1959 and 1983 in Bangladesh (FAO, 2015). Similarly in India, mangrove forest cover has reduced by 5.5% between 1986–2012, despite significant afforestration in the northern part and the char lands within the tidal creeks (Samanta and Hazra, 2016). This decline is mainly due to top dying from salinity increase and overharvesting in past decades. Also, despite a total ban on all killing or capture of wildlife other than fish and some invertebrates, there appears to be a pattern of depleted biodiversity or loss of species (notably at least six mammals and one important reptile this century), and the "ecological quality of the original mangrove forest is declining" (IUCN 1994). The estimated cost of environmental damage associated with ecosystem degradation and biodiversity loss is about INR 6.7 billion annually, which is equivalent to about 5 percent of the Sundarbans' gross domestic product (GDP) in 2009 (World Bank, 2014)

7.5 Natural Resources Management

The Sundarbans has been under some sort of scientific management since 1875, although no specific information is available about its conservation practices during that period. Both in Bangladesh and West Bengal, the Sundarban comprises of reserve forest areas where there is no habitation and peripheral areas which houses a population dependant on the mangrove forest for their livelihoods. Political and administrative boundaries have different values for resources that manifest themselves into differential policies and priorities for how lands are used. These different land use practices inevitably create distinct zones in a greater ecosystem that reflect the anthropogenic priorities. Borders also have distinct impacts on the social perception and interaction with both the landscape and human residents of neighbouring jurisdictions. These ecologically arbitrary lines fracture both human and natural communities, even if only by creating the perceived separation.

Bangladesh SRF

As a reserve forest, Forest Department (FD) controls overall top down management of the Sundarban activities are mostly geared towards protection of plants and animals, with little focus on habitat management. The Sundarban is managed through three wildlife sanctuaries where any sort of resource harvesting is illegal. There is also a felling moratorium in the entire reserve forest. Fishing is banned in the sanctuaries which are 23% of the total areas of the Sundarban. Rest of the area is open for fishing except the small water bodies where fishing is prohibited on every alternative year.

Recently, policy aims to assure the sustainable harvesting of forest products and maintains this coastal zone in a way that meets the needs of the local human population although degradation continues. As per the provisions of Environmental Conservation Act, 1995, the 10-km wide band surrounding the northern and eastern boundaries of the SRF, was declared ecologically critical area (ECA) with the main

objective of providing protection to the SRF and conservation of its biodiversity. However, other than a few uncoordinated activities by government and non-government agencies, no real initiative has been taken to manage and develop the ECA area so far. There has been a great deal of change in the land use patterns upstream in the forest interface landscape zone of Sundarban and agricultural lands have been transferred to gher that are developed for fish and shrimp culture. The local people of the interface zione are characterized by poverty, natural calamities, poor education and health services, drinking water scarcity, and little income opportunities, all of which contribute to high biotic pressure on the natural resources of the Sundarban and its surrounding areas.

India SBR

The degree of protection varies greatly across the Sundarban Biosphere Reserve, creating confusion for the peripheral population who are dependent on the the forest for their livelihoods. While no human activity is allowed in the Sundarbans National Park, limited access to wildlife sanctuaries is allowed and reserve forests offer greater access to the people. Human-wildlife conflicts and illegal extraction in the protected areas have been all too common, further serving to alienate local people from taking an active role in the conservation of this commons.

Moreover, there is no nodal agency that coordinates all of the government work in the Sundarban. The presence of numerous governmental organizations with overlapping authorities and responsibilities gives rise to duplication of efforts, especially in terms of socioeconomic development, and monitoring of outcomes is limited. While the Project Tiger is federally managed, the national park and the wildlife sanctuaries are under the forest departments of the state of West Bengal, who have varying degrees of control in different parts. Additionally, the secretariat of the biosphere reserve, which is the custodian of the entire 9630 km^2 of the Indian Sundarbans, is headed by a director. Up until the 1990s the Indian Sundarban were managed exclusively by the state, and the community was excluded from using it, leading to frequent protests by the local population. Development support has been neglected, with inadequate power and transportation infrastructure and poor health and education services (Ghosh et al 2015; World Bank, 2014).

7.6 Lack of data and information base

Data and information are the basis of good management. Presently, relevant government agencies systematically and regularly collect and compile data and information on different issues in the region. Unfortunately, much of these efforts are done in isolation and there is no coordinated approach to collect and analyse the data and information for a more holistic approach to management of the Sundarban. Additionally there is a great interest in the Sundarban by wildlife biologists, botanists, hydrologists, morphologists, economists, environmentalists as well as writers, journalists, artists and litterateurs leading to many studies, reports, books and article on the Sundarban. While these add to the knowledge about the Sundarban, these efforts are temporary and project based. Most importantly, after 1930, there has not been any coordinated assessment of the entire Sundarban. The different types of data that are needed include:

Forest inventory:

The forest inventory of the entire Sundarban was carried out in the early part of the 20th century and these inventories were used to support management plans focussed on estimating sustainable yields based on projections of timber, fuelwood and other forest produce. F. Trafford wrote the first detailed management plan for Sundarbans for the period 1912-13 to 1931-32. But there is little information about the related inventory. The second management plan for Sundarbans was written by Mr. S. J. Curtis in 1930. The inventory and detailed maps prepared based on physical survey are considered milestones in the history of Sundarban management and were found to corroborate very closely with the high-tech inventories conducted at later ages. Curtis' plan came into operation in April 1931 (FAO, 2007).

In the Sundarban Impact Zone, so far four inventories have been done. The first detailed inventory was carried out in 1959, the second in 1983, the third in 1996 and the most latest was in 2005-2007. During late 1950s, the detailed inventory of the forest resources was carried out by techniques modern for that time like aerial photography and photogrammetric methods. From 1960s onwards the inventories were done blockwise. The most recent inventory used remote sensing as well as ground inventory.

Forest Survey of India (FSI) has been conducting national assessments of forest resources since 1965. FSI initially used aerial photographs and ground inventory to assess forest resources then, in the early eighties, remote sensing satellite data have also been utilized. Today, information of forest resources over the last five decades are generally obtainable from three different sources: (i) year-wise land use statistics compiled by the Ministry of Agriculture which is based on revenue records (ii) information on forest area based on legal status of land compiled from State Forest Departments and (iii) assessments of forest cover using modern technologies of remote sensing. Since 1986, FSI has been assessing forest cover on a two year cycle and is releasing the findings to the public through its "State of Forest Report" (SFR). The first seven SFRs (1987 to 1999) gave information of only forest cover while SFR 2001 provided information of forest cover as well as tree cover. In addition to information on forest cover, FSI also has conducted special studies to provide information on the growing stock of forests, tree cover (trees outside forests), and pilot studies.

Wildlife census and survey:

Having an understanding of the number of animals, their distribution and numerical trends forms one of the most basic sets of information necessary for the informed management of a wildlife operation. Records for most faunal groups of the Sundarban are fragmented and different estimates for species numbers exist in different literature. Wildlife census in the Sundarban focus on larger species and updated comprehensive information based on detailed census or surveys are found for tigers, crocodiles, dolphins and deer (spotted and barking deer). Presently there is no inadequate or no monitoring of fish stock and fisheries resources hasn't been inventorised for over a decade (Hoque, 2014). The census or surveys carried out in both countries usually use same methodologies and although survey periods may differ. While there is a drive to use more modern technologies and state of the art equipment for census and inventories, the modernisation is slow, as a result, reliability of the census becomes an issue. For example, until 2015, the tiger population was estimated at 400 using the traditional pugmark census technique. The recent camera trapping method has revealed the number of

tigers to be much less at 106. Moreover, gaps still remain in understanding population density and fluctuation, activity pattern, movement, dispersal, herd structure and habitat preference of many of the species. This is because accurate estimation of wildlife population density is difficult and requires considerable investment of resources and time. Population indices are easier to obtain but are influenced by many unknowns and the relationships to actual population densities are usually unclear.

A starting point is a regular and accurate assessment of population size of possibly all, but certainly the ecologically and economically most important species.

