ECOLOGICAL RISK ASSESSMENT OF SUNDARBANS MANGROVE FOREST DUE TO SEA LEVEL RISE

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ABSTRACT

With a total area of over 10,000 square kilometers, the Sundarbans constitute the World's largest contiguous mangrove ecosystem. The floristic composition of the Sundarbans is rich compared to many other mangroves of the world. In recognition of this richness in biodiversity, both Indian and the Bangladesh Sundarbans were declared world heritage sites by UNESCO. Mangrove offers both tangible and intangible benefits to the people. It plays an important role in the national economy of Bangladesh.

Since the viability of the Sundarbans rests on the hydrology of the Ganges and its tributaries, climate change is expected to have significant impact on the Sundarbans. A rise in sea level would occur under climate change which would cause increased backwater effect in the major distributaries of the Ganges and tend to push the saline front further inland. The backwater effect would also reduce the discharge of freshwater flow from the northern reaches of the tributaries of the Ganges resulting in a relatively prolonged inundation of the forest land. The effects of climate change on the Sundarbans would be considerably more critical during the dry season. Climate models predict a decrease in precipitation during this period which might further reduce freshwater flows. This reduction in freshwater inflows into the Snndarbans could be exacerbated by increased evapo-transpiration losses and water use on account of rising winter temperatures. Reduced freshwater flows coupled with sea-level rise would conseqnently further enhance the dry season salinity levels in the Sundarbans. Northward penetration of the salinity front would result in salinity induced succession problems in the Sundarbans and as a result, the symbiotic process in the entire ecosystem wonld change completely. Majority of the mesohaline areas will be transformed into polyhaline areas, while oligohaline areas would be reduced to mesohaline areas.

This study has been conducted to assess the ecological risk of sea level rise to three ecological entities like ecological zone, ecological health in terms of productivity and regeneration in the Sundarbans ecosystem. Ecological risk has been calcnlated as a function of probability of sea level rise and vulnerability of ecological entity.

In this study, the Sundarbans has been divided into three ecological zones depending on salinity. The prepared maps of spatial distribution of salinity at base condition and 88cm sea level rise clearly indicate transformation of ecological zones. The probability of 88cm sea level rise has been calculated to be 20 percent. Due to 88cm sea level rise about 9 percent area of less saline water zone will be transferred to moderate saline water zone while about 3 percent area of moderate saline water zone will be transferred to strong saline water zone. The vulnerability to ecological zones transformation is 0.13 where the risk to zone transformation is 3 percent. Vnlnerability of 88cm sea level rise to the ecological health of the Sundarbans has been calculated considering the compartments to be affected and it is 0.07 and so the risk to ecological health is 1.45 percent. In the similar way, the vulnerability to regeneration has been calcnlated and it will be 0.15 due the 88cm sea level rise and the risk to regeneration is 3 percent. Vulnerability to regeneration of Sundry (*Heritiera fomes*), most valuable trees in the Sundarbans, is 0.4 and thus the risk to regeneration of *Heritiera fomes* is 8 percent.

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ABBREVIATIONS

SRF	Sundarbans Reserved Forest
IUCN	International Union for Conservation of Nature and Natural Resources
CCSLR	Climate Change and Sea Level Rise
IPCC	Intergovernmental Panel on Climate Change
ERA	Ecological Risk Assessment
WMO	World Meteorological Organization
UNEP	United Nations Environment Program
TAR	Third Assessment Report
SAR	Second Assessment Report
EPA	Environmental Protection Agency, USA
DOE	Department of Environment
GBM	Ganges Brahmaputra Meghna
SLR	Sea Level Rise
DHI	Danish Hydraulic Institute

CHAPTER ONE
INTRODUCTION

1.1 Background

The Sundarbans is the largest contiguous mangrove ecosystem in the world, with a total area of approximately 1 million hectares of which 62 percent fall within the territory of Bangladesh while the remaining area belongs to India. An estimated 4,143 sqkm of the Sundarbans Reserve Forest (SRF) consists of land and 1,874 sqkm rivers, creeks and canals. The SRF comprises 51 percent of the reserved forest estate of Bangladesh. As the largest remaining forest area in the country, and with its extensive aquatic and marine components, the SRF represents a significant storehouse of biodiversity. The Sundarbans is one of the richest natural gene pools for fauna and flora in the world. The flora contains at least 69 species, with the Sundari (*Heritiera Fomes*), which gives the forest its name and the Gewa (*Excoecaria Agallocha*) being the dominant species that provide timber for paper and wood products. Forest inventory indicates that there are 315 species of birds, 120 species of commercially important fish, 42 species of mammals, 35 species of reptiles and 8 species of amphibians, including a number of threatened or endangered.

Bangladesh is already perspiring with different types of natural disasters. In the foreseeable future, the country is likely to be affected by long lasting and global scale human-induced disaster-the climate change and sea level rise (CCSLR). Bangladesh is thought to be one of the most vulnerable countries of the world to CCSLR (Ali, 1999). A rise in sea level would cause increased backwater effect in the major distributaries of the Ganges and tend to push the saline front further inland. The final location of the saline front during the monsoon will therefore be the result of two opposite effects: enhanced freshwater flows and enhanced backwater effect, and is hard to predict precisely. The backwater effect would also reduce the discharge of freshwater flow from the northern reaches of the tributaries of the Ganges resulting in relatively prolonged inundation of the forest land (OECD, 2003). 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. The Bangladesh country study (BCAS and DOE, undated) put the range of sea level rise at 30-100 cm by 2100, while the Intergovernmental Panel on Climate

Change (IPCC) Third Assessment (IPCC, 2001) gives a global average range with slightly lower values of 9 to 88 cm. A 45 cm sea level rise would inundate 75% of the Sundarbans, and a 67 cm sea level rise could inundate all of the system (Agrawala *et al.*, 1999). Extrapolating from this information, Smith et al. (1998) calculated that a 25 cm sea level rise would result in 40% mangrove loss. The rise in sea level and availability of less fresh water particularly during winter when rainfall will be less will cause inland intrusion of saline water. Northward penetration of salinity front would result in salinity induced succession problems in Sundarbans (World Bank, 2000). As a consequence of salinity penetration in the Sundarbans, majority of the mesohaline (water salinity = 5 to 18 ppt) areas will be transformed into polyhaline (water salinity = 18 to 30 ppt) areas, while oligohaline (water salinity = 0.5 to 5 ppt) areas would be reduced to only a small pocket along the lower-Baleshwar river in the eastern part of the forest (OECD, 2003). As a result, many mangrove species, intolerant of increased salinity, may be threatened. Increased temperature and sea level rise will seriously affect the Sundarbans ecosystem and bio-diversity (Ali, 1999).

The study will assess ecological risk of sea level rise to the Sundarbans mangrove forest. Risk is often defined as the product of the probability of a hazard and the consequences if that hazard occurs. Risks are characterized in terms of probability, consequence and the sensitivity to management interventions. More specifically, ecological risk assessment (ERA) is a relatively new technique that is now available for assessing the level of risk to the ecosystem posed by stressors.

1.2 Objectives of the study

Specific objectives of the study are as follows:

a. To determine the probability of sea level rise at different height.

b. To relate salinity intrusion and sea level rise.

c. To assess the ecological effect on mangroves at different salinity level and

d. To make an assessment of the risk to the Sundarbans mangrove forest.

1.3 Possible Outcome

The ultimate result of this study will be a measure of risk that the Sundarbans ecosystem will face in future. It will help decision makers to manage Sundarbans Mangrove Forest accordingly.

1.4 Scope of the Study

Risk is defined as function of probability of occurrence of hazard and its consequences. Since the Sundarbans has both numerous floral and faunal composition, all of them will be affected due to sea level rise. But in this study, only following items have been considered to assess the risk of 88cm sea level rise on the Sundarbans.

- Though both floral and faunal species will be affected by 88cm sea level rise, only floral species that is mangroves has been considered for ecological risk assessment.
- Sea level may rise at different heights. Though maps of salinity intrusion under 32 cm and 88 cm of sea level rise are available only 88 cm sea level rise was considered in this study because the ecological effect is remarkable at 88 cm sea level rise whereas at 32 cm, the vulnerability to the ecological entities is not recognizable.
- Risk due to only salinity ingress has been considered.
- Only Bangladesh part of the Sundarbans was considered in this study.
- Although fourth assessment of IPCC has been published, the third assessment has been considered in this study. According to the fourth assessment the rise of sea level will be lower than that has been reported in the third assessment.

1.5 Limitations of the study

Assessment of ecological risk is very difficult task. The limitations of this study are as follows:

- No probability of saline water intrusion was calculated or determined. The probability of 88cm sea level rise was considered as the probability of saline water intrusion under this scenario.
- The data on saline sensitivity of mangrove are not available. The relationship between mangrove's characteristics e.g. height, diameter, canopy closure etc. and salinity have not yet been developed.

- Resiliency of mangrove species was not considered. Every species has some capacity to recover from any disturbance. After 88cm sea level rise, some mangrove species in the Sundarbans will lose their usual characteristics but after a period of time they may gain their original or characteristics. That was not considered in this study.
- Though saline level in all three saline zones will be changed, ecological impact of only low and moderate saline water zones was considered in this study. Because the changes in ecological entities in high saline zone can not be determined due to lack of information.
- Saline intrusion model does not consider tidal harmonics.

CHAPTER-TWO

THE SUNDARBANS ECOLOGY AND ECOSYSTEM

2.1 Introduction

The Sundarbans, the largest continuous mangrove forest in the world (Chaudhuri and Naithani, 1985), is located at the southern extremity of the Ganges river delta i.e., the plain bordering the northern margin of the Bay of Bengal. The forest covers an area of about 10,000 sq.km of which 62 % fall within the territory of Bangladesh while the remaining area belongs to India.

The Bangladesh Sundarbans lies between the latitudes 21° 31′ and 22° 30′ N and between the longitude 89° and 90° E. It is a reserved forest and has been divided into four administrative ranges with 55 compartments. During the British period, i.e., before 1947, the entire Sundarbans was administered as a single forest management division.

The Sundarbans is a deltaic swamp formed by the transportation of millions of cum of silt by the river system. Consequently, the land surface is flat and the elevation is at present hardly 3 meters above mean sea level. A complex network of streams and rivers varying considerably in width and depth intersect the entire area (Chaudhuri, 1968). The network of total tidal waterways is about 1700 sq. km in area. The width of the waterways varies from a few meters to as much as 10km. The rivers inside the Sundarbans are more stable than the main streams of the Ganges and the Brahmaputra further east.

A number of geomorphological and resultant hydrological changes have contributed to the present location and condition of the Sundarbans. This alteration in the course of the main river influenced the reduction of fresh water flowing in the western part of the delta. This resulted in the accretion at the river mouth and increase in salinity water intruding in the western part of the delta (Morgan and McIntire 1959, Chaudhuri and Choudhury, 1994).

2.2 Structure of Sundarbans Ecosystem

The structure of the mangrove ecosystem can be divided into two components. Figure 2.1 identifies these components and their sub-components and their relationship with each other.

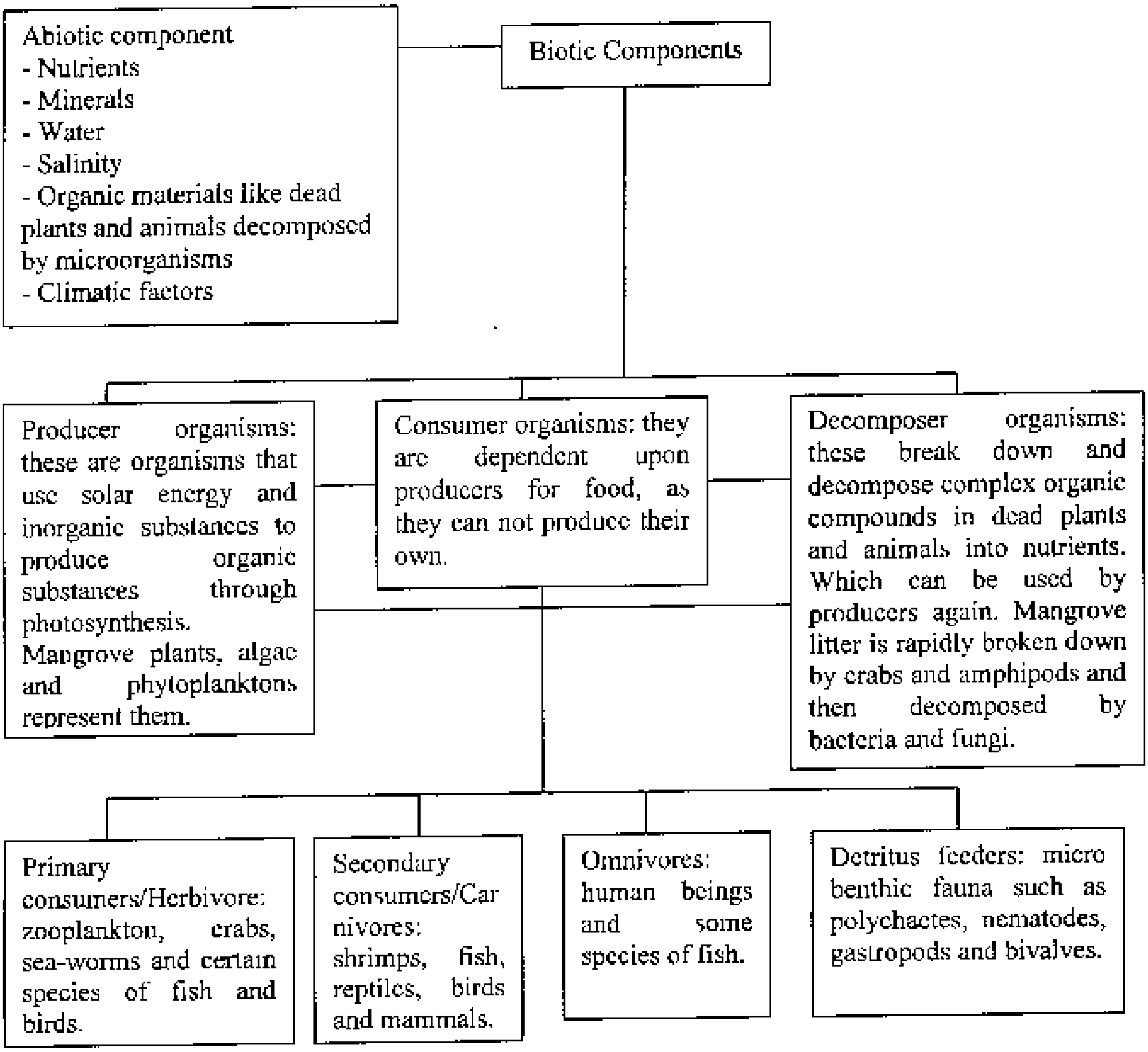


Figure 2.1: Components and sub-components of Sundarbans Mangroves

Source: Sherina, 1999

2.2.1 Abiotic Component

2.2.1.1 Minerals and Nutrients

The mangrove soils are usually alluvial. It has been reported that the quality of mangrove soils largely depends on the source of origin. The shell bearing sediments of sea, more further form crystals of calcium carbonate and enhance alkalinity of such soil. Under anaerobic conditions, sulphates from the sea are usually reduced to Iron sulphate. Natural or artificial drainage and aeration of these pyrite sediments lead to their oxidation and to formation of sulfuric acid which is released in the absence of calcium carbonate. By oxidation process of the cyanophyceae flora, inorganic phosphate as well as ammonical radicle is released. These ammonical radicles afterwards are converted to nitrate molecules. The excreta and exuviae of the mangrove biota enrich silty clay soils of the upper layer with the deposition of inorganic nitrate, phosphate and other substances (Rahman, 1995). Sodium and calcium contents of the soil vary from 5.7 to 29.8 meq/ 100g in oven dry soil and are generally low in the eastern region and higher towards the west. The available potassium content of the soil is low in comparison with sodium and calcium. Potassium concentration in western part is higher than in the east. The presence of higher concentrations of Na and Mg in the soil hampers plant growth. Distribution of available calcium in the Sundarbans soil is not uniform.