Hydro-meteorological monitoring:

Hydrological, meteorological and morphological data and information of the Sundarban remains the largest knowledge gap in Bangladesh and India. Yet, the Sundarban region is characterized by a network of morphologically dynamic tidal river systems and the health of this hydrological system largely influences the entire ecosystem, thus managing the water resources system is equally important for sustainable management of the Sundarban. Hydro-meteorological data collection networks maintained by different agencies are already present and basic hydro-meteorological indicators are collected and maintained with these agencies in the region. But the extent of investigation, conservation strategy and focus of management and subsequently, type of data and information is considerably different in the two countries. The overall knowledge gap has been summarized as follows:

- Influence of water regime of the internal river system, and water quality on Sundarban bio-diversity and ecosystem
- Effects of external drivers of change (SLR, trans-boundary flow, land use change, human interventions at the upstream basin etc) on the hydro-morphology and ecosystems
- Response of bio-diversity of Sundarban under different extreme event (storm surge, high flood, drought etc.)
- Limited knowledge on the impact of Relative Mean Sea level Rise (RMSL) and climate change (temperature and rainfall) on the Sundarban bio-diversity and ecosystem
- Impact of upstream flow on Sundarban bio-diversity and ecosystem services
- Flood plain sedimentation rate and soil properties of Sundarbans and its surrounding area

7.7 Inadequate capacity of governments and communities to meet the challenges

Other than by excessive local exploitation and natural hazards, the main underlying reason threatening the future of the Sundarbans is inadequate management, as evidenced by disconnected development plans, ineffective policy implementation, poor coordination between the various government agencies, and an unwillingness to include local people in management decisions. The region contains protected areas with associated statutory conservation and multiple socio-economic zones with varied development requirements, thus there are numerous agencies present with mandates and activities concerning matters ranging from conservation to coastal issues to centralized schemes for socioeconomic development. The institutional arrangements are overlapping in many cases and many of the agencies lack required capacities, supporting administration, and adequate budget resources. According to SEALS (2010) the weaknesses that ultimately lead to over-exploitation of resources include

ineffective patrols, lack of people's participation, lack of enforcement of laws and regulations, institutional corruption and lack of Forest Department capacity. Some of the institutional challenges are:

- While considerable institutional capacity has improved over the past few decades, there is still inadequate capacity to effectively implement strategic interventions in the Sundarban. Existing institutions are frequently affected by lack of resources. The availability of adequately trained staff remains a constraint in many organizations: doctors, teachers, and other technical professionals have no incentives to work in such a remote area where environmental risks are very high;
- Lack of trained manpower and necessary logistics is a major challenge for the management of the Sundarban. The Forest Department's Wildlife and Nature Conservation Circle, formed in 2001, is yet to take charges of the three Wildlife Sanctuaries from the territorial authority. Staffs are regularly transferred between wildlife and territorial posts and also between forests, which do not help in developing trained and experienced manpower for conservation. The sanction of fuel for motorboat for patrol duty has been drastically reduced to 100 litres from 1,200 liters (Khan 2011).
- Working norms as well as a needs' assessment of skilled and qualified personnel in specialized fields in the government forestry institutions are still lacking. The shortage of staff in terms of number, skills and capability in all is common. NGOs engaged in forestry activities suffer even more from weak capacities;
- Outdated technical approaches continue to be used: examples include prevalence of monospecific forestry, overreliance on excessively restrictive and unenforceable conservation regulations, and lack of modernized systems to handle isolated communities in need of basic social services. In the absence of a holistic vision, the sectoral approaches to forest and land management of these agencies are not sufficient or effective to meet multiple challenges of poverty alleviation, biodiversity conservation, and food production;
- An emphasis on decentralization of service provision, in many cases to the municipal level is present in both countries. However, many of the decentralizing reforms have left the sector with a highly fragmented and inefficient structure and local bodies that lack the necessary resources to deal effectively with the complexity of the processes involved in providing drinking water supply, sanitation, health, education and energy services;
- Each component of the ecosystem (i.e. water, fisheries, vegetation, forests and wildlife etc.) is governed by a different legal regime. Laws and institutions rarely include cross-cutting issues and are often confined within sectorial boundaries. This is compounded by a fragmented legal regime and inconsistencies within laws and regulations (Allan et al, 2013);
- Inter-agency cooperation or coordination is lacking; this has resulted in overlapping and often contradictory initiatives over the past decades. A complex mosaic of interests, mandates and capabilities adds to this lack of cooperation and many agencies and line ministries take decisions unilaterally without consultations of other related agencies;
- Although most data and information on inventories, revenue collection, production of resources and other forest and socio-economic indicators are collected at regular intervals and available publicly, in many cases online; there are prevailing gaps especially in hydro-morphological information and understanding of bioecological processes. The necessary planning tools are

Moreover, information and knowledge sharing between the agencies is absent which further hampers a coordinated approach;

- Being remote, the presence of Dakoits (bandits) and the influence of local elites and interest groups results in inequitable governance systems that are not governed by law but rather by force and influence (Allan et al, 2013);
- Over the last few decades participatory processes have been promoted and incorporated in policy related to natural resources management of the Sundarban in both countries. Yet on the ground, the scenario is quite different, government agencies often take a top-down approach and communities have only a nominal role and involvement in planning and management resulting in exclusionary conservation practices (Sen 2016). This leads to lack of ownership and for alternative sources of income, poaching, illegal felling, over and unauthorised harvesting is still present. In Bangladesh especially, the administration lacks inclusive decision making and a combination of changing mindset as well as adjusting economic and social structure is essential for achieving participatory management (Allan et al, 2013).
- There is no risk allowance to compensate for the unique dangers faced by government staff in the Sundarban. There is also no budget set aside to cope with emergency situations such as periodic cyclones. Cyclone Sidor struck in November 2007 and Aila in 2009 destroyed many guard posts in the eastern side of the Sundarban in Bangladesh. As a result, several guard posts were deserted. A disaster recovery process is needed to ensure that patrolling levels are returned to normal as quickly as possible after these devastating cyclones.
- By contrast, in West Bengal and India more generally, the Disaster Management Framework remains significantly more vertically integrated and centralized, with a comparatively weaker interface with communities that would facilitate volunteer engagement.
- Many of the institutions active in the Sundarban in India are also active statewide, with general mandates that do not necessarily mesh well with the on-the-ground realities or challenges of the Sundarbans region. One reason for this is that institutional mandates are often the same for the Sundarbans as they are for the mountainous parts of West Bengal far to the north. In many situations, this is not an issue: all citizens are entitled constitutionally to certain service standards, and all parts of India face similar constraints, for example, shortages of doctors.

7.8 Sundarban landscape approach

Any strategic mechanism for supporting collaborative approaches to managing shared ecosystems requires appropriate knowledge and comprehensive understanding of the ecosystem in its entirety. This joint landscape narrative integrates a mosaic of information linked together to support the development of an action plan for the Sundarban that addresses poverty, livelihoods, biodiversity conservation as well as climate change adaptation. Most importantly the narrative creates a multilayered and holistic understanding of the Sundarban to establish planning boundaries that transcends political boundaries, narrow perspectives and multiple scales.

In both countries the Sundarban has been of great interest to researchers, scholars, wildlife biologists, botanists, hydrologists, morphologists, economists, environmentalists as well as writers, journalists,

artists, litterateurs and enthusiasts from the region and abroad. Thus literature on the Sundarban is abundant, as much as 20,000 books, reports, essays and documents can be catalogued covering various aspects including biodiversity, hydro-morphology of the region, cultural history, social development, livelihood, resource utilization and management. Yet there is very little attempt to understand the Sundarban in its entirety, as one ecosystem, as one landscape or one region (Dipu and Ahmed, 2013; Gopal and Chauhan, 2005; Sarker 2010). For example, the most recent survey of forest resources of Sundarban as one ecosystem was carried out in the 1930s, the successive inventories and assessments have been at country level. So the information of the forest as one ecosystem is not up-to-date and current literature also remains divided by the boundary, focusing on only one part of the Sundarban.

Moreover, the extent of investigation, conservation strategy and focus of management and subsequently, type of data and information is considerably different in the two countries. For example, according to Gopal and Chauhan (2005) and Seidensticker (1991), in Bangladesh the Sundarban is managed as a refuge where wildlife is protected in small sanctuaries located in “hot-spots” essential to the maintenance of wildlife populations, whereas, in India, 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. On the other hand, analysis of 60 online documents show that substantial data and information on salinity of Bangladeshi Sundarban is available and publicly accessible information dates back to 1962, whereas in India the salinity related reports are much less and oldest information found dates back to 1995.

There is a growing recognition that sectoral approaches to land management are not sufficient or effective to meet multiple challenges of poverty alleviation, biodiversity conservation, and food production. Integrated approaches are needed address complex issues to facilitate the simultaneous framing of development and conservation goals (Reed et al, 2014; Sayer et al 2012; Frost et al, 2006). Key issues and themes in the landscape narrative include ecological flows in landscape mosaics, land use and land cover change, scaling, relating landscape pattern analysis with ecological processes, and landscape conservation and sustainability. There is also a need to understand the role of human activities and development processes on the ecosystem, the coupling between biophysical and socioeconomic sciences is required (WCED (1987); UN, 1992, Angelstam et al. 2013a; Angelstam et al. 2013a). Thus it is important to take a broader look at the natural resource base and consider the full range of ecosystem processes that provide and sustain those resources. This more holistic, expanded view of ecosystem management often requires more coordination between different agencies, stakeholders or governments who must work across jurisdictional boundaries making natural resources management more politically, legally and ecologically complex. Governance in the Sundarban Region is disjointed and narrow sector driven, lacking coherence of purpose. Sectoral projects and programs, often in conflict with each other (or at least not in coherence with each other) are implemented without an integrated framework of decision-making. While it is up to the respective national governments to move toward integrated planning and management, analytical underpinning to move in the direction of integrated management will be a useful input to the governments.