2.2.1.2 Organic Materials

Normally, alluvial silty clay soil of the estuarine mangrove area is not much productive until or unless these sediments receive and deposit humus matter or exuvial of organisms and molluscan or crustacean shells. In the Sundarbans mangrove delta, silty clay soils are normally very fertile due to abundant humus deposition as well as for the long wide spread rivers of the Ganges- Brahmaputra system. The Sundarbans soil is comparatively recent in origin and is well stored with organic detritus before its deposition. The top soil layer is much sticky mud and contains decayed plants and animal detritus (Rahman, 1995).

2.2.1.3 Hydrology

The Sundarbans hydrology is related to high seasonal rainfall, as well as the depth and duration of tidal inundation (Hassan et al., 1990). Productivity and survival of mangrove communities is directly dependent on fresh water inflow and micro-topographic changes due to deposit of sediments carried by river on tidal currents and in turn influences the condition of vegetation succession (Rahman, 1995).

The Sundarbans receives large volumes of fresh water from inland rivers flowing from the north and of saline water from the tidal incursions from the sea The fresh water is charged with alluvium containing plant nutrients. This together with the salinity of the tidal water is the major factor determining the productivity of the forest ecosystem (Siddiqi, 2001).

At a comparatively recent period, all the rivers were connected with the Ganges. Now only the Baleswar has direct connection and is responsible for fresh water supply to the eastern part of the Sundarbans. A number of rivers namely, the Passur, the Sibsa, the Arpangasia, the Malancha and to a slight extent the Jamuna and the Raimangal have indirect connections and receive the overflow of the Ganges during the rainy season. They also receive a considerable amount of local drainage throughout their long and meandering courses during the monsoon (Siddiqi, 2001).

2.2.1.4 Climatic Condition

The climate of the Sundarbans is humid. Temperature is fairly equable due to the proximity of the sea. Highest temperatures occur in April and May and lowest in December and January. Mean annual maximum and minimum temperatures vary between 30° and 21° C. Mean annual relative humidity varies from 70% to 80%. Humidity is highest in June-October and lowest in the month of February. Annual rainfall in the Sundarbans is in the range of 1640-2000 mm as apparent from the data recorded in the four stations adjacent to the forests. July, August and September are the wettest months and December, January and February the driest. On average, 80% of the total annual rain is received from June to September. Following the monsoon, from November to February, the cool season sets in. From February or March, temperatures begin to rise and in April and May there are usually violent storms. Further storms may also occur in the monsoon and tidal waves can result in widespread inundation. Damage to vegetation and animal life of the forests is not uncommon due to cyclones and tidal surges (Siddiqi, 2001). As stated in different newspapers damage due to cyclone 'Sidr' was extensive.

2.2.1.5 Salinity

In the mangrove ecology, salinity is the dominant ecological factor controlling species distribution and association pattern. Salinity is also a constituent of growth or the rate of growth. Salinity of water is a source of salts (either as nutrients or toxicants) for physiological activity of plants. The survival rate of the mangrove seeds, which are dispersed through the rivers, is also critically governed by salinity of water. A high concentration of salt in the root affects plant growth and maturity in two ways. High levels of salinity can either limit the availability of water by affecting the osmotic gradient or it can increase ionic accumulation within plant tissues at toxic concentration. This can lead to reduction in forest productivity as indicated by following table 2.1.

Table 2.1: Forest productivity and salinity

Blocks	Total merchantable wood (m3/ha)	Soil salinity (ppm)	River salinity (ppm)
4	59.5	4.6	3.4
1	53	7.1	3.4
5B	36.6	8	19
2	4.9	6.1	13.4
3	23.6	9.3	12.5
7	21.6	13.2	21
8	19.5	12	23
5A	18	14	19
6	17	10	21

Source: Chaffey et al., 1985

So there is an optimal salinity range for maximum growth of mangrove species. The optimum salinity tolerance varies from species to species. At salinities higher than the optimum, respiration increases and there is decreased net growth. At lower than the optimum salinity, competitor species better adapted to the conditions gain the upper hand (Snedaker, 1976). At extreme levels mangrove species suffer damage and even mortality. Three ecological zones have been recognized within the Sundarbans area based upon salinity and species composition. These are low, moderate and high saline water zones. Different mangrove species have preference for different levels of salinity for survival and optimal growth. Sundari is the characteristic species of the low saline water zone, Gewa of the moderate saline water zone and Goran is typical of the high saline water zone of the Bangladesh Sundarbans (Siddiqi, 2001). Table 2.2 shows variation in vegetation density varies in the different zones. The characteristics of these three saline zones are discussed below:

2.2.1.5.1 Low saline water zone

Low saline water zone is located in the eastern and northeastern part of the forests. The area receives fresh water supply from the Ganges. The forest floor is comparatively high so the tidal water does not frequently inundate the area. This zone supports the best stands growing up to a height of 15m. In the northeast, the trees are tall and vigorous. Sundari forms pure stands or stands in association with Gewa. In addition to Sundari and Gewa, Passur, Kankra and Baen are also present. Golpata is plentiful and grows most luxuriantly on the bank of rivers and canals. Keora is also found in good proportion. It is a pioneer species and short-lived (Siddiqi, 2001). Following table was prepared from table given in siddiqi, 2001.

Table 2.2: Vegetation density in different saline zones

Species*	Less Saline (%)	Moderately Saline (%)	Strongly Saline (%)
Sundari	52.6	42.9	4.5
Gewa	31.32	31.18	37.5
Keora	22.22	55.56	22.22
Others	47.43	24.36	28.20

* Species with stems dbh 10 cm and above per hectare
Others includes Passur, Dhundul, Kankra and Baen
Source: Extracted from Siddiqi, 2001

2.2.1.5.2 Moderate saline water zone

This occupies the middle portion of the forest. Gewa is the dominant crop. A mixture of Gewa Sundari with varying proportion of Goran and other species are the characteristic of this zone. Sundari decreases towards the west and south. Canopy height is usually about 10m. However, Sundari, Passur, Baen and Dhundul may attain a greater height (Siddiqi, 2001).

2.2.1.5.3 High saline water zone

This occupies the south and western part of the forests and covers a sizeable portion of forest lands. Salinity is higher in the dry season and water salinity is almost that of normal seawater salinity. Soil is hard due to lack of silt deposition. The forest is typically closed under story of Goran having a height of about 4m with the isolated recurrence of keora, Baen, Kankra, Passur, Dhundul and garjan (Siddiqi, 2001).

2.2.2 Biotic Component

2.2.2.1 Producer

These are organisms that use solar energy and inorganic substances to produce organic substances through photosynthesis. Mangrove, algae and phytoplankton are the producers of the Sundarbans.

2.2.2.1.1 Mangrove Plants

The floristic composition of the Sundarbans is rich compared to many other mangroves of the world. Prain (1903a reported in siddiqui, 2001) recorded 334 species of plants belonging to 245 genera and 75 families for the Sundarbans and adjoining areas. Heining (1892 reported in siddiqui, 2001) reported 70 species from 34 families for the entire Sundarbans (India and Bangladesh). Chaffey and Sandom (1985) presented a list of 66 species in the Bangladesh Sundarbans from 37 families. *Heritiera fomes* and *Exocoecaria agallocha* are the principal species. *Heritiera fomes, Heritiera fomes- Excoecaria agallocha, Excoecaria agallocha- Heritiera fomes amd Ceriops decandra- Excoecaria agallocha* forest type cover 21%, 29.7%, 14.8% and 14.46% of the area respectively. Important plants in the Sundarbans are given in table 2.3.

Table 2.3: Important plants in the Sundarbans and their type

Vernacular Name	Scientific Name	Type of Plant
Baen	*Avicennia officinalis*	Tree
Kankra	*Bruguiera sexangula*	Tree
Goran	*Ceriops decandra*	Shrub or small tree
Shingra	*Cynometra ramiflora*	Shrub or small tree
Gewa	*Excoecaria agallocha*	Tree
Sundari	*Heritiera fomes*	Tree
Kripa	*Lumnitzera racemosa*	small tree
Golpata	*Nypa fruticans*	Recumbent palm
Hantal	*Phoenix paludosa*	Thorny palm
Keora	*Sonneratia apatala*	Tree
Dhundul	*Xylocarpus granatum*	Tree
Passur	*Xylocarpus mekongensis*	Tree
Amur	*Amoora cucullata*	Small tree
Bhola	*Hibiscus tiliaceous*	Shrub
Garjan	*Rhizophora mucronata*	Tree with stilt roots

Source: Siddiqi, 2001

The ecological condition of the Indian Sundarbans is to some extent different from the Bangladesh Sundarbans particularly with regard to level of salinity and degree of tidal inundation. This might influence the species difference and abundance (Siddiqi 2001). Some species growing in the Sundarbans are highly useful and of great commercial value. In general, the forest is more closed in the east than in the west. The canopy closure in the east is usually more than 70%, in the middle part is between 30 and more than 70% and in the western part from 30 to less than 70%. There is a decrease in canopy closure in recent years. The vegetation is differentiated into three height classes i.e., 1 (height>15m), 2 (>10m but < 15m), and 3 (>5m but < 10m). The height of the forest is greater in the east. The height decreases as one proceeds towards the west (Siddiqi 2001).

2.2.2.1.2 Algae

Blue green algae, green algae and diatoms act as nitrogen fixing and sulphur reducing agents in alluvial tidal soils. These nitrogen and sulphur rich soils may be utilized by higher groups of plants. Several of these algae normally grow on ill consolidated saline humus soils, which are hydrophilic and biologically very active. These algal floras which decompose to well consolidated soil, furthermore accelerates the growth of chlorophyceae group of algae.

2.2.2.2 **Consumers**

These are the organisms which are dependant upon producers for food, as they can not produce their own. The consumers of the Sundarbans can be divided into four groups. These are primary consumers, secondary consumers, omnivores and detritus feeders. The fauna in the Sundarbans is rich and varied. However, in recent decades several important animals have disappeared from the area for good. Many more are endangered or in a vulnerable condition. The fauna of the Sundarbans is summarized below.

2.2.2.2.1 Mammals

About 50 species of mammals are reported from the Sundarbans. Some important animals are Tiger (Panthera tigris), Spotted Deer (Axis axis), wild Boar (Sus scrofa), Rhesus Macaque (Macaca mulatta) and otter (Lutra perspicillata). The Sundarbans is one of the biggest reserves of the Royal Bengal Tiger.

2.2.2.2.2 Birds

A total of about 300 species of birds are reported from the Sundarbans. Nine species of kingfishers are available in the forest. Herons, egrets, storks, sandpipers, curlew and numerous other waders are seen along the muddy banks, which become exposed during the dry season. Apart from those species particularly associated with the sea and wetland, there is also a considerable variety of forest birds such as woodpeckers, barbets, shrikes, drongos, mynas, minivets, babblers and many others (Blower, 1985).

2.2.2.2.3 Reptiles

As many as 50 species of reptiles have been reported. The largest reptile of the Sundarbans is the Estuarine Crocodile (Crocodylusprosus). Its population has drastically declined. A Good number of snakes occur in the Sundarbans.

2.2.2.2.4 Amphibians

Eight species of amphibians have been recorded from the Sundarbans. These include tree frog, bullfrog, green frog, common toad and others (Rashid et al., 1994).

2.2.2.2.5 Fishes, Crustaceans and Molluscs

The fishery resources consist of fish, molluscs and crustaceans. The Sundarbans water supports 53 species of pelagic fish belonging to 27 families, 124 species of demersal fish belonging to 49 families. Besides, 24 species of shrimps belonging to 5 families, 7 species of crabs belonging to 3 families, 2 species of gastropods, 6 species of pelecypods, 8 species of locust lobster and 3 species of turtles are reported from the Sundarbans (Archarya and Kamal, 1994). In the eastern part of the Sundarbans the salinity level is low. Some species that are only found in this low salinity zone are the fishes *Pangasius panagasius, Hilsa ilisha, Lates calcariger* and *Macrobrachium rosentbergii*. The Sundarbans is the nursery ground for many important species like *Penaeus monodon* and *Metapenaeus monocepros* which feed in the brackish water mangrove forest until they are adult, at which time they leave for the open area.

2.3 Functions of Sundarbans Ecosystem

The two main functions of a mangrove ecosystem are the nutrient cycle or the exchange of food from one trophic level to the next and energy flow within the various trophic levels. The two major food chains in terms of nutrient recycling in a mangrove are the phytoplankton food chain (moves from green plants to other organisms at various trophic levels moving from lower to higher levels) and the detritus food chain (starts from detritus and moves on to other organisms at the higher level).

The energy flow is also linked to the food chain but differs from it in that it is unidirectional facilitating transfer of energy from producers to consumers (Figure 2.2). As energy flows from producer to herbivore to carnivore, the organisms at the highest level of food chain receive only 5-30% of the original input. The remaining 80-95% is utilized for respiration and lost as heat at various intermediated levels.

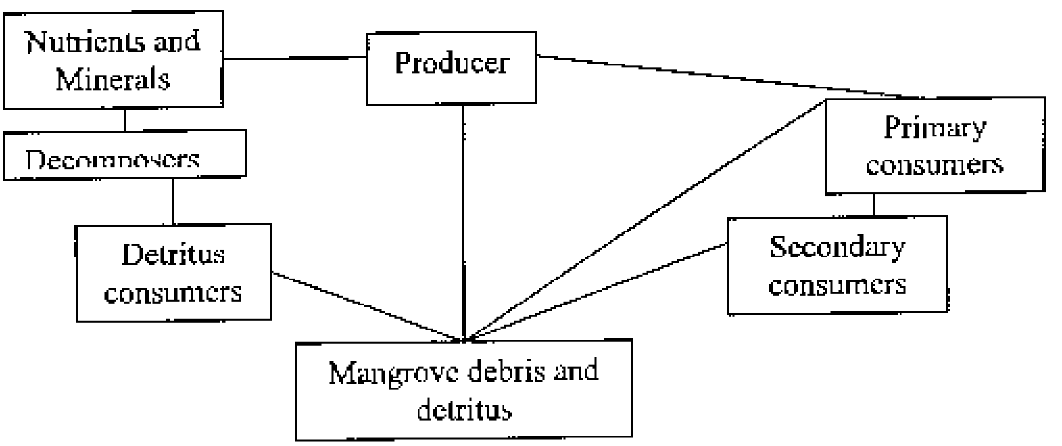


Figure 2.2: Pathway of the principal flow of energy

Source: Sherina, 1999

2.4 Plant ecology of the Sundarbans

With the exception of Sundari, Keora and Baen, the natural mangroves of the Sundarbans are halophytic two storied groves rarely outstripping a height of 10 meters. At the community level, salinity. soil structure, water tolerance and specific chemical and climatic thresholds influence the composition and apportioning of species. At individual levels, these factors also influence species affiliation and organization, ecological fragmentation, densities, life sequence and growth. A saline environment is required for stable mangrove ecosystem as many species are less competitive under non-saline condition (Lugo AE, 1980). However, hyper salinity can adversely affect mangroves in a given site.

The most remarkable feature of mangrove plants is the different types of above ground root systems which serve the mechanical purpose of anchoring the trees in the soft and mobile substratum and function as respiratory tracts for the plants. Some of the more common ones found in the SRF are aerial roots proper, buttress roots, pneumatophores and knee roots.

A spongy tissue called aerenchyma usually coats these roots to facilitate gaseous interchange between the outer layers and the inner tissues. Lenticels on the tree bark are also designed for admitting air. Many plants are viviparous in the sense that seeds germinated growing some embryonic roots while still attached to the mother plant, taking root immediately after they are dropped. This is to ensure regeneration and reduce seed death by contact with excessively salty water and oxygen depleted soil. In order to regulate salinity internally, some species have salt secreting glands which leave a powdery salt residue on the undersurface of leaves, while other species have salt excluding tissues at the root level. The different species also have to adapt to other difficult situations such as frequently low pH and anoxic conditions of the coastal soil sediments.

Ecologically speaking, majority of the mangrove plant species are salinity tolerant if not exclusively halophytes. Different morphological and physiological features and mechanisms determine salinity tolerance among various species (Sherina, 1999). These can be broadly grouped into three main categories:

- Obstruction of sodium chloride and other salts infiltration at root level
- Secretion of excess salts by special salt glands at the leaf level
- Accumulation and immobilization of salts at different tissue levels

2.5 Succession in the Sundarbans

Succession refers to orderly change in the communities of species. As mangrove ecosystem is highly dynamic, changes in vegetation are remarkable. However, plant succession is gradual, where others replace on community till a climax stage is attained. A number of factors are responsible for the ecological succession in the Sundarbans. These include (a) Geomorphologic change (b) Level of salinity in water/soil (c) Degree of tidal inundation (d) Intensity of sunlight or shade (e) Silvicultural characteristics of species (f) Impact of animals etc (Siddiqi, 2001).

Geomorphologic changes in the mangrove environment are rapid. Surfacing of new lands, erosion and compensatory accretion along the rivers and canal banks are regular phenomena. There is loss of established stands of valuable tree crop and non-timber forest produce through erosion. Side by side, with the surfacing of new lands, the process of plant succession is initiated. Grasses and sedges become established first. They are subsequently replaced by various species of shrubs and trees. The pioneer tree species e.g., *Sonneratia apetala* or *Avicennia officinalis*, prefer soft soil and new lands for colonization. Growth rate of the species is quite fast. Within only two years profuse growth of aerial roots is noticed. It may be noted that longer time is required for the development of aerial roots for the species that appear at later stage. Changes in the vegetation community continue to occur till the final or climax stage is attained. Both *H. fomes* and *E. agallocha*, the dominant species of the Sundarbans grow on apparently stable lands. The mangroves being a highly dynamic ecosystem, replacement of one community by another over time is remarkable and understandable by visual observations (Siddiqi, 2001).

The Sundarbans supports a diversified flora. Different species have different requirements for survival, establishment and optimal growth. Depth, duration and frequency of tidal inundation are important factors for the occupation of a site by a particular species. *Sonneratia apetala*, being a pioneer species, thrives under higher levels and duration of inundation. *Heritiera fomes* grows well in less inundated areas. In fact, best stands of *H.fomes* are found where the forest floor remains dry for at least 2 to 3 months. There is gradual rise of forest floor, in other words lowering of inundation over time following steady deposition of silt in different places of the forests. This influences the succession. Under the *S. apetala* stand, regeneration of this species does not occur. Naturally the area is replaced by another species. Generally species that exist at later stage require lower inundation in the Sundarbans ecosystem. Regular tidal inundation is not a pre-requisite for all the mangroves (Siddiqi, 2001).

Different species have different levels of light requirement for optimal growth. The pioneer species e.g., *S. apetala* and *A. officinalis* are strong light demanding. So, they need open lands for colonization. There are also non-productive areas either in the form of raised lands or depressions. In the depressions, mangrove regeneration cannot survive due to water logging. Contrary to this, some areas in the northeastern part have become so raised due to silt deposition that mangrove regeneration is not found in those areas for future stocking (Siddiqi, 2001).

With regard to salinity, it is believed that the salinity of water and groundwater has increased in the lower levels following diversion of the Ganges water flow upstream at Farakka. Salinity plays an important role in the distribution and productivity of species. Under optimal range of salinity, a species shows best performance other factors remaining favorable. In fact, species zonation in the Sundarbans is considerably dependent on the levels of soil salinity. Animals also play an important role in the succession of species (Siddiqi, 2001).

There is no uniform pattern in the succession for the entire Sundarbans ecosystem. It proceeds differently in various parts of the forests. Succession is the outcome of the interaction of a number of factors. Sufficient observations in this direction have not been made. Levels of salinity and elevation of the forest floor appear to be the determining factors driving the succession processes and pattern (Siddiqi, 2001).

2.6 Regeneration in the Sundarbans

The Sundarbans is absolutely dependent on natural regeneration for future stocking and its continuity. Natural regeneration refers to renewal of a forest crop by natural means, as opposed to artificial regeneration by mean of planting or sowing. A number of factors contribute to the productivity of a forest. And adequate natural regeneration is one of those factors. However, regeneration of forests is a common problem in most of the mangroves of the world (Siddiqi, 1996). Natural regeneration takes place successfully under a variety of favorable abiotic and biotic conditions.

Natural regeneration on tidal forests is usually adequate and can be established by the selection-cum improvement system. Sometimes, however, it is difficult to obtain adequate seedlings of a particular species in a particular locality due to constant changes in edaphic and other environmental factors (Champion et al., 1965). Shafi

(1982b) claimed that regeneration rates had decreased by as much as 100% in 1981 as compared to the levels of 1959, while Rahman (1990a) stated that regeneration status of *Heritiera fomes* remained stable and satisfactory over the period from 1970 to 1986. However, a comparison of results of two successive forest inventories (1959 and 1983) indicates that regeneration of the principal species has been low (Anon, 1989).

While viviparous species such as *Rhizophora* and *Avicennia* regenerate under the parent trees or on soft mud, the principal species of the Sundarbans, namely *Heritiera fomes* and *Excoecaria agallocha* are non-viviparous and the buoyant fruits are disseminated by water. Height of ground above mean sea level, distance from the sea, depth and frequency of inundation and degree of salinity cause succession changes and thus alter the pattern of the vegetation. Tidal currents, which are generally proportional to the tidal range, play an important role in the transport of mangrove seedlings.

Excoeraria agallocha and *H. fomes* are dominant species in the Sundarbans and it is natural to have a higher proportion of seedlings of these species. However, the relative proportion of *E. agallocha* is very high considering the fact that *H. fomes* constitutes about 65% of merchantable timber. Shafi (1982) noted that the proportions of seedlings of *H. fomes, E. agallocha* and other species were 15, 77, and 8 percent respectively for Compartment No. 3 of the forests and concluded that *H. fomes* was in the process of replacement by *E. agallocha*. Chaffey et al. (1985) reported that regeneration (height<1.3m) for *H. fomes, E. agallocha* and other species were 41, 45 and 14 percent respectively.

A significant decrease in seedling recruitment is noticed with an increase in the level of salinity (Siddiqi, 2001). This is independently true for *H. fomes* and *E. agallocha*. Both species prefer a level of lower salinity. Salinity plays a vital role in the distribution of species in the Sundarbans. Germination of seeds of some halophytes is linked to salinity levels (Siddiqi et al., 1989). Variation in yearly seedling recruitment among the three salinity zones is significant (Siddiqi, 2001).

Seedling survival is recorded for a period of 33 months since their appearance. Greater proportion of seedlings disappears during this period. Only about 17% seedlings of *H. fomes* in low saline and 2 % in moderate saline water zones survive at the end of 33 months with no survival in the high saline water zone. The survival rates of *E. agallocha* in the low and high saline water zones are about 0.5% and 14% respectively with no survival in the moderate saline water zone. With regard to other species combined, 6 % and 0.5% seedlings survive in low and moderate saline water zones respectively, while in the high saline water zone, all the seedlings disappear within 3 months. Seedling half-life for *H fomes* in low, moderately and high saline water zones is 13.7, 8.8 and 6.3 months respectively and for *E. agallocha* it is 8, 9.2, 11.6 months respectively. For species other that *H. fomes* and *E. agallocha*, half-line is 10.5, 6.3, and 6.7 months respectively in low, moderately and high saline water zones.

2.7 Impact of Farakka barrage on Sundarbans

In 1974 India built a barrage on the Ganges at Farakka in order to divert water for its own use. The water is diverted to the Hoogley River via a 26-mile long feeder canal. The unilateral and disproportionate diversion of the Ganges since that time has caused a dangerous reduction in the amount of sediment and water flow of the Ganges in Bangladesh. (Khalequzzaman, 1993). One of the changes taking place in the Sundarban ecosystem is an increase in salinity. This is a result of a reduced level of fresh water flowing through the Sundarbans into the Bay of Bengal. When the barrage is closed during the dry season, the water level in the Ganges in Bangladesh is so low that almost no water flows through the Gorai. As a result of the diminished flow, the intrusion of sea water in the southern part of the country has become so pronounced that the salinity has gone up more than sixty times than the pre-Farakka times. Thus soils are affected by a increasing level of salinity which in turn negatively influences the natural regeneration of the forest. The increase of salinity in such magnitude has significantly altered the ecology of the region. Already the largest mangrove forest of the world, the Sunderban is being depleted. (Ahmad, undated).

The increase in salinity is thought to be one of the main causes of the recent top-dying of the Sundri, the tree that characterizes the Sundarbans. As the sundri struggle in the changing conditions of the Sundarbans, gewa, which is a true mangrove, seems to be taking over from the sundri in some areas. As table 2.4 shows, relative to sundri, gewa has become more predominant than in the past. The volume of sundri has decreased faster than that of gewa.

Table 2.4: Changes in volumes of forest types in Sundarbans 1959-83

Forest type	Estimated % of the Sundarbans in 1959	Estimated % of the Sundarbans in 1983
Pure Sundari	31.6	21.0
Sundari-Gewa	24.4	29.7
Gewa-Sundari	15.6	14.8

Source: Galappatti, 1993

The direction of this decline is closely related to the reduced flow of freshwater though the rivers that passes through the forest, due to human intervention (Hussain *et al*, 1994). Following figure shows the impact of Farakka barrage on Sundarbans.