8. Emerging opportunities for coordinated and concurrent activities

The basis for bilateral cooperation in the Sundarban between India and Bangladesh lies in the Memorandum of Understanding (MoU) on conservation of the Sundarban, and a protocol on conservation of the Tiger in the Sundarban, signed by both countries on 2011. This MoU on Sundarban is anchored within the Ministry of Environment and Forests (MoEF) in Bangladesh and Ministry of Environment, Forest and Climate Change (MoEFCC) in India. Both countries have agreed that the biodiversity, particularly the Tiger, of the Sundarban must be conserved by joint actions and none of the two countries will do anything that might threaten the Sundarban. Under these two mutual agreements a number of strategic actions have been proposed to be done in collaboration such as joint research and monitoring (on Tiger, prey and other biodiversity), adoption of joint management, sharing of relevant information and technical knowledge (e.g. on tiger-human conflict) between the concerned officials of the two countries, execution of patrolling along the respective borders of the two countries to prevent poaching and illegal trade, and capacity building by exchanging personnel for training and promotion of education.

While the MoU clearly outlines a set of joint activities, facilitates commitment to transboundary goals and also confers legitimacy for joint and coordinated activities there is a need to further expand and elaborate on some of the opportunities that the two countries can focus on. Identifying common ground and differences between Bangladesh and India; inspite of obvious similarities in the mandate for economic development and management of natural resources there are equally obvious differences with respect to institiutional systems, levels of service provision, socio-economic perceptions and even cultural traditions. Hence identifying specific needs and priorities should be the first step in setting up a framework for cooperation. With this in mind, based on literature review and consultative multi-stakeholder processes in Bangladesh and India involving the participation and contribution of civil society organisations, research organizations, government officials, private sector representatives and local inhabitants the following potentials were identified as areas where both countries can work together,

- Natural resources management
- Enhancing information and understanding
- Disaster management
- Stronger economic growth
- Strengthening public services
- Raising awareness
- Fisheries and aquaculture
- Adaptation and mitigation
- Cultural and media exchanges
- Sustainable Tourism
- Natural regeneration and reforestation
- Marine resources conservation

It is important to note, this chapter highlights a spectrum of activities that can be taken up in these areas. Many of these activities are beyond the mandate of MoEF and MoEFCC. As a result, multi-agency approach that facilitates integrated working in collaboration with MoEF/MoEFCC is essential for demonstration projects, service delivery and on the ground implementation. An Indo-Bangladesh platform of technical and social experts in close contact with public administration and private sector needs to be set up for collective learning, feeding back up scaling the results collaborative activities.

8.1. Natural resources management

Despite human habitations and economic exploitation of the forest, Sundarban retained a forest closure of about 70% and the forest boundary has remained unchanged since 1960 (ODA, 1985). On the other hand, the areal extent of the Indian Sundarban mangrove forest remained more or less stable since the 1960s. However, substantial decline in *H. fomes* has been reported, the decline has been around 76% since 1959 and about 70% of the remaining H. fomes trees are affected by the 'top dying' disease (Sarker et al, 2016). Future climate and sea level rise; and ongoing habitat degradation may alter the current spatial distributions of mangrove species and forest composition. Regulatory instruments for natural resources management that must be enforced are already in place, but new market-based incentive mechanisms could improve regulatory efficiency and help realize positive biodiversity conservation outcomes. Key approaches for conserving biodiversity include enhancing levels of conservation protection of the forests, restoring mangrove forests, and reducing pressure on the forests by providing transition zone residents with livelihood options that are sustainable. Joint activities can focus on,

- The future of the wildlife and biodiversity of the Sundarban depends on the proper management of the entire landscape (especially the protected areas), the restoration and breeding/recovery programmes, and finally the national and international initiatives to save this unique and fragile ecosystem for the future generations. Integrated management of both forests and wetlands of the Sundarban for producing products and generating services while maintaining their environmental roles and functions is feasible but ecologically complex.
- It is now widely recognized that a forest that has value for conservation, production, protection or recreation, and has clear user rights attached to it, is a forest that will be protected, a forest that will be taken care of. A better recognition of the full value of forests is therefore crucial. From the economic point of view, this can result in better profitability of forest management, which in turn becomes an incentive for public and private investments in the forest sector.New mangroves should in principle be allowed to recolonize portions of the newly unprotected lands. But the size of this new mangrove area should be carefully controlled. Benefit-cost analyses of mangrove afforestation show marginally positive net benefits.
- The poaching, retribution killing and habitat loss can be controlled by implementing the national acts and policies. Scientific research and monitoring are also necessary to ensure informed management of wildlife, while public awareness and public participation in conservation and management are vital. Moreover, the Forest Department officials who work in the Sundarban should get sufficient logistic support, risk allowances and prizes so that they are equipped and encouraged to conduct stronger anti-poaching operations. Motivation and awareness

programmes should be done and alternative livelihoods should be made available (e.g. local ecotourism organisations, cottage industries, agroforestry, etc.) so that human-wildlife conflict is reduced. Groups of trained dogs and handlers can patrol along the forest-village boundary so that Tigers are discouraged to stray into villages. The groups will also be able to drive the stray Tigers from the village to the forest with a plenty of noise and light. This will teach the Tiger not to stray into the village. Additionally, some traditional practices can be helpful such as: fencing, watchposts with guards having fire-crackers and lights, and excavation/restoration of canals along the forest-village boundary (this will not stop the Tiger, but will reduce the trespassing of cattle and people into the forest). While these cativities are often very local, they have regional implications, therefore, planning and monitoring can be done regionally.

- The threatened species of wildlife, particularly those facing extremely high risk of extinction in the immediate future (i.e. Critically Endangered species) require major intervention to recover the populations. This can be done either by assisting their feeding and breeding in the wild, or collecting parent animals and breeding them captivity in joint centres. Captive breeding and re-introduction programme of River Terrapin and Olive Ridley Turtle should start urgently.
- Local agencies, that is the Forest Departments need to increase capacity by recruiting people with proper training and motivation, and adding modern equipment and vehicles. Moreover, the Forest Department should develop local intelligence networks to collect information, mainly to aid detection and prevention of poaching. Involving local communities to support joint activities such as patrolling and collecting inventory information with financial incentive will encourage communities to support natural resources management activities.
- Both countries can take up simultaneous programs for community forestry and learn from best practices. Community forestry seeks to ensure both social interests and sustainable management of forests and offers an integrated package of benefits.
- Continuous research and monitoring on the wildlife and biodiversity together with different biological and physical aspects of the Sundarban should be maintained so that we know the trend of different species over time. The research and monitoring should preferably be done by teams of experts from different institutions and departments so that there is no scope for mistakes or biases. The outcomes of research and monitoring should feed into the management and conservation practices, so that the practices become more and more appropriate.
- A limited understanding of mangrove spatial distributions and mangrove species habitat requirements has reduced the success of conservation initiatives in Bangladesh and India (Sarker et al, 2016). Joint habitat modelling of mangrove distribution based on fine-scale species and environmental data to can be done to improve understanding of the threatened ecosystem of the Sundarban.

Insitutional actors:

- In Bangladesh, Department of Forest
  In West Bengal Sundarban Development Board, Department of Forest/ MoEF

8.2. Enhancing information and understanding

When an ecologically connected resource spans a border, there will be lack of coordination and information exchange can lead to inefficient, inconsistent, and even conflicting resource management regimes. There is an obvious need for wholistic information spanning the entire ecosystem, for better information on social and ecological implications, for an understanding of the management process itself (including the provision of information in decision support systems) and for monitoring and assessment methods. Joint data collection system and joint modelling activities can be taken up by Bangladesh and India for enhancing information and better understanding of the Sundarban region.