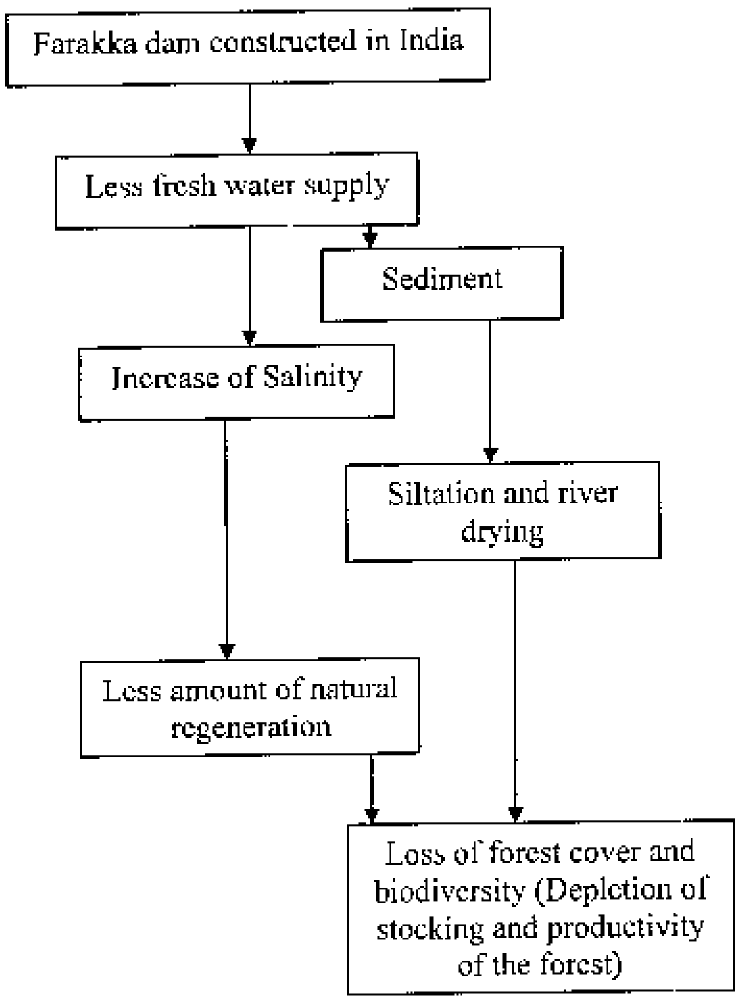


Figure 2.3: Summary of impact of Farakka Barrage

Source: Extracted from figure 5.4 in Akhter, 2006

The perception in Bangladesh is that the increase in salinity in the Sundarbans is largely a result of the construction of the Farakka Barrage. The forest showed evidence of recent extensive damage in localized areas during a visit to Sundarbans by a team to verify the extent of deterioration and to evaluate causes of deterioration reported by Bangladesh government (Crow, 1995). Three causes of deterioration were cited. These are insufficient fresh water, increased salinity and chlorinity and insufficient nutrients. The variation in the volume which can be harvested from each acre of forest in from 1,500 cubic feet, in the best quality (Class I) forest in the fresh water zone, to 20 cubic feet in the worst forest (Class III) in the saline zone. Special Studies team provided a calculation that all Class I and II forests would be replaced by Class III. So the Sundarbans has already been degraded by Farakka barrage and climate change induced sea level rise will be a further threat to this world largest mangrove forest (Crow, 1995).

CHAPTER THREE

CLIMATE CHANGE AND SEA LEVEL RISE

3.1 Climate Change and Sea Level Rise

The Intergovernmental Panel on Climate Change (IPCC), established in 1988 under World Meteorological Organization (WMO) and United Nations Environment Program (UNEP), published a number of reports on global context of climate change and the potential sea level rise.

IPCC (1990) estimated 107 cm sea level rise by the year 2100. For the last several years, the most widely cited estimates for future sea level rise have been those reported by IPCC (1990) because all climatologists agreed to deal with climate change considering 1990 as base year. Environmental Protection Agency (EPA, 1995) developed probability-based projections that can be added to local tide-gauge trends to estimate future sea level at particular locations. It uses the same models employed by previous assessments of sea level rise. The key coefficients in those models are based on subjective probability distributions supplied by a cross-section of climatologists, oceanographers, and glaciologists. The experts who assisted this effort were mostly authors of previous assessments by the National Academy of Sciences and the Intergovernmental Panel on Climate Change (IPCC). The estimates of sea level rise are somewhat lower than those published by previous IPCC assessments, primarily because of lower temperature projections. This IPCC report estimates that global temperatures are most likely to rise 1°C by the year 2050 and 2°C by the year 2100, that there is a 10 percent chance that temperatures will rise more than 4°C in the next century, and a 90 percent chance that they will rise by at least the 0.6°C warming of the last century. EPA temperature estimates are lower because (a) they assume lower concentrations of carbon dioxide; (b) they include the cooling effects of sulfates and stratospheric ozone depletion; and (c) their panel of experts included a scientist who doubts that greenhouse gases will substantially increase global temperatures (EPA, 1995).

EPA compares their projections for the year 2100 with those of IPCC (1990). Their draft results, however, show that the median sea level estimate would have been lower than the IPCC (1990) estimate even if their temperature estimates had been as high as those of IPCC (1990). The draft and IPCC (1990) both assumed a warming of about 3°C over the 1990–2100 period, but the draft projected a sea level contribution of only 51 cm. About half of this downward revision (compared with IPCC) resulted from lower thermal expansion estimates, which stemmed from changes in ocean modeling assumptions. EPA nonlinear model of the Greenland contribution, combined with explicitly considering increased precipitation, resulted in a much lower estimate of this ice sheet's sensitivity to a warming of a few degrees (C). Finally, we incorporated recent work suggesting that small glaciers are less sensitive to global temperatures than previously thought.

The range of sea level rise presented in the Second Assessment Report (SAR) was 0.13 to 0.94 m (IPCC, 1996). According to the Third Assessment Report (TAR) of IPCC (2001), mean sea level will continue to rise throughout the 21st century with a likelihood of rise to the tune of 9 to 88 cm by the year 2100. The main contributions to this sea level rise are:

- ◊ a thermal expansion of 0.11 to 0.43 m, accelerating through the 21st century;
- ◊ a glacier contribution of 0.01 to 0.23 m;
- ◊ a Greenland contribution of −0.02 to 0.09 m; and
- ◊ an Antarctic contribution of −0.17 to +0.02 m.

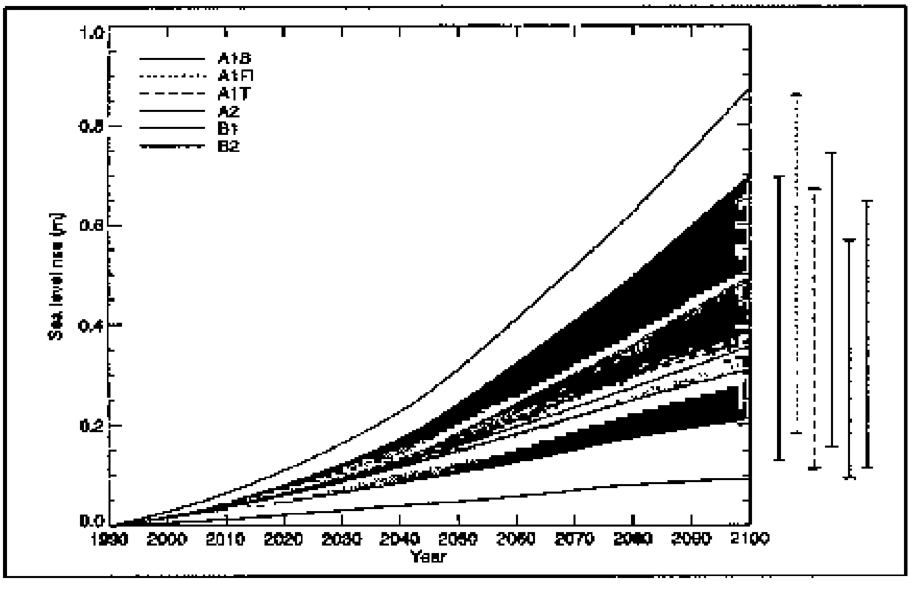


Figure 3.1: Predicted Global Sea Level Rise: 1990 to 2100 (IPCC, 2001)

For the full set of Special Report on Emission Scenarios (SRES), a sea level rise of 0.09 to 0.88 m is projected for 1990 to 2100 (Figure 3.1), primarily from thermal expansion and loss of mass from glaciers and ice caps. The central value is 0.48 m, which corresponds to an average rate of about two to four times the rate over the 20th century. Despite higher temperature change projections in the third assessment, the sea level projections are slightly lower, primarily due to the use of improved models, which gave a smaller contribution from glaciers and ice sheets. Scenarios in figure 3.1 are alternative images of how the future might unfold and are an appropriate tool with which to analyse how driving forces may influence future emission outcomes and to assess the associated uncertainties. They assist in climate change analysis, including climate modeling and the assessment of impacts, adaptation, and mitigation. Four different narrative storylines were developed to describe consistently the relationships between emission driving forces and their evolution. Four qualitative storylines yield four sets of scenarios called "families": A1, A2, B1, and B2. Altogether 40 SRES scenarios have been developed by six modeling teams. All are equally valid with no assigned probabilities of occurrence. The set of scenarios consists of six scenario groups drawn from the four families: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments of energy technologies. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability (IPCC, 2000). Following table shows the characteristics of these scenarios.

Table 3.1: Characteristics of the scenarios

Characteristics	**Scenarios**					
	A1FI	A1B	A1T	A2	B1	B2
Population growth	low	low	low	high	low	medium
GDP growth	very high	very high	very high	medium	high	medium
Energy use	very high	very high	high	high	low	medium
Land- use changes	low-medium	low	low	medium/high	high	medium
Resource availability	high	medium	medium	low	low	medium
Pace and direction of technological	rapid	rapid	rapid	slow	medium	medium
change favoring	coal ,oil & gas	balanced	non-fossils	regional	efficiency & dematerialization	"dynamics as usual"

Source: IPCC, 2000 (Collected from internet)

The IPCC Fourth Assessment Report (IPCC, 2007) projects a global sea-level rise of between 18 and 59 cm in 2095, relative to 1990 sea levels. These numbers seem significantly less than the range projected in the Third Assessment Report. This narrower range reflects an improved understanding of some processes that influence sea level (e.g. ocean heat content). However, the report acknowledges that other unaccounted for processes make the high end projection conservative. Due to current uncertainties, the IPCC notes that the following factors are not fully reflected in the current generation of IPCC models:

• Evidence suggests that warming tends to reduce land and ocean uptake of atmospheric carbon dioxide, increasing the portion of man-made emissions that remain in the atmosphere. This would result in further warming and cause additional sea-level rise.

• Observations record that melt water can run down fissures and lubricate the bottom of ice sheets, resulting in faster ice flow and the calving of large ice masses into the ocean. This process directly contributes to sea level rise.

The sea level projections in the fourth assessment include observed contributions from the Greenland and Antarctic ice sheets between 1992 and 2003, but exclude future changes in ice sheet behavior because of limited understanding of how to quantify potential changes from this source.

3.2 Probability of Global Sea Level Rise

The EPA (1995) has calculated the probability of different sea level rise for global aspect. The main reason to estimate probability distributions is that decision makers need this information. If the published literature does not provide a probability distribution, then engineers, economists, and decision makers must implicitly or explicitly develop their own estimates, which are likely to be less accurate than the results of expert panels. The EPA presents the methods and results of a two-part effort to estimate the probability distribution of future sea level rise implied by the expectations of approximately twenty climate researchers.

In the first phase, EPA developed a simplified model for estimating sea level rise as a function of thirty-five major uncertainties, derived probability distributions for each parameter from the existing literature, and conducted a Monte Carlo experiment using 10,000 simulations.

Figure 3.2 illustrates the relationships between the various models they used and developed to project sea level. Given the emissions projections, they used existing gas-cycle models to project atmospheric concentrations and the resulting radiative forcing. They developed simple models of how upwelling may change, based on the results of three-dimensional models. They used an existing model to project the resulting temperature and thermal expansion estimates. They devised simple models for projecting changes in polar climate and Antarctic water temperatures, as well as the impact of water temperatures on ice-shelf melting. They developed a simple model of a possible fast-but-stable impact of ice-shelf melting on the Antarctic ice sheet contribution, while using existing models to simulate an unstable response and a stable but- slow response. They developed a simple model of how the runoff elevation in Greenland responds to climate change, but used existing models to project the actual contribution of the Greenland ice sheet to sea level. They used an existing model to estimate the impact of small glaciers on sea level. To estimate relative sea level at a specific location, one can combine tidal-gauge observations with the estimated glacial and thermal expansion contributions.

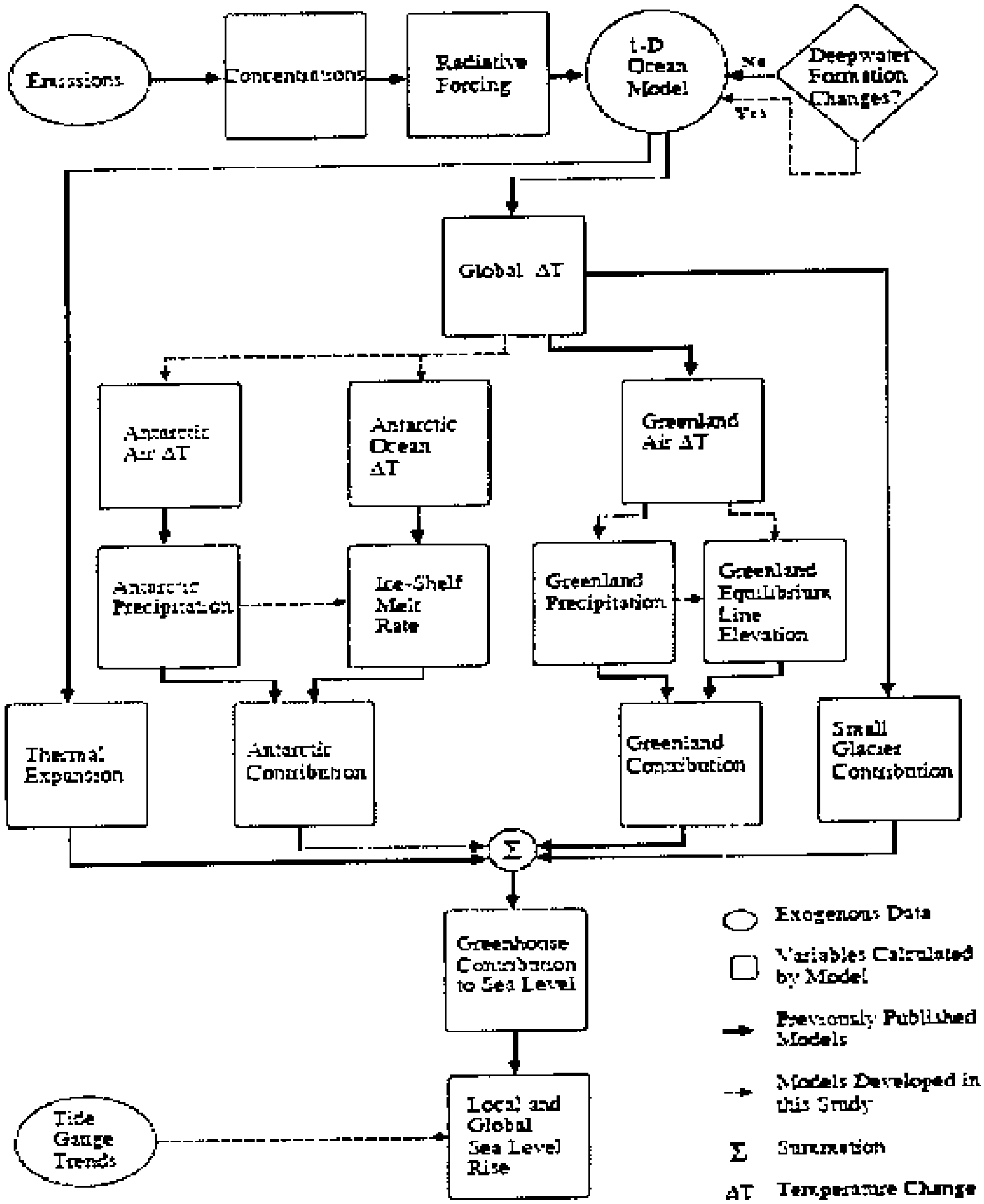


Figure 3.2: Relationship between the various models used to project sea level

In the second phase of this study, they circulated the draft report to a "Delphic" panel of experts— approximately two dozen climatologists and glaciologists In each case, EPA directed their attention to specific chapters, and asked them to review EPA's assumptions, and suggest the assumptions that they would have used had they conducted the analysis. A few of the researchers provided comments without probability distributions; but twenty of the researchers did give EPA their best assessment of the values of the model coefficients most closely related to their own research. Moreover, five researchers even provided alternative model specifications.

Given the probability distributions specified by EPA's Delphic panel of experts, they reran the 10,000 simulations. EPA summarized the reviewer changes and presents the results of the Delphic Monte Carlo experiment. The meaning of the term "Monte Carlo analysis" has evolved. Originally, the term referred to the use of many trials to numerically approximate a probability distribution—as opposed to analytically solving the equations. As the use of Monte Carlo techniques evolved, mathematicians have shown that the original approach of randomly selecting the input values is not as efficient as nonrandom sampling approaches such as Latin Hypercube. Although Latin Hypercube is a Monte Carlo technique in the original sense of the word, many authors use the term "Monte Carlo analysis" to refer only to exercises that employ totally random samples. EPA's overall approach is as follows:

$$SL = M (a, b, c, ...),$$

Where SL is sea level, M is the model, and a, b, c,... are unknown coefficients. They assume that the model would be true if they knew the actual values of the coefficients. But because no one knows their precise values, EPA must rely on estimates, each of which is uncertain. Based on available estimates and reasonable assumptions about the shapes of the distributions, one can estimate a probability density function for each coefficient. In the simple case, where $SL= aX + bY$ and they have data on X and Y, probability theory provides them with a simple formula for estimating the distribution of SL. Projections of sea level rise, however, are nonlinear: Even simple models must multiply uncertain temperatures by uncertain melting-sensitivity parameters, and most models are far more complex. Under these circumstances, solving for the distribution is too complicated to be practical. EPA developed Normalized Sea Level Projection. Table 3.2 shows the cumulative probability of sea level rise.

Table no. 3.2: Cumulative probability of sea level rise

Normalized Sea Level Projections, Compared with 1990 Levels (cm)

	Sea Level Projection by Year:					
Cumulative Probability	2025	2050	2075	2100	2150	2200
1	−10	−16	−21	−24	−32	−40
5	−3	−4	−5	−6	−7	−8
10	−1	−1	0	1	3	5
20	1	3	6	10	16	23
30	3	6	10	16	26	37
40	4	8	14	20	35	51
50	5	10	17	25	43	64
60	6	13	21	30	53	78
70	8	15	24	36	65	98
80	9	18	29	44	80	125
90	12	23	37	55	106	174
95	14	27	43	66	134	231
97.5	17	31	50	78	167	296
99	19	35	57	92	210	402

3.3 Sea Level Rise Scenarios for Bangladesh

Bangladesh has a humid, warm, tropical climate influenced primarily by monsoon and partly by pre-monsoon and post-monsoon circulations. The south-west monsoon originates over the Indian Ocean and carries warm, moist, and unstable air. The monsoon has its onset during the first week of June and ends in the first week of October, with some inter-annual variability in dates. Besides monsoon, the easterly trade winds are also active, providing warm and relatively drier circulation.

A very brief introduction of climate change and sea level rise scenarios for Bangladesh will be made here in respect of temperature, evaporation and precipitation. There are various estimates of temperature rise in Bangladesh. One estimate (e.g. Ahmed and Alam, 1999) is that the average increase in temperature in Bangladesh would be 1.3°C and 2.6°C by the year 2030 and 2075 respectively with respect to the base year 1990. The seasonal variation of temperature will be more in winter than in summer. Karmakar and Shrestha (2000), using the 1961-1990 data for Bangladesh, show that annual mean maximum temperature will increase by 0.40°C and 0.73°C by the years 2050 and 2100 respectively. The mean minimum temperature will correspondingly rise by 0.04°C and 0.08°C. But the mean annual temperature will increase by 0.22°C and 0.41°C respectively. Global warming will enhance evaporation and change precipitation pattern. Ahmed and Alam (1999) show that the average evaporation in Bangladesh would remain almost nnchanged in 2030 but would be slightly higher in 2075 with respect to the base year 1990. In 2030, precipitation will increase slightly in winter and moderately in summer But in 2075, evaporation would be much higher in winter. There would be more precipitation during the monsoon period and precipitation would decrease in winter. This means that increased rainfall would lead to more severe flood situation in summer, and low precipitation and higher temperature in winter will cause more drought like conditions in winter. On the other hand, in 2075, the change will be very pronounced in monsoon while there would not be any noticeable precipitation in winter. Karmakar and Shrestha (2000) predict that annual total rainfall over Bangladesh is likely to increase by 295.94 mm and 542.55 mm by 2050 and 2100 respectively. Global warming will increase the intensity of south-west monsoon. A project on Climate And Sea Level Change in part of the Indian Sub-Continent (CLASIC) was taken to examine the implications of change in climate and sea level on water resources availability and coastal flooding in part of the Indian sub-continent with particular reference to Bangladesh (CLASIC, 2007). The project studied the impacts of climate change over the Indian sub-continent on three vulnerable areas: (i) water resources in Bangladesh, (ii) to a lesser extent, upon possible fluvial flooding impacts on Bangladesh, and finally (iii) upon storm surge impacts on coastal flooding in the Bay of Bengal. Predicted impacts of climate change on river flows indicate possibility of substantial changes in future river flow in Bangladesh. According to this study, north-west and south-west regions are likely to be worst sufferer (CLASIC, 2007).

Various scenarios have been predicted about SLR in Bangladesh. Two estimates of potential future SLR for Bangladesh are 0.3-1.5m and 0.30-0.50m for 2050 (DOE, 1993). Mahtab (1989) mentioned a scenario of a one meter change in sea level by the middle of the 21st century; it combines a 90 cm (average of 30 cm and 150 cm) rise in sea level and about 10 cm local rise due to subsidence. Several factors such as non-uniform rise in temperature, accelerated rise in temperature, geological subsidence and sedimentation may influence this rate. (Singh, et al. 2000) shows that mean tidal level at Hiron point, Char Changa and Cox's Bazar is showing an increase of 4.0 mm/yr, 6.0 mm/yr and 7.8 mm/yr respectively, which is much higher than the global rate. This study has used 22 years historical tidal data of these three coastal stations. Variation among the stations has also been found for these three stations. Though only 22 years historical data are not enough to ensure, table 3.3 represents the trend of tidal levels in these stations.

Table 3.3: Trend of tidal level in three coastal stations

Tidal Station	Region	Latitude (N)	Longitude (E)	Datum (m)	Trend (mm/year)
Hiron Point	Western	$21^0 48'$	$89^0 28'$	3.784	4.0
Char Changa	Central	$22^0 08'$	$91^0 06'$	4.996	6.0
Cox's Bazar	Eastern	$21^0 26'$	$91^0 59'$	4.836	7.8

Source: SMRC, No. 3

The low-lying topography of the coastal landforms in Bangladesh suggests that a change in sea level can have catastrophic impacts and increase vulnerability significantly. The GBM delta is morphologically highly dynamic and the coastal lands are simultaneously subject to accretion and tectonic subsidence (Huq *et. al.*, 1996). Compaction of sediment may also play a role in defining net change in sea level along the coastal zone due to the fact that the landform is constituted by sediment decomposition. Lacking more specific information, if one assumes that sediment loading cancels out the effects of compaction and subsidence, then the net sea-level rise can be assumed to be close to the global average as projected by the IPCC.

The Government of Bangladesh has prepared an action plan for adaptation to climate change under the National Adaptation Program of Action (NAPA, 2005) program. The likely climate change and sea level rise scenarios, which were selected for developing options for adaptation of climate changes, are shown in Table 3.4.

Table 3.4: Climate Change Scenarios Considered in Bangladesh NAPA Project

Year	Temperature Change (°C) Mean			Precipitation Change (%) Mean			Sea Level Rise (cm)		
	Annual	DJF	JJA	Annual	DJF	JJA	IPCC (Upper range)	SMRC	NAPA
2030	1	1.1	0.8	5	-2	6	14	18	14
2050	1.4	1.6	1.1	6	-5	8	32	30	32
2100	2.4	2.7	1.9	10	-10	12	88	60	88

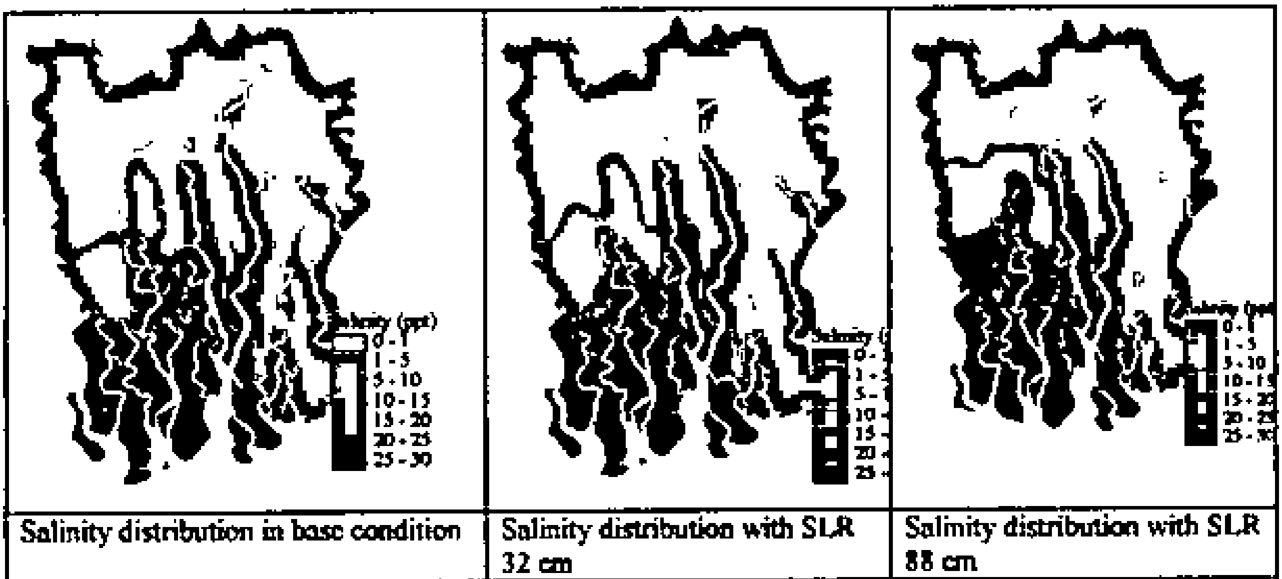
Note: DJF= December- January February (Source: Adopted from IPCC 2001, SAMC Report 1999, OECD Report 2003), JJA= June-July-August, SMRC= SAARC Meteorological Research Center

3.4 Sea Level Rise and Salinity

Due to the SLR the salinity front will be moved toward the inland if the fresh water flow from the river remains constant. Reduced freshwater flows coupled with sea-level rise would consequently further enhance the dry season salinity levels in the Sundarbans. As a response to reduced flow regime, the salinity front would penetrate inland both inside the forest areas and in the entire south-western areas of the country. Similar ingress of salinity is also expected on the Indian side of the Sundarbans (OECD, 2003). It can be simply presumed that, with the SLR the downstream will rise and that will move the salinity front towards the inland. This will cause increase in salinity in terms of intensity and area in both surface water and groundwater.

For the base condition, the salinity concentration has been prepared and area statistics under different ranges of salinity has been estimated by a study completed by CEGIS (2006). CEGIS used model to define present and future distribution of salinity under different sea level rise scenarios. A combination of two-dimensional and one-dimensional model of Bay of Bengal and Southwest region of Bangladesh using MIKE21 and MIKE11 software, developed by Danish Hydraulic Institute (DHI), was applied for defining the base condition and scenarios. The existing calibrated and validated models have been used for this study with latest available data to simulate the hydrodynamic conditions for different sea level rise scenarios. The two-dimensional model of the Bay of Bengal describes the flow, water level and sediment transport processes in the Bay. The result of two-dimensional Bay of Bengal model was used as the downstream boundary condition for the one-dimensional southwest regional model.

In the salinity model, constant salinity boundary was used for simulation for different sea level rise conditions. To find the salinity boundary for different SLRs, first 2D Bay of Bengal model was run for different sea level rise scenarios together with the base scenario. Then the results obtained were analyzed to see the trend of increase of salinity from base condiion to different SLR scenarios. The increased amount of salinity for different SLR conditions was added to the available existing observed maximum salinity to get the respective downstream constant salinity boundary. Then the salinity maps for different SLRs were prepared for the assessment of impacts. The movement of the salinity front can be assessed from Figure 3.3.