Data and information are the basis of good management. They underpin all stages in the conservation and management process including formulating policy, developing management plans, and evaluating progress and updating policy and plans to provide for continuous improvement. Moreover, in transboundary basins, information exchange and sharing of data between riparian countries is regarded as a first and essential step towards fostering cooperation and trust (Timmerman and Langaas 2005; Khan et. al. 2011; Gerlak et. al. 2013). In many regions of the world, countries are taking advantage of modern technology and web based communication systems for facilitating information exchange and monitoring of change across borders (Gerlak et. al. 2013). Examples include Nile Information System (http://nileis.nilebasin.org/data) and Mekong River Commission Flood Forecasting System (http://ffw.mrcmekong.org/). The setting of operational objectives and indicators will identify what information will need to be routinely collected in order to feed into the decision-making process, as well as the short-term (annual) and long-term (3–5 years) reviews and assessments of management performance. Given the complexity of the ecosystems and the dynamic nature of the myriad of interactions that can occur, a broad range of stakeholders need to be consulted including biologists, mathematicians, sociologists, economists and technologists working in collaboration with local stakeholders. The aim of the joint data collection and storage system could be:

- Increased sharing of data and information;
- Developments in information technology, availability of comprehensive data for national and regional level users;
- Improved accuracy and lead time for weather forecasts and multi-hazard early warnings for sustainable management;
- More scope of research in sustainable management of Sundarban region;
- Promote mutual community-oriented economic growth through creating evidence and advocacy on issues such as eco-tourism, sustainable fisheries and aquaculture management;
- Preparation of a clearer vision for future, to better promote the sustainable development in the region;
- Increased transparency and trust between the two countries;
- Improved global profile of Sundarban Region as a key test for meeting climate change challenges.

Joint modelling exercises has become a key component for facilitating understanding, dialogue, discussions and management of trans-boundary resources. Modern day models have reached a point of maturity that allows complex management scenarios to be explored by a wide variety of stakeholders and help organize a process in which its primary function is to provide a framework for thinking by

enabling participants to make their implicit assumptions explicit in a systematic manner. Both countries have state of the art models which are being used by decisionmankers; this experience and existing models can be the base for joint modelling exercises to facilitate joint planning and management.

8.3. Disaster management

The Sundarban, like many mangrove systems of the world is situated at the front line to many coastal hazards. The fragile ecosystem and communities living in and around the Sundarban Region are exposed to tropical cyclones, storm surges, erosion, flood, frequent inundation by high tide causing loss and disruption to lives, livelihood and often irreparable or long term damage to the ecosystem. The ecosystem and population living in the Sundarban, are found to be more resilient than many natural systems and cultural resources, but disaster management is essential for saving lives and assets. Disaster management, especially focusing on tropical cyclones and storm surges in the Sundarban region, thus remains high on the agenda for both countries.

The Hyogo framework (2005-2015) and the Sendai Framework (2015-2030) provide guiding principles and practical means for achieving regional disaster resilience:

- Promote regional programmes including for technical cooperation, capacity development, the development of methodologies and standards for hazard and vulnerability monitoring and assessment, the sharing of information and effective mobilization of resources;
- Undertake and publish regional and sub-regional baseline assessments;
- Coordinate and publish reviews on progress and support needs, and assists countries in preparation of national summaries;
- Establish specialized regional collaborative centers;
- Support the development of regional mechanisms and capacities for early warning, including for tsunami.

For the Sundarban the World Bank (2014) recommends a combination of interventions including, “hard investments” (embankment realignment), “soft investments” (restoration of mangrove bioshields), and defensive safety net investments (early warning systems, cyclone shelters, and safe water supplies). Many of these interventions can be better planned at the regional level,

- According to WMO (2009,) effective early warning systems have the potential to significantly reduce the loss of lives and assets due to cyclones and storm surges. Studies show an increase in water and climate related hazards during 1956-2005 but a comparatively slight decrease in associated economic losses and decrease in deaths. In the Bangladesh the early warning system is well established. In West Bengal, India, by comparison, early warning systems are still in their infancy, perhaps because the state has experienced far fewer deadly cyclones than Bangladesh. Nevertheless, the state's coastal area remains at risk of high intensity cyclones. Equally important are the information networks that feed into these systems. In Bangladesh, with Cyclone Aila, 27% claimed they did not get warned in time to evacuate. By contrast, in West Bengal and India more generally, the Disaster Management Framework remains significantly more vertically integrated and centralized, with a comparatively weaker interface with communities that would facilitate volunteer engagement. A regional early warning and dissemination system for the Sundarban will help both countries towards better disaster management.
- As more weather extremes start to unfold, demand for more accurate, timely and effective weather forecasts and climate prediction at all-time scales and other crucial information will be sought for the human safety and wellbeing and for planning. Strengthening multi-hazard end to end early warning systems in the selected areas in collaboration with the related agencies in both countries will strengthen early warning systems in remote areas, especially near the border.
- Many activities can be done regionally after the cyclone to reduce deaths of wildlife. Sometimes wildlife do not get access to freshwater after the cyclone so replacing the saline water by freshwater in some ponds and waterholes in key areas would be a great support for wildlife. Many wildlife including the Tiger and the Spotted Deer are dislocated from their territories and in the process of finding or establishing the territory after the cyclone they wander into the villages and often get killed by people.
- These vagrant wildlife can be saved by the Forest Department as well as teams of volunteers from local villages and elsewhere by raising awareness and by driving these animals back to the forest. This should be done at regional level as animals often stray beyond the border.
- Vulnerabilities and capacities of the different sectors like health, water supply and sanitation, food etc can be assessed regionally in order to measure and map post disaster risks. The structural and functional capacity of existing facilities to withstand and respond to the impact of hazards should be assessed and adaptation options can be given at the regional level.

Insitutional actors:

- Ministry of Disaster Management and related Deprtments and agencies in both countries;
- NGOs and civil society organisations.

8.4. Stronger economic growth

Poverty remains one of the biggest challenges in the Sundarban region and stronger economic growth leading to sustained poverty reduction has been recommended as one of the key pillars to more sustainable management of the Sundarban (World Bank, 2014, IUCN, 2014, Danda et al, 2011). Poverty reduction is high on the agenda for both Bangladesh and India. Both countries recognize the potential of pursuing a 'green' economy and growth to take advantage of their rich natural capitals and national

level policy and plans emphasize the need for reconciling economic growth with forest conservation. Improved cooperation across the border can start with exchange of good practices and focus on the key economic activities (aquaculture and sustainable tourism have been discussed in separate sections) of the region.

- Most of the population living in the Sundarban region in both countries is dependant on agriculture. Improvements in agricultural productivity can be accomplished by placing more emphasis on climate-resilient agricultural practices, including adoption of salt-resistant paddy seeds, use of efficient technologies, precision agriculture, crop diversification and integration of renewables. The Sundarban Development Board (SDB) under the Government of West Bengal has already introduced the paddy cum fish culture with rainwater harvesting facilities in which 2/3 land is devoted to agriculture and 1/3 to aquaculture or water storage in some areas. There is a need for sharing learnings of these kind of initiatives. Agricultural extension services and NGOs in both countries can undergo joint scoping exercises and training programmes for identifying and implementing innovative agricultural practices across the region.
- Promoting low-cost, climate-adaptive alternative farming methods focussing on the indigenous commercial species like seaweed, mushrooms and algal produce can be taken up in both countries. Since the socio-cultural acceptance of such products becomes an issue, government agencies and NGOs can launch joint campaigns to encourage these activities. There needs to be a strong local bottom-up approach that takes into account both ecological and socio-cultural diversity.
- Eco-tourism, green industries like IT, commercial activities like hotels and marketplace in the less vulnerable zones of the Sunderban and fish processing units need to be promoted to improve the economic condition of local populations.
- A strategy for poverty reduction focussed on human capital and improved livelihood opportunities like remains the most important option for reducing dependency on the forest resources. Alternate livelihood options can include like, local tour operators, tour guides, cottage industries, honeybee culture However, many programs take up by government agencies in both countries often deliver poor results due to misalignment with cultural preferences, poor marketing structures and inequitable benefit sharing mechanisms between and amongst the state and the locals.
- A significant aspect of the growing India-Bangladesh ties has been the setting up of border haats (markets) along the international border in the North East. The haats had been thriving centres of trade and commerce, restoring economic and commercial ties between the people of both sides of the border and reduce informal trade that persists. This could be introduced in the Sundarban region, but environmental concerns and issues have to be taken into account adequately, as there maybe a need upgrading and expanding border infrastructure, including road and constructing border haats to boost cross-border trade.

Insitutional actors:

- In Bangladesh, Ministry of Local and Rural Development, District
- In West Bengal Sundarban Development Board

8.5. Strengthening public services

Access to basic amenities in populated areas of the Sundarban has improved over the years; however, access to adequeate social services still remains a major issue in the region. Stagnation in infrastructural development such as road network, health care, education, water supply, sanitation, energy and communication facilities has affected the lives and livelihoods of the local population hampering stable social equilibrium and economic growth on the region. Joint planning, a unifying agenda underpinned by goals and targets and cross-transfer of experiences can be the mode of cooperation in strengethening social services in the region.

- Every year, the coverage of drinking water and sanitation is being revised, partly due to technological failures, a piecemeal approach, poor governance and lack of monitoring and evaluation. Decentralisation of service provision has left the sector with highly fragmented local bodies that lack the necessary resources to deal effectively with the complexity of the processes. In this case, a joint platform can be the medium between decentrelisation and fragmentation of services and can be effective for achieving economies of scale or economic viability for providing drinking water supply and sanitation services. The metrics of successful water and sanitation projects need to reflect actual use as well as promote accountability for keeping the services operational, regional monitoring and evaluation can ensure transparency and ensure the solutions are local like; streamlining the maintenance of school water supply and sanitation facilities and community sanitary complexes; redesigning toilets to reduce their cost and enhance the ability of toilets to withstand the effects of cyclonic storms; campaigns for hygiene education to encourage handwashing and to improve household sanitation in food handling and preparation.
- Development, introduction and promoting new science based affordable energy efficient devices for domestic cooking will play an important role in reducing dependency on forest resources. In both Bangladesh and India there has been technological development and limited commercialisation. Scaling up of local success stories can be a priority of collaboration.
- Energy being the precursor to stronger economic growth is a challenge that needs to be addressed. Village-level minigrids based on biomass gasifier, solar photovoltaics, wind-diesel hybrid and tidal power technologies can be used for supplying electricity for domestic and commercial applications. In addition, solar home lighting systems and portable lanterns can also used in many households. Both countries have made commitments to increase renewable sources of energy, and Sundarban can be a test case for regional cooperation.
- Collaboration and coordination among government agencies horizontally and vertically should be ensured. This is particularly needed across different levels, such as district and provincial levels, and to involve agencies responsible for protected area management where this is not the purview of the forestry department

- Collaboration and coordination among government agencies horizontally and vertically should be ensured. This is particularly needed across different levels, such as district and provincial levels, and to involve agencies responsible for public services such as water and sanitation, health and communication.
- Improvement of communication and transport infrastructure in the Sundarban region needs to follow an ecologically sensitive plan. It should be noted, infrastructure influence hydro-ecological conditions and processes across a range of organizational levels and scales, including creating barriers, habitat fragmentation, local disturbances and noise and water pollution. Collaborative actions at the regional level can help to improve the process of infrastructure planning and design in the following ways (National Research Council, USA, 2005):
    - ◊ Provide policy, guidance, and funding for infrastructure design and decision making that take ecological processes into account;
    - ◊ Expand the knowledge base for assessing potential effects of transportation and communication activities through regionally funded research projects;
    - ◊ Encourage cross-disciplinary dialogue between engineers, ecologists, and other environmental professionals to raise mutual awareness of each other's expertise, needs, and challenges;
    - ◊ Share information from practical experience. The larger perspective of national agencies and organizations permits identification and promotion of positive examples of success as well as lessons learned.

Insitutional actors:

- In Bangladesh, Ministry of Local and Rural Development, District
  In West Bengal Sundarban Development Board

8.6. Fisheries and aquaculture

Aquaculture, especially shrimp aquaculture, has the potential to become a major source of growth in the area if environmental and hydrological concerns are addressed. Already shrimp is the second largest export industry in Bangladesh and contributes 4.99% of the national earnings (Rahman and Hossain, 2009). According to India's Marine Export Development Authority (MPEDA), overall marine product exports are account for eleventh largest export item, with 62.12 percent of that value coming from its burgeoning shrimp sector. However, the rapid expansion of shrimp aquaculture in the Sundraban region has been of great environmental and social concern. In India there is legislation, in the form of issuance of licenses for shrimp farming is in place, however, insufficient consideration of the ecological and social environment in the granting of licences, there is very limited field control of the precise location and the current land use of proposed farms, and insufficient monitoring afterwards on compliance with environmental and social requirements (FAO, 2005). In Bangladesh, licensing or other sort of regulation is not present for shrimp farming.

Apart from shrimp farming, open water fisheries and aquaculture of other fish are important economic activities and support a major portion of the population. The following fisheries resources improvement measures can be taken jointly by both the countries:

- A joint fisheries stock assessment can be done at five years interval to look at important issues including total production of fish and other aquatic organisms, fishery-wise production, gear-wise production, species wise production, and fish population dynamics. The assessments need to generate basic information for management decisions. This will help in allocating the number of permit issue, restriction of gear use, species caught, etc. Important aspects to be considered for periodic studies and long-term data collection include, i) long-term data collection for monitoring salinity changes; ii) impacts of pollution on the fisheries and human health; iii) status and changes in water chemistry, hydrology, and ecology of the waters of the Sundarbans and their impacts on fisheries; iv) assessment of the presently fishing ban areas to determine how effective they are for fisheries conservation; and v) fisheries malti-culture and cage-culture on pilot basis.
- Fisheries service remain inadequate in the region and planning and coordination activities can target providing services for local fishers would include hatchery development, more feed and medicine, skill development, ice industry development, transport facilities, storage facilities, linkages with microfinance institutions and coordination with the extension field officials of the Department of Fisheries. Activities can also include, value chain analysis, fishers selection and group formation, service/input provider/seller selection, monitoring of production and growth, skill development training for fishers and service providers, product development (grading, packaging, branding, etc.) training for fishers, exposure visits to demonstration sites, marketing group formation, and field tours for establishing market linkages.
- In addition to the wetlands and fish sanctuarie in both countries, more fish sanctuaries need to be identified especially in the common rivers such as Raimangal and fishing bans need to be in place based on the natural life cycle of common fish in the Sundarban;
- Possible activities for developing fisheries markets would include forming marketing groups of fishers, and linking with fish markets at regional, district and local levels. The fishers depend on money lenders and are deprived of fair price of their perishable fish as oftenly they are bound to sale their catch to/through the money lenders. Establishing few fish landing and marketing centers on the landside of the Sundarbans, and also some ice factories through private public partnerships can help in breaking this cycle;
- Joint effective awareness and motivation efforts can be taken amongst the fishers and local people. The government agencies can use the co-management organizations for their assistance in this campaign;
- Fostering backyard hatcheries to reduce the environmentally destructive dependence on wild shrimp fry is needed. In order to improve the productivity, intensive farming methods can be applied and farmers can be trained to use inputs for efficiently. Investment on cold chains and post-harvest services are needed to reduce losses at this stage. Again these efforts can be done jointly to have a more comprehensive result.

Insitutional actors:

- Ministry of Fisheries and related Departments in both countries

8.7. Adaptation and mitigation

Lifestyles and livelihoods have been regulated by the monsoons, floods, and tropical cyclones since the Sundarban was first settled. Even the mangrove system itself has survived some 100 meters of sea level rise over the past 10,000 years as it slowly shifts and adapts to changing morphological conditions. Through all of this change, the people, their cultures, and their habits have adapted to permit ongoing survival within an inherently hostile realm. The protective system of polders has been in place for some hundred years in West Bengal and fifty years in Bangladesh, and has permitted establishment of sedentary livelihoods relying on long-term cropping patterns. Inspite of this, the rise of sea level and more frequent cyclones that are predicted to happen in response to the global warming is the biggest threat to the Sundarban and its wildlife in the long-term.

Sundarban Region, with its ecological resources and a huge dependent population of around 10 million, will be the test case for the global adaptation agenda. Towards climate resilient development, Bangladesh and India have bilaterally agreed on several issues including conservation of the shared Sundarban ecosystem and tigers, and cooperation on renewable energy. On some of these, action has already been initiated. While such national and bilateral action is the way forward, it may be insufficient to meet the greater needs for adaptation in the Sundarban Region in light of anticipated impacts of climate change. Large-scale mitigation and adaptation (M&A) projects will be necessary to address the challenges of the near future. With high capacity to store carbon, mangrove ecosystems such as the Sundarban can play an important role in mitigation efforts. Recent studies show, the net biosphere-atmosphere exchange of carbon in the Sundarbans has been estimated at 2.79 tonnes per hectare per annum. Their degradation also releases large amounts of 'blue carbon' stored in sediments to the atmosphere, a process that has been underestimated up until recently. Moreover, mangrove forests of the Sundarban, by providing protection to coastal areas from tsunamis and cyclones and aids in coastal sedimentation processes, offer an important defence in limiting climate change impacts and increasing adaptation capacities. Thus large-scale adaptation project(s) in the Region will potentially benefit about 12 million people while providing mitigation co-benefits – and can possibly serve as the single largest contiguous adaptation site in the world. Both countries can focus on the following activities:

- A climate change adaptation lens needs to be mainstreamed within regional development planning. Conduct medium- and long-range planning that incorporates climate change and variability.
- Regional or scaled up local projects in the Sundarban as one ecosystem can be an important contender for international adaptation and mitigation initiatives such as REDD+, BioCarbon Fund, Adaptation Fund, Green Climate Fund etc.
- Clear and integrated regional guidelines for REDD+ and community forestry should be created, including guidance on stakeholder rights, roles, responsibilities, and returns. Mitigation initiatives, such as REDD+, while articulating safeguards and giving high value to protection of local rights, ultimately aim at maximizing carbon sequestration in forests.
- Integrated modeling, that is ecological, hydrological of watersheds can become a very important part of the wetland restoration and management process. A joint model would be able to predict the effects of climate change on wetland system of Sundarban, and general trends in the system more effectively.
- The capacity of some mangroves to act as a carbon sink is an important function that may provide additional impetus for undertaking the regional conservation of Sundarban. There is a

dearth of information regarding dynamics of carbon sequestration by mangroves, joint studies on the Sundarban in collaboration with local, regional and international scientists can make important contributions to understanding the value of the Sundarban and mangroves in climate mitigation.