Salinity distribution in base condition	Salinity distribution with SLR 32 cm	Salinity distribution with SLR 88 cm

Condition	Salinity (ppt)						
	0-1 ppt	1-5 ppt	5-10 ppt	10-15 ppt	15-20 ppt	20-25 ppt	> 25 ppt
Base condition	10.8%	16.2%	19.1%	20.9%	15.9%	12.6%	4.5%
SLR 32 cm	9.2%	17.8%	18.0%	18.6%	15.6%	15.7%	5.0%
SLR 88 cm	4.0%	21.0%	17.8%	15.6%	14.9%	17.9%	8.8%

Source: CEGIS, 2005

Figure 3.3: Salinity distribution in different scenario

3.5 Vulnerability of the Sundarbans to SLR

As a result of salinity intrusion, many mangrove species may be threatened. According to a number of studies available on the Sundarbans (Karim, 1994; Siddiqi, 1994), complex forest processes such as the natural regeneration of vegetation and forest succession also depend on salinity regime. 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). For example, the freshwater loving Sundari is projected to decline or disappear entirely under climate change. Areas with best quality standing timber 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. With such a dramatic series of anticipated changes in forest vegetation under climate change, the productivity of the forest would be severely constrained. Chaffey *et al.* (1985) demonstrated that, total merchantable wood volume per unit area of forest land would decline with increasing soil and river salinity. Preliminary estimates suggested that, disappearance of oligohaline areas combined with decreasing mesohaline areas would result into over 50% loss of merchantable wood from the Sundarbans (Ahmed *et al.*, 1998). Increase in salinity in the Indian side of the forest would have compounding effect to existing poor productivity of the forest.

Since the composition of vegetation has profound effect on distribution of forest fauna, a change in forest succession would in turn affect the long-term sustainability of the ecosystem. Considering the timeframe of such changes and the land-use patterns inland, it is highly unlikely that forest species would have sufficient time or room to migrate inland in response to these changes (OECD, 2003).

Chapter Four

Methodology

4.1 Methodological Framework

Data from different sources were collected. Different methods started from literature review to vulnerability assessment were used to assess ecological risk. The figure 4.1 represents methodological framework, which was followed in this study.

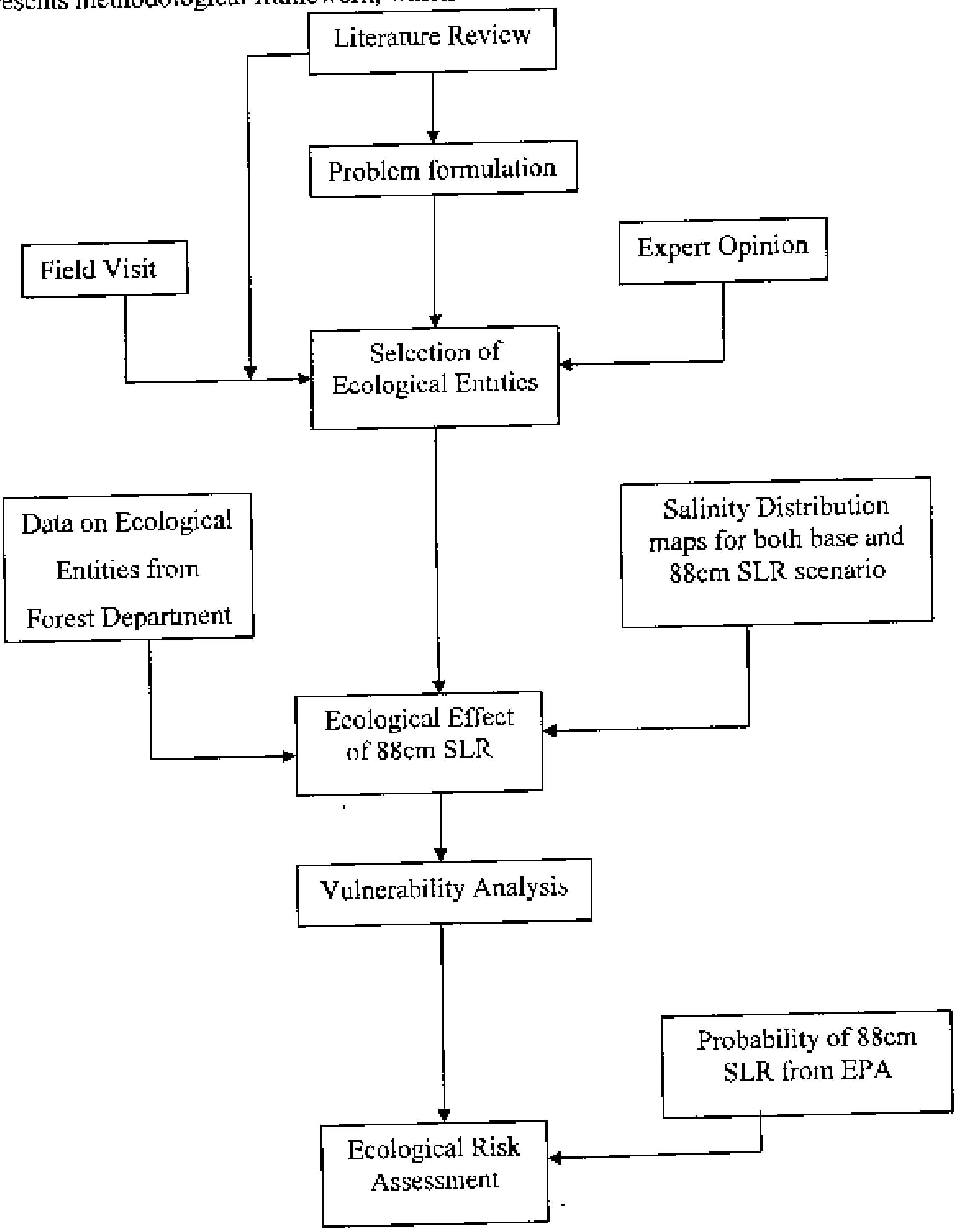


Figure 4.1: Methodological Framework of the study

4.2 Literature Review

Reports from government and non-government organizations, different journals and books on the Sundarbans and climate change have been studied to have an idea about Mangrove forest and consequences of climate change hazard. Chapter two and three of this paper represents the literature review of this study.

4.3 Problem Formulation

Climate change is a global Issue, which causes sea level rise and other problem throughout the world. Reviewing literature, the problem of the Sundarbans due to sea level rise has been identified.

4.4 Selection of Ecological Entities

Assessment of entities is explicit expressions of the actual environmental value that is to be protected, operationally defined by an ecological entity and its attributes. EPA establishes three criteria (ecological relevance, susceptibility, and relevance to management goals) for determining how to select, among a broad array of possibilities, the specific ecological characteristics to target in the risk assessment that are responsive to general management goals and are scientifically defensible. All ecosystems are diverse, with many levels of organization (e.g., individuals, populations, communities, ecosystems, landscapes) and multiple ecosystem processes. It is rarely clear which of these characteristics are most critical to ecosystem function. The EPA criteria were used to select ecological values that may be appropriate for assessment ecological entities. To identify the entities a field visit was performed, the opinion from experts were considered and literature was also reviewed.

4.4.1 Field Visit

A field visit from 6th may to 11th may, 2006 was undertaken to have an idea about mangrove species and to verify the secondary data collected form Forest Department (FD). The objectives of the field visit were as follows:

- To identify the different mangrove species with the help of local people working in Sundarbans.
- To understand the characteristics of different mangrove species in different saline zone. and
- To verify the secondary data on mangrove species collected from FD and
- To identify ecological entities for this study.

4.4.2 Selected Entities

Reviewing literature, getting opinion from experts and after performing field visit, the ecological entities of this study were selected. These entities are regeneration mainly seedlings of mangrove species, ecological health mainly productivity and ecological zone. Ecological Risk will be assessed considering the impact upon these three entities.

Regeneration of species was selected as entities because it is more sensitive to salinity stressor. The future stock of mangrove species depends on regeneration. So it is ecologically relevant. If the regeneration of species is protected from salinity stressor the Sundarbans ecosystem will be free from the threat of transformation.

Health of an ecosystem can be assessed by productivity and biodiversity. In this study, biodiversity, the variety and variability of specie in a given area within specified period of time, was not considered because it may not be changed by salinity hazard. Some species like Sundari are very sensitive to salinity whereas other favor salinity for their growth. The productivity of different saline zones is different. It is sensitive to salinity. That's why productivity has been selected as an ecological entity.

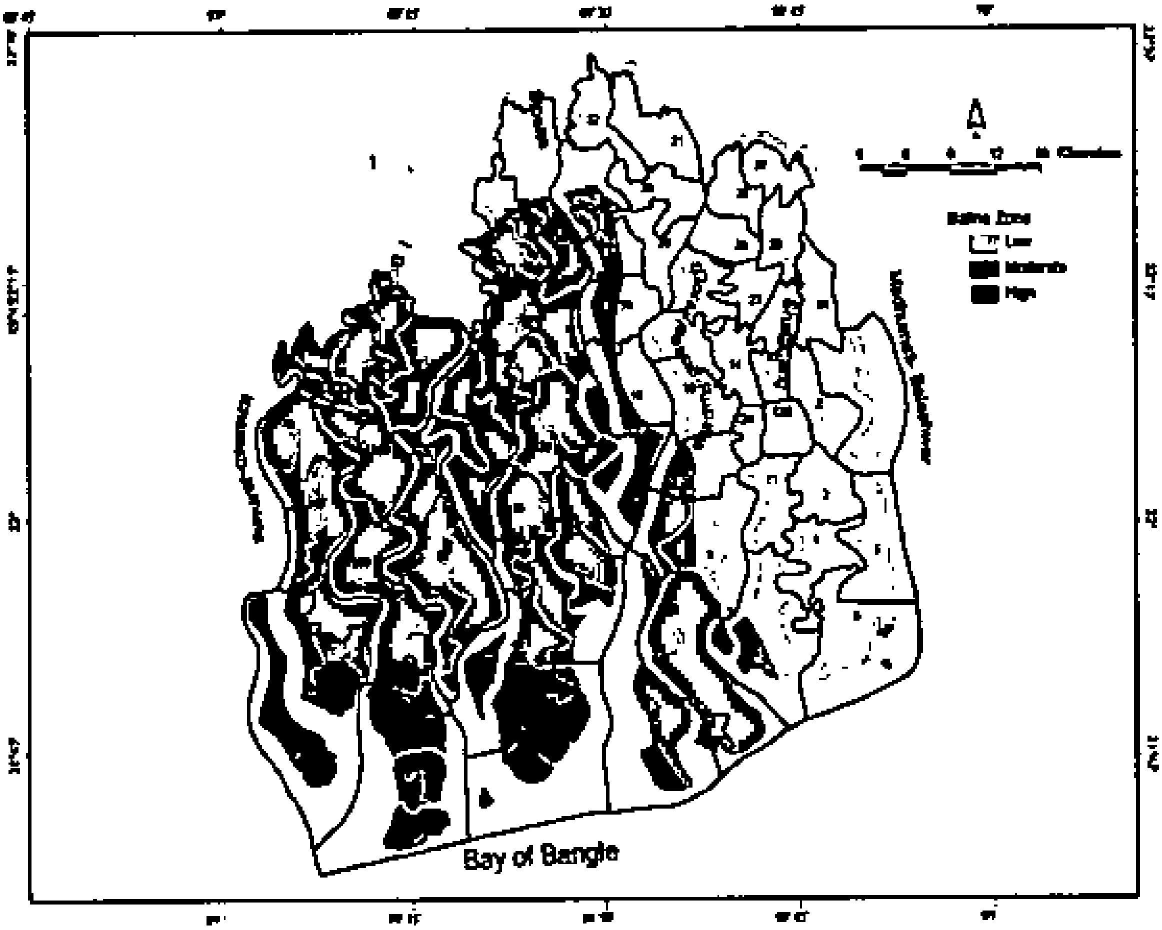
Another entity is ecological zone itself. Due to saline water intrusion, these zones may shift. If these zones are shifted, the ecosystem of the Sundarbans will also be shifted. The impact on these three entities was used to quantify the ecological impact due to sea level rise.

4.4.3 Data on Ecological Entities

Compartment wise data on seedlings, productivity and number of specific mangrove species were collected from Forest Inventory (1998).

4.5 Salinity distribution at different sea level scenarios

Salinity distribution maps both for base condition and 88cm SLR scenario were prepared with the help of Center for Environmental and Geographic Information Services (CEGIS). The model used for salinity distribution at different SLR has been developed by DHI.



Source: Prepared with the help of CEGIS

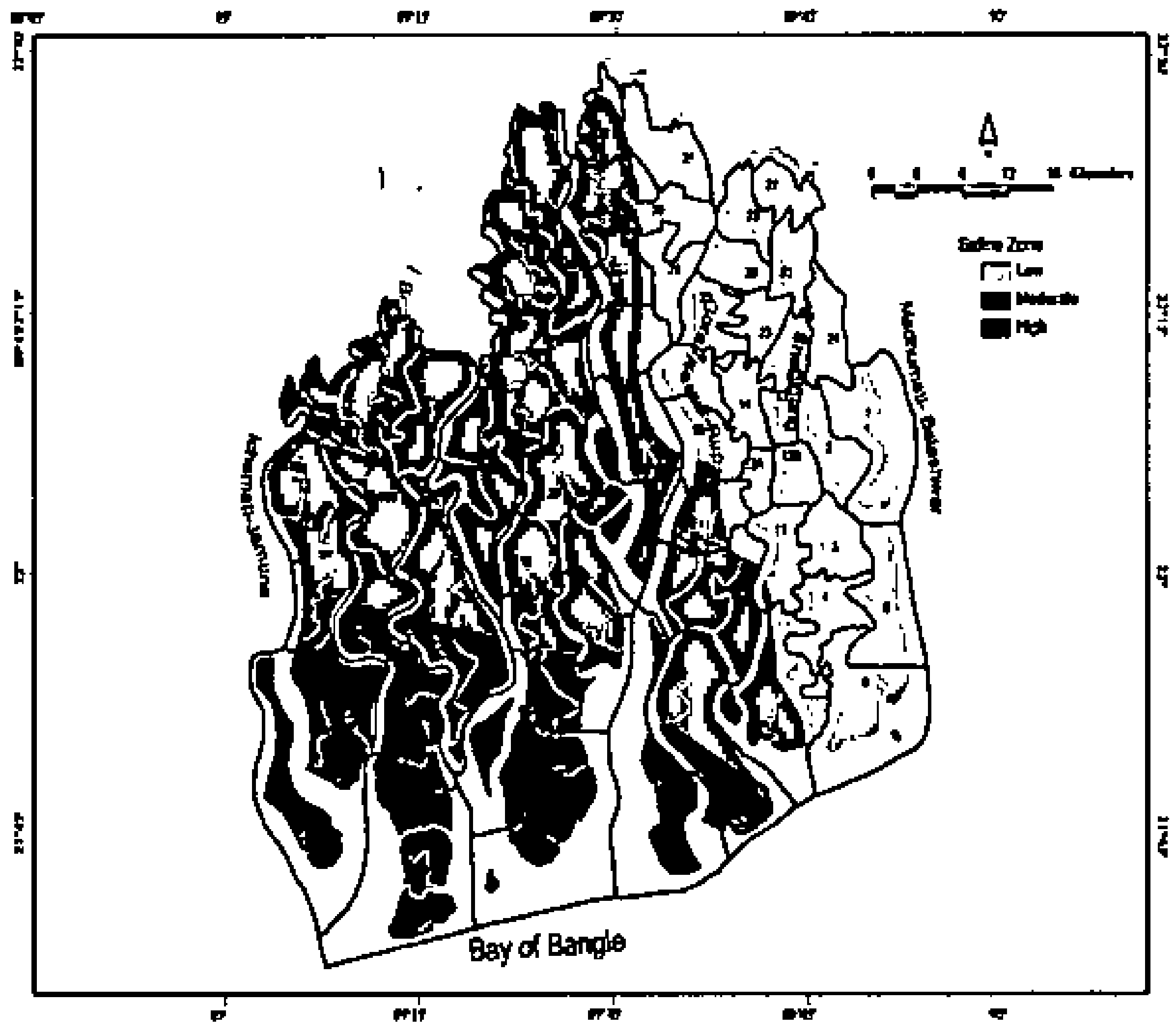


Figure 4.2: Salinity Distribution in the Sundarbans at base and 88cm SLR Scenario.