- Impacts of sea level rise can be ameliorated with acquisition of inland buffer zones to provide an opportunity for habitats and wildlife to migrate inland. Setback lines for coastal development can be effective at establishing zones for natural coastal migration based on projected sea level rise. Storm surge should be considered in establishing buffer zones and setback boundaries. In other cases, restoration of natural hydrology could facilitate sediment accretion and building of deltaic coastal wetlands. These activities, if done concurrently will be more effective.
- Policy-makers can identify models of successful mitigation–adaptation initiatives and scale up at national and regional level, where appropriate, prioritizing the documentation of lessons learned.

8.8. Cultural and media exchanges

Implementation of strategic social media programs and communication programs can drive cultural exchange and create new connections with communities across the border. Exchanges can trigger a convergence of perceptions, ideas and even initiatives while offering a frame through which to view future innovations. Cultural exchange is very important for the enhancing our bilateral relations. A Cultural Corporate Agreement, signed in 1972 is already active between the two countries.The 2015-2017 implementation plan of the the Cultural Corporate Programme of this agreement focusses on,

- Art and culture
- Youth affairs and sports
- Mass media

The programme already has well defined activities supported by both governments and thus can form the basis of cultural and media exchanges in the Sundarban region. These activities can be further tailored to focus on the conservation and management of the Sundarban region.

Insitutional actors:

- Ministries related to Culture and Education in both countries

8.9. Sustainable Tourism

Travel and tourism are among the world's fastest growing industries and are the major source of foreign exchange earnings for many developing countries like Bangladesh and India. Tourism, the single largest industry in the world, accounts for one third of all international trade, and many view tourism as a vehicle for economic development. Market research shows that eco-tourists are particularly interested in wilderness settings and pristine areas. The local communities living around the forest can benefit from creation of work opportunities, better infrastructure, and improvements in health and safety standards. The changing sentiment of the travelers' concerns about rights, justice and fairness, and about bettering the lot of local people and wildlife, have grown in the last decade, and can be the driving force for ecotourism.

Ecotourism in the Sundarban can also provide an opportunity for strategic cooperation and joint actions between Bangladesh and India, resulting in simultaneous poverty reduction and sustainable ecosystem management. Putting ecotourism on a truly sustainable path is a major challenge, requiring partnership and cooperation between the tourism industry, governments, local people and the tourists themselves. With consorted help from all key players, the ambitious goal of initiating cross-border tourism in Sundarban Region can be achieved. Examples from Kenya-Tanzania borderlands, show that cross-border ecotourism ventures generate half a billion dollars a year in tourism revenues for Kenya and Tanzania.

The above is adequately self-evident. We strongly solicit in favor of this model as an exemplary one. Our recommendation towards a futuristic, sustainable tourism action plan in Sundarban:

1. Sundraban tourism should not be focused upon the forests; rather it should be primarily river-centric;
2. Cultural tourism should replace the jungle tourism for the masses;
3. The native people of Sundarban are to be encouraged and motivated towards the protection of their own traditional culture;
4. Regarding the showcasing of the tourist attractions the host communities should be consulted thoroughly following "every sacred is not for selling" policy;
5. Community initiatives/ micro-investments are to be promoted in hospitality sector of Sundarban, not the corporate interventions through building up upscale resorts or big cruisers. The investment model should ensure the fair share of the tourism receipt to the community people. Only if the communities are considered as the principal stakeholders of tourism business in Sundarban, the traditional culture could be protected generously.
6. "Leave no footprint', seriously ignored in Sundarban tourism, is to be stipulated as a core ethical policy.

The current trend of tourism, mostly by domestic tourists, in this region, can provide a solid base for gradual tourism development, leading to expansion into the international market as the tourism facilities improve. For fragile ecosystems such as the Sundarban, limited, low-impact ecotourism, as opposed to mass tourism, can be the only sustainable option.

- Facilities and infrastructure elements such as transport, lodging and trails should be designed and upgraded to optimize visitor circulation and while ensuring minimum disturbance to natural features of the region. Tourism in Sundarban is of three types: (i) wildlife and nature focused tourism; (ii) religious tourism; and (iii) beach tourism. All three can be brought under the umbrella of ecotourism. Islands in Sundarban (India) in the transition zone or villages in the periphery of Sundarban Reserve Forest (Bangladesh) can be developed and zoned: Deep woods, Leisure Zone, Culture Zone and Adventure Zone. Interpretative pathways and bridges can be laid down through the island for trekking. In India, the existing Forest Department facilities for the crocodile and River Terrapin and in Bangladesh, ecotourism centre at Karamjal may be made more interactive. For students and corporate group events, activities can be organized for education programs and team building.

- There are numerous islands in Sundarban (India) transition zone or villages in the peripheral zone (Bangladesh) which can be turned into a constructed mangrove refugium. Tourists can be involved in planting mangroves, fishing, having mudbath, kayaking and honey collecting inside the mangroves. Experts can design diversified activities centered on voluntourism which is "the practice of individuals going on a working holiday" for the "the restoration of certain specific environments or research into aspects of society or environment", "alongside touristic activities".
- Packages with diverse options of activities and circuits or routes, including in-country as well as regional can be introduced. Visitors who want to experience the changing natural beauty and cultural diversity of the Sundarban can select destinations in both Indian and Bangladeshi part. Indian nature enthusiasts will be able to enjoy a more dense forest with abundance of Sundri trees in the Bangladeshi side, while Bangladeshi travelers will be able to experience village life in the vicinity of a forest. Sundarban also has a place in the literature of the region. The regional historic routes, can be revived to take advantage of literary tourism or or focus on nostalgic aspects. Tourist activities can also be seasonal or festival based, for example, during honey hunting season (Bangladesh) or rashmela (India).

Insitutional actors:

- Ministries and government agencies related to Tourism in both countries

8.10. Natural regeneration and reforrestation

One of the most challenging issues in the Sundarban is environmental degradation due to an expanding population, dangerous levels of water pollution and water scarcity, massive land degradation, large scale deforestation, enlarged transportation networks, development of local economies and climate change and sea level rise (Sen 2016; Aziz and Paul, 2015; World Bank, 2015). Thus, there is an imperative need to to formulate proper restoration practices for the mangroves ecosystem in the Sundarban. According to Lamb and Gilmour (2003), forest restoration policies should emphasise the following:

- ◊ an approach to forest management that includes improving the livelihoods of local communities
- ◊ a wide range of goods and services, rather than simply focus on planting trees;
- ◊ linkages between forest restoration and rehabilitation activities at the site level with the environmental, social and economic needs to the landscape and ecoregional level;
- ◊ a multi-sector approach that ensures the participation of interest groups in decision-making

Most experts now support a more comprehensive ecological approach to restoration, with considerations of the past history of a proposed restoration site and more careful measurements of existing hydrology of both reference and impact sites. Natural Regeneration has been assessed as simple, inexpensive and effective technique to conventional reforestation methods and there is an increased awareness on the potential of Assisted Natural Regeneration in forest restoration. Assisted Assisted Natural Regeneration aims to accelerate, rather than replace, natural successional processes by removing or reducing barriers to natural forest regeneration such as soil degradation, competition with weedy species, and recurring disturbances (e.g., wood harvesting, climate disasters) and is more

compatible to traditional systems of natural resources management (Shono et al, 2007; Durst and Ganz, 2003). The following benefits can occur from natural regenartion:

- Regenerate native forest
- Biodiversity conservation
- Improve the connectivity of fragmented forest resources
- Soil protection
- Protection of fragile water catchment areas
- Improve regional water supply
- Greater infiltration of water and build up to topsoil will enhance forest growth

Regeneration projects can be conducted through integrated conservation and development projects or community based natural resource management programs engaging local communities and focusing on ecosystem services provided by mangroves in part to try to establish protection of biodiversity through sustainable use. Both countries can focus on the following activities:

- Fund pilot projects on Assisted Natural Regeneration in both countries, while concurrently organizing training and demonstration
- Update documentation to facilitate cross-country exchange of knowledge
- Conduct joint training, study tours and exchange visits to different forests across the globe, to demonstrate best practices of natural regenartion
- While assisted natural regenaration reduces or eliminates the costs associated with propagating, raising, and planting natural process of establishment of seeds of mangroves, it is still important to develop nurseries and herbaries to store seeds and grow saplings. These may be distributed for homestead forestry or agro-forestry.
- Develop a joint monitoring plan for assisted natural regeneration. Remote sensing can be used to provide spatial and temporal information on mangrove forest area and distribution, as well as on species differentiation, health status, and population changes.
- Assisted natural regeneration falls in line with the principle of REDD+ , which is that plants and trees will be allowed to grow for an indefinite period, die and decompose naturally, slowing down the release of greenhouse gases. Compensation will be accrued from developed countries. However, to achieve the REDD+ goal, measures to protect soil and water need to be taken into consideration for the restoration of the Sundarban.

8.11. Marine resources conservation

The Sundarban provides an important breeding and nursing habitat for diverse marine biodiversity and organisms. Many marine invertebrates and fishes with complex life cycles, in which larvae are transported to mangroves and estuaries, metamorphose, grow to subadult stages, and then move to adult habitats offshore. Many biotic and abiotic factors influence the habitat value of mangroves including abundance of nutrients and food, absence of predators and interception of fish larvae. In fact many studies have demonstrated a strong relationship between mangrove presence and marine fish catch with fishery catch being influenced by the relative abundance of mangroves in a region

(Nagelkerkena, 2000). Bangladesh and India have signed a MoU on Blue Economy and Maritime Cooperation in the Bay of Bengal and the Indian Ocean in 2015. Thus conservation of marine resources in the Bay of Bengal can be an important area of joint and coordinated management:

- ◊ Integrating mangroves conservation in the marine resources conservation can be an important approach for both countries. The Swatch of No Ground is the first Marine Protected Area (MPA) of Bangladesh declared by MoEF in 2016 is 45km away from the Sundarban. India so far does not have any MPA near the Sundarban (Singh, 2013). However the strategy has a fragmented and sectoral approach with focuses at species level rather than the ecosystem. Joint identifification of priorities and activities for ecosystems based approach can be taken up.
- ◊ Bangladesh and India are engaged in an active collaboration in the area of ocean research through National Institute of Oceanography (NIO), under the Council of Scientific and Industrial Research (CSIR), India and Dhaka University (DU) (Herald, 2017) Further to this joint stock assessment including joint study on a better understanding of the habitats that serve as nurseries for marine species.
- ◊ There are several education institutions that are offering undergraduate and post- graduate education on marine sciences, marine fisheries, oceanography, maritime governance etc in both countries. Joint courses and curriculum development focissing on on applied /advance researches such as marine bio- technology, marine fertilization and habitat modeling can be introduced.

The emerging opportunities and activities are summarised in Table 8.1.

Potential Areas for Collaboration	Intervention/Activities	Concurrent or collaborative activities	Conditions/Pressure	Institutional Actors
Natural resources management	Regulatory instruments for natural resources management are currently present but new market-based incentive mechanisms could improve regulatory efficiency	➢ Integrated management of both forests and wetlands for producing products and generating services. ➢ New mangroves should allow colonizing portions of the newly unprotected lands. ➢ The poaching, retribution killing, and habitat loss can be controlled by implementing the national acts and policies. ➢ Scientific research and monitoring are also necessary to ensure informed management of wildlife. ➢ Motivation and awareness programmes should be done and alternative livelihoods should be made available. ➢ Critically Endangered species require major intervention to recover the populations. ➢ Forest Department should develop local intelligence networks to collect information, mainly to aid detection and prevention of poaching. ➢ Both countries can take up simultaneous programs for community forestry and learn from best practices. ➢ To know the trend of different species continuous research and monitoring should be maintained.	Future climate and sea level rise; and ongoing habitat degradation may alter the current spatial distributions of mangrove species and forest composition. Regulatory instruments for natural resources management that must be enforced are already in place, but new market-based incentive mechanisms could improve regulatory efficiency and help realize positive biodiversity conservation outcomes.	Bangladesh, Department of Forest West Bengal Sundarban Development Board, Department of Forest/ MoEF
Enhancing information and understanding	Collaborative data collection system and joint modelling activities can be taken up by Bangladesh and India for enhancing information and better understanding of the Sundarban region	➢ Increased sharing of data and information ➢ Improved accuracy and lead time for weather forecasts and multi-hazard early warnings ➢ Increased transparency and trust between the two countries ➢ Joint modelling exercises for management of trans-boundary resources in Sundarban	The complexity of the ecosystems, lack of coordination and information exchange can lead to inefficient, inconsistent resource management in the Sundarban region.	

Potential Areas for Collaboration	Intervention/Activities	Concurrent or collaborative activities	Conditions/Pressure	Institutional Actors
Disaster management	➢ hard investments (embankment realignment) ➢ soft investments (restoration of mangrove bioshields), and ➢ defensive safety net investments (Early warning systems, cyclone shelters, and safe water supplies).	➢ A regional early warning and dissemination system ➢ Collaboration with related agencies in both countries will strengthen early warning systems in remote areas, especially near the border. ➢ Reduce deaths of wildlife after the cyclone, different activities can be done regionally by the cooperation of nearby village peoples. ➢ For measuring and mapping post disaster risks capacity and vulnerability of different sectors can be assessed regionally	The fragile ecosystem and communities living in and around the Sundarban region are exposed to tropical cyclones, storm surges, erosion, and flood, often causing a long term damage to the ecosystem.	Ministry of Disaster Management and related Deprtments and agencies in both countries; NGOs and civil society organisations
Stronger economic growth	Poverty reduction is high on the agenda for both Bangladesh and India. Both countries recognize the potential of pursuing a 'green' economy through reconciling economic growth through forest conservation.	➢ Improvements in agricultural productivity done by climate-resilient agricultural practices ➢ Collaborative scoping exercises and training programmes for identifying and implementing innovative agricultural practices across the region. ➢ Promoting low-cost, climate-adaptive alternative farming methods. ➢ Eco-tourism, green industries need to be promoted to improve the economic condition of local populations. ➢ Setting up of border haats (markets) along the international border in the North East region for accelerating the ties between India-Bangladesh	Poverty remains one of the biggest challenges in the Sundarban region and stronger economic growth leading to sustained poverty reduction has been recommended as one of the key pillars.	In Bangladesh, Department of Forest, Ministry of Local and Rural Development, District In West Bengal Sundarban Development Board
Strengthening public services	Concurrent planning, a unifying agenda underpinned by goals	➢ Providing drinking water supply and sanitation services. ➢ Promote accountability for keeping the services operational	Lack of proper infrastructural development affected the lives and livelihoods of the local population	In Bangladesh, Ministry of Local and Rural

Potential Areas for Collaboration	Intervention/Activities	Concurrent or collaborative activities	Conditions/Pressure	Institutional Actors
	and targets and cross-transfer of experiences can be the mode of cooperation in strengthening social services in the region.	➢ Introduction and promoting new science-based affordable energy efficient devices for domestic cooking. ➢ Village-level minigrids based, solar photovoltaics, wind-diesel hybrid, and tidal power technologies can be used for supplying electricity for domestic and commercial applications ➢ Collaboration and coordination among government agencies horizontally and vertically ➢ Transport infrastructure in the Sundarban region needs to follow an ecologically sensitive plan	,hampering stable social equilibrium and economic growth on the region	Development, District In West Bengal Sundarban Development Board
Fisheries and aquaculture	Aquaculture, especially shrimp aquaculture, has the potential to become a major source of growth in the area if environmental and hydrological concerns are addressed. In India there is legislation, however, there is insufficient consideration of the ecological and social environment in the granting of licences and insufficient monitoring (FAO, 2005). In Bangladesh, licensing or other sort of regulation is not present for shrimp farming.	➢ A joint fisheries stock assessment can be done at five years interval ➢ Development of fisheries services like hatchery, feed and medicine, ice industry, transport facilities, storage facilities and proper skill. ➢ In both countries, more fish sanctuaries need to be identified especially in the common rivers such as Raimangal ➢ Establishing few fish landing and marketing centers on the landside of the Sundarban. ➢ Fostering backyard hatcheries to reduce the environmentally destructive dependence on wild shrimp fry	The rapid expansion of shrimp aquaculture in the Sundraban region has been of great environmental and social concern. In where shrimp is the second largest export industry in Bangladesh and In India, the overall eleventh largest export item is from the marine product.	Ministry of Fisheries and related Departments in both countries
Adaptation and mitigation	Bangladesh and India have bilaterally agreed on several issues including conservation	➢ Regional or scaled up local projects in the Sundarban as one ecosystem can be an important contender for international	The rise of sea level and more frequent cyclones is the biggest threat to the Sundarban and its	