Source: Prepared with the help of CEGIS

4.6 Ecological Effect of 88cm SLR

From salinity distribution maps (Figure 4.2), the ecological effect of the Sundarbans under 88cm SLR has been assessed considering the changes in the ecological entities. The following have been used to quantify the effect on ecological entities.

4.6.1 Effect on Regeneration

4.6.1.1Loss of seedlings in low saline water zone = Number of seedlings of compartments to be affected in low saline water zone - Number of seedlings of compartments in moderate saline water zone to be shifted into low saline water zone

4.6.1.2 Loss of seedlings in moderate saline water zone = Number of seedlings of compartments to be affected in moderate saline water zone - Number of seedlings of compartments in high saline water zone to be shifted into moderate saline water zone
4.6.1.3 Loss of seedlings in whole Sundarbans = Number of seedlings of compartments to be affected - Number of seedlings of compartments to be shifted

4.6.2 Effect on Ecological Health

4.6.2.1 Loss of productivity in low saline water zone = Average productivity of compartments to be affected in low saline water zone - Average productivity of compartments in moderate saline water zone to be shifted into low saline water zone
4.6.2.2 Loss of productivity in moderate saline water zone = Average productivity of compartments to be affected in moderate saline water zone - Average productivity of compartments in high saline zone to be shifted into moderate saline water zone
4.6.2.3 Loss of productivity in whole Sundarbans = Average productivity of compartments to be affected - Average productivity of compartments to be shifted

4.6.3 Effect on Ecological Zone

4.6.3.1 Loss of area in low saline water zone = Total area of low saline water zone at present - Total area of low saline water zone after saline water intrusion
4.6.3.2 Loss of area in moderate saline water zone = Total area of moderate saline water zone at present - Total area of moderate saline water zone after saline water intrusion
4.6.3.3 Total area shifted = Total area of whole Sundarbans at present - Total area of whole Sundarbans after zone transformation

4.7 Vulnerability Analysis

Vulnerability is defined as degree of loss. For risk estimation, vulnerability is essential part. In this study, the vulnerability of mentioned entities was estimated. There are 55 compartments in the Sundarbans. All of these compartments are distributed among three saline zones. All of them will not be affected by sea level rise induced salinity. The compartments near the transition line between saline zones will be affected. Few compartments in fresh water saline zone will be replaced by few compartments in moderate saline water zone and the same will be predictable for moderate and high saline zones.

4.7.1 Vulnerability to regeneration

Regeneration vulnerability can be estimated for low and moderate saline water zones and also for whole Sundarbans. The following ways were used to estimate vulnerability to regeneration:

4.7.1.1 Vulnerability to regeneration for low saline water zone

In low saline water zone the vulnerability has been assessed using following equations-

Vulnerability = Loss of seedlings / Number of seedlings of compartments to be affected in low saline water zone

4.7.1.2 Vulnerability to regeneration for moderate saline water zone

In moderate saline water zone the vulnerability has been assessed using following equations-

Vulnerability = Loss of seedlings / Number of seedlings of compartments to be affected in moderate saline water zone

4.7.1.3 Vulnerability to regeneration for whole Sundarbans

In whole Sundarbans the vulnerability has been assessed using following equations-

Vulnerability = Loss of seedlings / Number of seedlings of compartments to be affected

4.7.2 Vulnerability to productivity

Vulnerability to Productivity can he estimated for low and moderate saline water zones and also for whole Sundarbans. The following way the vulnerability to productivity has been estimated:

4.7.2.1 Vulnerability to productivity for low saline water zone

In low saline water zone the vulnerability has been assessed using following equations-

Vulnerability = Loss of productivity in low saline water zone / Average productivity of compartments to be affected in low saline water zone

4.7.2.2 Vulnerability to productivity for moderate saline water zone

In moderate saline water zone the vulnerability has been assessed using following equations-

Vulnerability = Loss of productivity in moderate saline water zone / Average productivity of compartments to be affected in moderate saline water zone

4.7.2.3 Vulnerability to productivity for whole Sundarbans:

In whole Sundarbans the vulnerability has been assessed using following equations-

Vulnerability = Loss of productivity / Average productivity of compartments to be affected

4.7.3 Vulnerability to Ecological Zones

Vulnerability to ecological zones can be estimated for low and moderate saline water zones and also for whole Sundarbans. The following way the vulnerability to ecological zones has been estimated:

4.7.3.1 Vulnerability for low saline water zone

For low saline water zone the vulnerability has been assessed using following equations-

Vulnerability = Loss of low saline water zone / Total area of low saline water zone at present

4.7.3.2 Vulnerability for moderate saline water zone

For moderate saline water zone the vulnerability has been assessed using following equations-

Vulnerability = Loss of moderate saline water zone / Total area of moderate saline water zone at present

4.7.3.3 Vulnerability for whole Sundarbans

For whole Sundarbans the vulnerability has been assessed using following equations-

Vulnerability = Loss of total area / Total area of whole Sundarbans at present

4.8 Probability of 88cm SLR

EPA suggested the following equation to estimate local seal level rise:

Local (t) = Normalized (t) + (t – 1990) X Trend

Where local (t) is the rise in sea level by year t; Normalized (t) is the normalized projection of sea level rise; and trend is the current rate of relative sea level rise.

Normalized projection of sea level rise and it's local trend was identified from table 3.1 and 3.2 respectively. Again probability of 88 cm sea level rise was identified using the table 3.1.

4.9 Ecological Risk Assessment

Ecological risk is often defined as a product of probability of a hazard and consequence if that hazard occurs. Ecological Risk Assessment (ERA) is relatively new technique that is now available for assessing the level of risk to the health of ecosystem posed by stressors. Ecological risk, in this study has been estimated by the following equation:

Ecological Risk = Probability of occurrence of hazard X Vulnerability

Chapter Five
Field Visit

The Sundarbans is located in the coastal region and spread over five districts namely Khulna, Satkhira, Bagerhat, Patuakhali and Barguna. Almost all part of it is under Khulna, Satkhira and Bagerhat district. There are four ranges in the Sundarbans. These are Satkhira range, Khulna range, Chandpai range and Saronkhola range. Satkhira range is in high saline wone, Khulna range is considered as moderate saline water zone and Chandpai and Sarankhola range are considered as low saline water zone. Figure 5.1 shows ranges and compartments of the Sundarbans Mangrove Forest.

During the visit of three stations namely Burigoalini, Kalagachia and Kateswar of high saline zone, Mr. Hossain of Forest Department helped to identify different species mainly Sundari, Gewa, Goran, Keora, Baen and Passure. It was observed that the Sundari is very rare species in high saline water zone, which complies with literature review. The species like Gewa, Keora, Baen are available species in observed stations. Passure was also observed but it was not available like Gewa, Keora and Bain. It was found in scattered way. It was very difficult for Mr. Hossain to make visitor familiar with Sundari species because he could not find them. It was also observed that the Gewa species was not in good health in this zone (Figure 5.3).

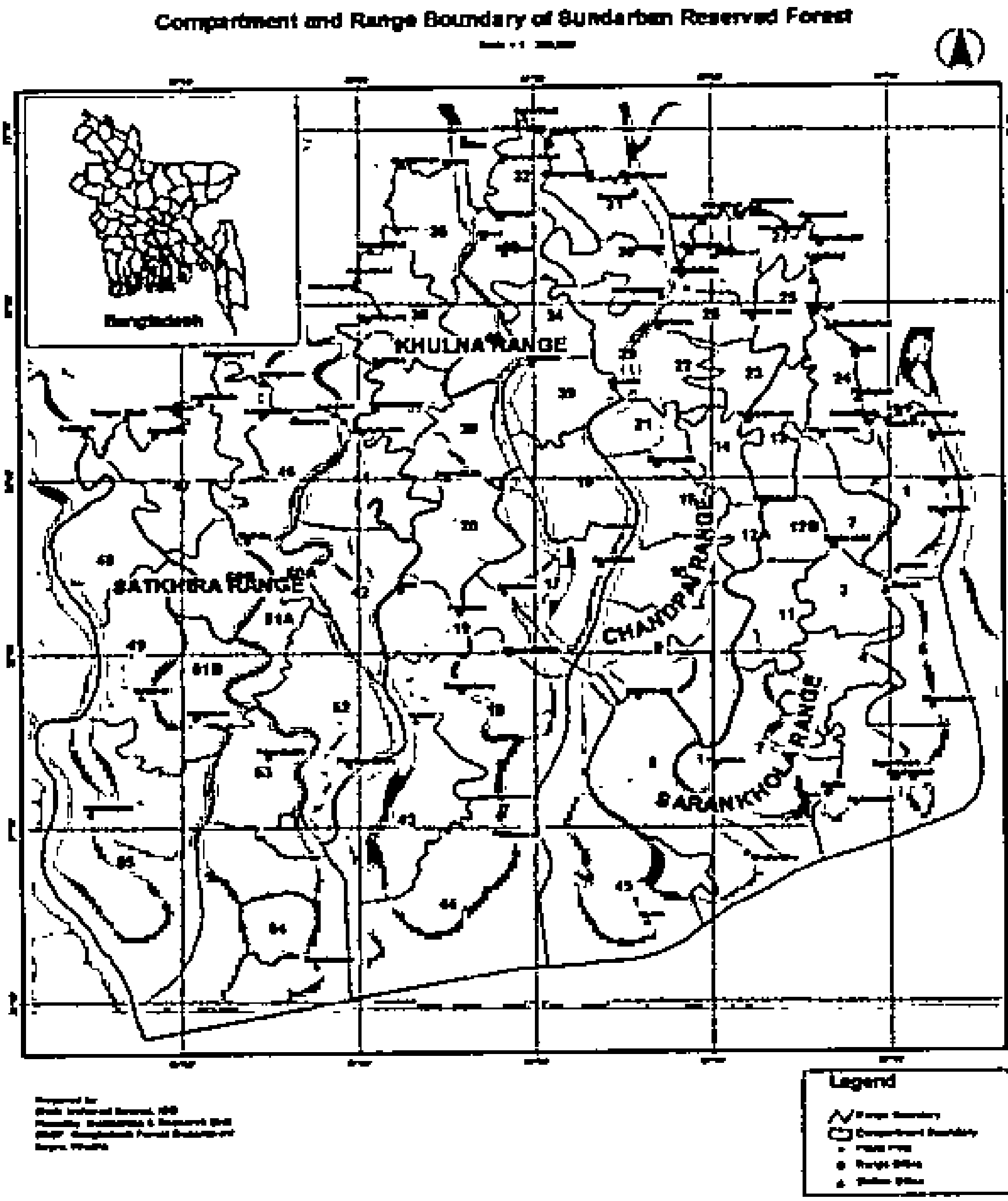


Figure 5.1: Ranges and Compartments of the Sundarbans

Mr. Hossain informed that high salinity is responsible for it. It was also observed that the height of mangrove species is low which corresponds with the literature review (Figure 5.2). Keora, some Baen and very few Passur were found in good height. It was also found that the Keora is dominant in newly accreted land and it was not found in all compartments. According to literature review it was learnt that Goran is the dominant species in high saline zone but during field visit it was observed that Gewa is dominant. It does not mean past study is wrong. Only the stations located in north-east of high saline zone, which are closest to the moderate saline water zone were observed. After coming from field, it was also discussed with a person working in silviculture in the Sundarbans. He was asked about Gewa. He replied probably salinity is one of the factors for it.

Figure 5.2: Mangrove height in high saline zone.

Figure 5.3: Gewa is not in good health in high saline zone

On the second day, the Andharmanik station (Figure 5.1) was studied. It is a boundary between two compartments (41 and 37). Compartment 41 is under moderate saline water zone and compartment 37 is under low saline water zone. According to the figure 4.2, the compartments 16, 36, 37, 38, 39, 40 of low saline water zone will be transferred to moderate saline water zone due to saline water intrusion in future.

The characteristics of the species of these compartments will be replaced by the characteristics of the species of moderate saline water zone. It was very difficult to visit all the compartments of interest due to fund and time limitation. Considering all the problems, it was decided to visit only compartment 41 and compartment 37, which represent moderate and low saline water zone respectively. These two were selected because they are near to Munshiganj than other compartments. The compartments 43, 44, part of 45, part of 8 and part of 18 of moderate saline water zone will also be transferred to high saline zone. It was tried to visit these compartments but it was not possible to do that. They were all very far from Munshiganj.

During the visit, the species composition in both compartments was also observed (Figure: 5.4). It was difficult to go inside of the Sundarbans. It was tried to enter into the deep jungle and observed properly the species composition of two compartments.