Potential Areas for Collaboration	Intervention/Activities	Concurrent or collaborative activities	Conditions/Pressure	Institutional Actors
	of the shared Sundarban ecosystem and tigers, and cooperation on renewable energy but it may be insufficient to meet the greater needs for adaptation in the Sundarban Region in light of anticipated impacts of climate change.	adaptation and mitigation initiatives. ➢ Clear and integrated regional guidelines for community forestry should be created ➢ A joint model could able to predict the effects of climate change on wetland system of Sundarban ➢ Joint studies on the Sundarban is needed to undertake the information regarding dynamics of carbon sequestration ➢ Setback lines for coastal development can be effective at establishing zones for natural coastal migration based on projected sea level rise.	wildlife in the long-term. Degradation of mangrove can release a huge amount of "Blue Carbon", In where sundarban has net biosphere-atmosphere exchange about 2.79 tonnes per hectar.	
Cultural and media exchanges	A Cultural Corporate Agreement, signed in 1972 is already active between the two countries.Day to day modification needed for joint cooperation.	Current activities can be further tailored to focus on the conservation and management of the Sundarban region.	Cultural exchange is very important for the enhancing our bilateral relations. Exchanges can trigger a convergence of perceptions, ideas and even initiatives while offering a frame through which to view future innovations.	Ministries related to Culture and Education in both countries
Sustainable Tourism	The current trend of tourism, is dominated by domestic tourists, and can provide a base for gradual tourism development leading to expansion into the international. Ecotourism in the Sundarban can provide an opportunity for strategic cooperation and joint actions between Bangladesh and India.	➢ Sundraban tourism should be focused upon river-centric ➢ Facilities and infrastructure elements should be designed and upgraded while ensuring minimum disturbance to natural features of the region ➢ Construct mangrove refugium at numerous islands in Sundarban (India) transition zone or villages in the peripheral zone (Bangladesh) for different tourist activities ➢ Introduce Packages with diverse options of activities and circuits or routes	Sustainable Ecotourism faces major challenges like partnership and cooperation between the tourism industry, governments, local people and the tourists themselves.	Ministries and government agencies related to Tourism in both countries

Potential Areas for Collaboration	Intervention/Activities	Concurrent or collaborative activities	Conditions/Pressure	Institutional Actors
Assisted reforestation	According to Lamb and Gilmour (2003), forest restoration policies should emphasize forest management, a wide range of goods and services, linkages between forest restoration and rehabilitation activities.	➢ Fund pilot projects on Assisted Natural Regeneration in both countries, while concurrently organizing training and demonstration. ➢ Update documentation to facilitate cross-country exchange of knowledge. ➢ Conduct joint training, study tours and exchange visits. ➢ Develop nurseries and herbaries to store seeds and grow saplings. ➢ Develop a joint monitoring plan for assisted natural regeneration. ➢ Protect soil and water for the restoration of the Sundarban.	Environmental degradation due to an expanding population, dangerous levels of water pollution and water scarcity, massive land degradation, large scale deforestation, enlarged transportation networks, development of local economies and climate change and sea level rise (Sen 2016; Aziz and Paul, 2015; World Bank, 2015)	
Marine resources conservation	Bangladesh and india have an MoU on Blue Economy and Maritime Cooperation in the Bay of Bengal and the Indian Ocean	➢ Integrating mangroves conservation in the marine protected areas (MPAs) ➢ Joint stock assessment including joint study on a better understanding of the habitats ➢ Joint courses and curriculum development	The Sundarban provides an important breeding and nursing habitat for diverse marine biodiversity and organisms. Many marine invertebrates and fishes with complex life cycles, in which larvae are transported to mangroves and estuaries, metamorphose, grow to subadult stages, and then move to adult habitats offshore.	

9. Way forward

Time and again at various fora it has been expressed that the Sundarbans across Bangladesh and India be visualized as a single biogeographical entity and that bilateral research cooperation be promoted to inform joint action for sustainable development and conservation of Sundarbans landscape. As mentioned in revious sections of this narrative, Bangladesh and India signed (non-binding) agreements in late 2011 on a number of issues to pave the way for joint action. However, thus far, the pattern of governance at the national and especially regional level in the Sundarban region has struggled to keep up with the management and development challenges posed by this complex system. In the absence of the needed new adaptive solutions this environmentally and economically important area is rapidly heading towards an uncertain future. The Sundarbans landscape is possibly the demographically largest site in the world in need of adaptation measures and investment.

Given this scenario, how can management plans be integrated and joint activities be implemented? The answer lies in addressing three key challenges:
a) building consensus,
b) building institutions for joint management; and
c) identifying and catalysing the processes necessary to mobilise institutions.

It is important to keep in mind that consensus building in joint ecology management and conservation efforts starts with national interests, including economic development, security, and concerns and needs of the local population. Consensus building then requires trust and political will, platforms for dialogue and transparency, knowledge and information, capacity and tools for integration of competing demands and for identifying mutual benefits. The successful management of the Sundarban will require crafting of effective institutions at multiple levels in order toprovide incentives and disincentives. More importantly, the institutions need to be “truly” representative and that involve different stakeholders. Regional platforms need to be established and developed to work alongside other regional platforms across sectors and with the drivers of change in different rivers and different basins. Agreements will work on the ground only if they involve stakehoilders and have their support and take into account local politics. In order to catalyse and mobilise regional platforms, it is necessary to have in place processes in national agendas and in international dialogues, and also processes that support interaction with stakeholders. Education of stakeholders, communication and capacity development, and strengthening of national institutions is required in order to make these processes effective. Effective governance at the national level, sound policies and laws that align with trans-boundary issues would also need to align with hydro-diplomacy processes. There would need to be a better understanding of the issues that countries and citizens want to solve and what their concerns are.

A Joint Working Group on the Conservation of Sundarban comprising officials from India and has been set up to implement the activities under the MoU. The Joint Working Group has so far held one meeting on July 21, 2016 at New Delhi, India. Although the agreement and memoranda signed in September 2011, are declarations of intent, these do not articulate the institutional and financial arrangements to operationalise the instruments already agreed upon. The objective being devising a way to support operationalization of the Sundarbans agreements between Bangladesh and India, and enhancing

technical cooperation, a Sundarban Joint Platform is suggested to bring to fruition the aims and objectives contained in the agreement and memoranda.

9.1. Joint Platform – (why, who, how)

The issue of institutional setup to support conservation and management is one of the foremost to confront while planning interventions. This holds particularly true in Bangladesh and India as there are many challenges and development priorities that need to be addressed at the national level. Management activities aiming at increasing sustainability can realise their potential only within the framework of supporting policy innovations. These have to consider the whole bandwidth of fields, from innovation, production and the systems of provision to the realms of consumption, and various domains and institutions of the political-administrative process of regulation. New role of governmental and non-governmental institutions

i. Social aspects
ii. Economic factors

According to Pirot et al (2000) multistakholder joint platforms are important for:

b. Reviewing policies of different sectors to identify areas of conflict and compatibility;
c. Sharing information on baseline research, innovative methods and successful results;
d. Sharing ideas for project actions based on country experiences;
e. Coordination and integration of information-gathering activities;
f. Avoiding duplication and responsibility for management;
g. Identifying sites and habitats that are critical to the provision of ecoservices and that require special forms of management and co-operation.

i. Ecological approach
ii. Broader regional cooperation
iii. Role of current and proposed institutions

The key questions that need to be addressed:

- Which individuals, groups, or agencies need to be involved in the project for creating the joint platform and how?
- What ecological and socio-economic boundaries need to be considered for the Joint Integrated Management Strategy?

Implementation level meeting
Yearly concrete schedule of meetings and adhere to them.
Data base
Common Vision for the Sundarban
Valuation of ecosystems services
Concurretly and parallel as possible

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ECOLOGY OF SUNDARBAN, BANGLADESH

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More than the poverty, however, what strikes you immediately is the growing vulnerability of the region. While the poverty and illiteracy in the region also need close attention, I argue that four additional vulnerability factors have caused widespread destruction of lives and livelihoods in the island. These are environmental hazards (including climate change), a difficult terrain, health

hazards, and incessant tiger attacks. - See more at: http://www.epw.in/journal/2016/53/insight/exclusionary-conservation-sundarbans.html#sthash.bEBvgY0i.XtPmAlQC.dpuf

land-base activities can generate high-quality emission reductions with strong environmental and socioeconomic benefi ts for local communities.

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