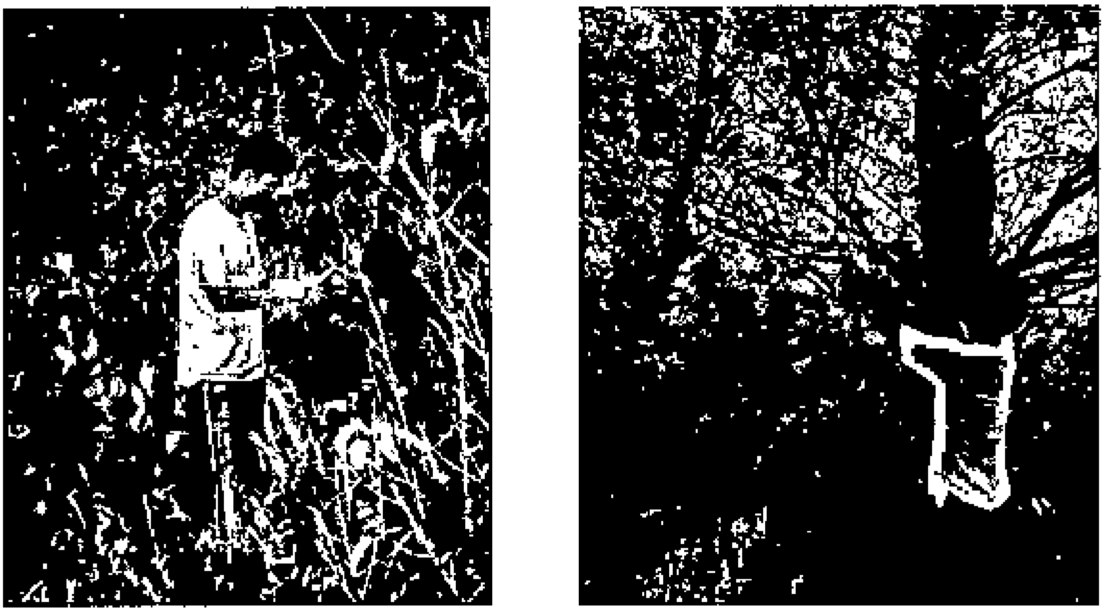


Figure 5.4: Observation of mangrove species in compartments 41 and 37.

Mangrove samples have been collected from the station (Figure 5.5).

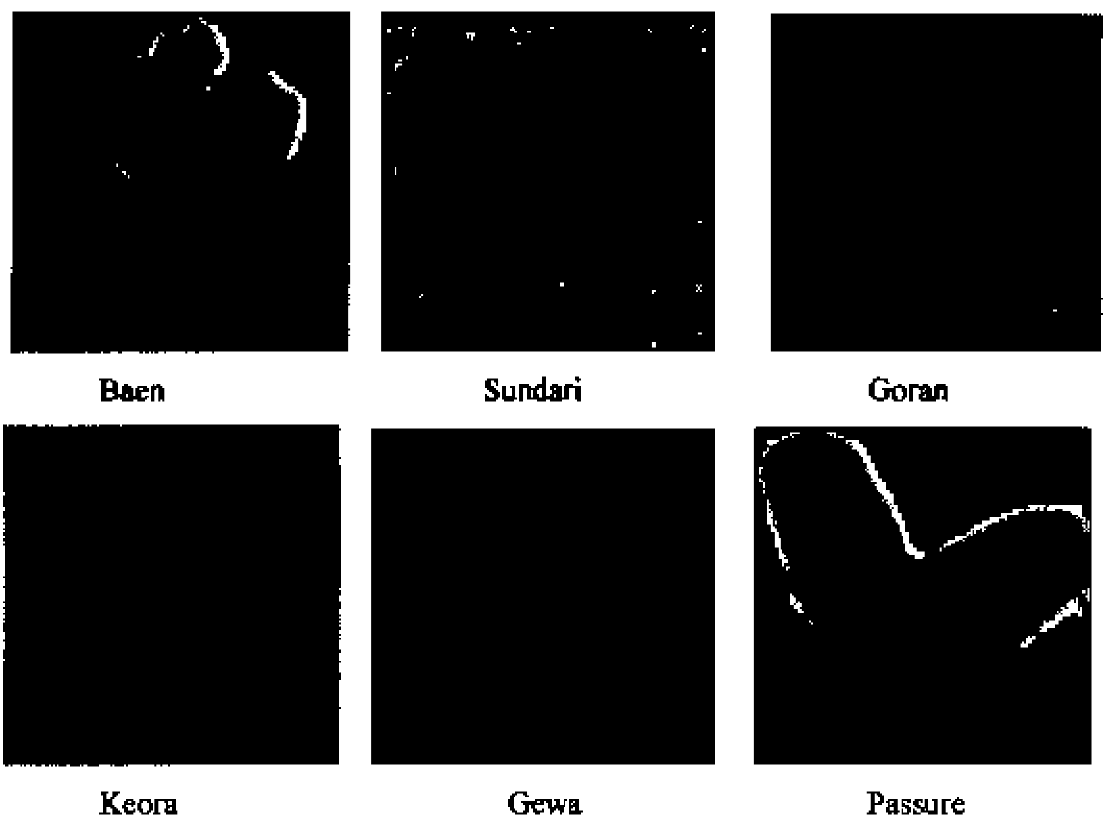


Figure 5.5: Sample of mangrove species in Sundarbans

After observation, different issues were discussed with the people (called as forester by local people) responsible for the protection of the Sundarbans (Figure 5.6). They were asked about species composition in both 37 and 41 compartments. They were also asked about the problem of Gewa (discussed earlier). They replied, it is not unusual. It happens to every mangrove species. Salinity is not responsible for it.

Figure 5.6: Discussion with the foresters in Andharmanik station

The foresters were asked to compare present species composition of compartment 41 and 37 with species composition of these two compartments in 1998. The comparison of these two compartments is given in the following table:

Table 5.1: Comparison of different species in compartment 37 and 41.

Compartment	Record	Sundari	Gewa	Baen	Keora	Others
41	Forest Inventory	24%	26%	10%	4%	36%
	Field visit	15%	35%	10%	5%	35%
37	Forest Inventory	57%	22%	1%		20%
	Field visit	45%	33%	5%	7%	10%

From the table, it can be inferred that the percentage of Sundari has been reduced by 10% where the percentage of Gewa has been increased by 10% in both compartments. Baen and Keora are as same as they were in 1998 in compartment 41. But in compartment 37, Baen and Keora have been increased. It is difficult to say due to increase in salinity the Sundari is replaced by Gewa because illegal tree felling may be one of the reasons behind the observation.

The fishermen in this zone were also asked about fish. They informed thai Bagda is a very common species in high saline zone and Vetki and Ilish are rare species. They also informed that Vetki is common in low saline water zone like in Saronkhola range. So in future due to salinity the Vetki will be threatened. So the present ecology of the Sundarbans will be transformed in future due to sea level rise, which will result in ecological disaster.

Chapter Six

Result and Discussion

6.1 Ecological Effect due to 88 cm sea level rise

In this study, three ecological entities have been considered to quantify the loss or damage due to sea level rise. These are transfer of ecological zone, loss of production and loss of regeneration capacity. The descriptions of these damages are described with the help of the figure 4.2.

6.1.1 Transfer of ecological zone

There are two maps identifying three ecological zones separately were prepared. One under base condition and other under 88cm sea level rise. From these maps, it has been calculated that the areas of fresh, moderate and saline water zone under base condition are 45%, 50% and 5% respectively. But due to sea level rise, the area of low and moderate saline water zone will be reduced to 36% and 47% respectively whereas the area of high saline water zone will be increased to 17%. Negative and positive sign in following table indicate loss and gain of area respectively.

Table 6.1: Effect of 88cm SLR on area of Ecological Zone

Base condition		88 cm scenario		Changes
Zone	Area (Ha)	Zone	Area (Ha)	Area (Ha)
Low saline water zone	183,956	Low saline water zone	147,046	-36,910
Moderate Saline Water Zone	203,292	Moderate Saline water zone	189,820	-13,472
High saline water zone	20,714	High saline water zone	71,796	51,082

From table 6.1, it is observed that due to sec level rise, low saline water zone will be reduced by 36,910 ha and moderate saline water zone will be reduced by 13,472 ha. There was minor error in area calculation of each saline zone when it was calculated by GIS. The total area under low and moderate saline water zone that will be reduced due to 88cm sea level rise is 50,382 ha while the area of high saline water zone will increase from 20,714 ha to 71,796 ha. But the increase of high saline water zone is not beneficial for the Sundarbans rather it will threat some valuable species.

6.1.2 Loss of production

The productivity of low saline water zone is higher than any other zone. From the salinity maps prepared under base condition and 88cm sea level rise scenario, it is clear that, all fresh water and moderate saline water zone will not be converted to moderate saline water and high saline water zones respectively. Only a portion of low saline water zone and moderate saline water zone will be converted to moderate and high saline water zone respectively. Only the compartments 8, 11, 15, 18, 29, 30, 32, 35, 49, 51A, 51B and 52 will be affected by sea level rise. Some compartments will be affected totally and some will be affected partially. It was assumed in this study that the productivity of these affected compartments of a zone will be replaced by the productivity of nearby compartments of other zone. For example, the productivity of the compartments of low saline water zone will be replaced by the productivity of nearby compartments of moderate saline water zone. If we deduct the production of moderate saline water zone from production of low saline water zone, we will get the changes in production that will be result of sea level rise. Following table shows changes in production in affected compartments of low saline water zone. The positive and negative sign indicates gain and loss of production respectively.

Table 6.2: Effect of 88cm SLR on production of low saline water zone

Compartment to be affected	Area (Ha)	Percentage to be affected	Affected area (Ha)	Present Production (Cum)	Production after SLR (Cum)	Changes in Production (Cum)
11	5,661	7	396	10,632	5,873	-4,759
15	5,576	20	1,115	62,239	44,374	-17,866
29	4,427	5	221	10,735	8,626	-2,109
30	5,231	20	1,046	49,182	40,770	-8,411
32	5,545	80	4,436	224,772	17,2871	-51,901
35	6,579	100	6,579	280,134	317,568	+37,435

Production Loss = 47,612 Cum

Note: Present production was obtained from forest inventory 1998. Cum = Cubic meter.

From the above table it can be said that, due to transformation of a part of low saline water zone to moderate saline water zone, production of 47,612 cum will be reduced.

The same thing will also happen to moderate saline water zone. A part of some compartments of moderate saline water zone will be affected. So due to transfer of zone, the production of affected compartments under moderate saline water zone will be replaced by the production of compartments of high saline water zone near the affected compartments. Table 6.3 shows changes in production in compartments of moderate saline water zone.

Table 6.3: Effect of 88cm SLR on production of moderate saline water zone

Compartment to be affected	Area (Ha)	Percentage to be affected	Affected area (Ha)	Present Production (Cum)	Production after SLR (Cum)	Changes in Production (Cum)
8	13,807	35	4,832	106,217	95,103	-11,115
18	12,676	30	3,803	68,336	64,153	-4,183
49	11,548	55	6,351	14,926	14,989	+64
51A	3,460	25	865	6,764	2,041	-4,723
51B	6,075	55	3,341	9,990	7,885	-2,105
52	11,773	60	7,064	21,898	28,962	+7,064

Production Loss =14,998 Cum

Note: Present production was obtained from forest inventory 1998. Cum = Cubic meter.

From the table 6.3 it is easily understood that due sea level rise the present production of moderate saline water zone will be reduced and the loss of production will be 14,998 cum. So due to sea level rise, the total production loss of the Sundarbans will be approximately 62,610 cum.

6.1.3 Loss of regeneration

Regeneration of species is defined either by seedling, sapling or pole. But in this study only seedling was considered because it is more sensitive to salinity. The future stock of species depends on regeneration. That's why it is very important to protect regeneration of seedling of different species of the Sundarbans for its existence. Similar to the production only seedlings of few compartments of low and moderate saline water zone will be reduced. It was also assumed in this study, that the seedlings of these affected compartments of a zone will be replaced by the seedlings of nearby compartments of other zone. For example, the seedlings of the compartments of low saline water zone will be replaced by the seedlings of nearby compartments of moderate saline water zone. Here in this study seedling of all species but Goran have been considered. Because Goran favors salinity. So the number of seedling of Goran will be increased if salinity increases. Table 6.4 shows changes in seedlings in affected compartments of low saline water zone. The loss and gain of seedling has been indicated by negative and positive sign respectively.

Table 6.4: Effect of 88cm SLR on seedling of low saline water zone

Compartment to be affected	Area (Ha)	Percentage to be affected	Affected area (Ha)	Seedling* at present (No.s)	Seedling* after SLR (No.s)	Changes in seedling (No.s)
11	5,661	7	396	16,873,177	11,042,856	-5,830,321
15	5,576	20	1,115	108,665,088	69,086,640	-39,578,448
29	4,427	5	221	9,641,785	5,564,518	-4,077,267
30	5,231	20	1,046	36,136,794	26,300,422	-9,836,372
32	5,545	80	4,436	145,154,792	111,516,604	-33,638,188
35	6,579	100	6,579	115,448,292	112,185,108	-3,263,184

*** Note- seedling of all species without Goran** **Seedling Loss= 96,223,780 Nos**

Note: Present seedling number was obtained from forest inventory 1998.

From the above table it can be said that, due to transformation of a part of low saline water zone to moderate saline water zone, approximately 96,223,780 numbers of seedlings will be reduced.

The same thing will also happen to moderate saline water zone. A part of some compartments of moderate saline water zone will be affected. It was assumed that due to transfer of zone, the number of seedlings of affected compartments of moderate saline water zone will be replaced by the number of seedlings of compartments of high saline water zone near to the affected compartments.

Table 6.5 shows the effect of SLR on seedling in compartments under moderate saline water zone. From Table 6.5, it is seen that due to sea level rise the number of seedlings of moderate saline water zone will be reduced and the loss of seedling will be approximately 15,623,565 numbers (million). So due to sea level rise the total seedling loss of the Sundarbans will be approximately 111,847,345 numbers. Though this number is not quite high but the most important thing is that, the Sundari, the most valuable tree species in the Sundarbans, is under threat of extinction.

Table 6.5: Effect of 88cm SLR on seedling of moderate saline water zone.

Compartment to be affected	Area (Ha)	Percentage to be affected	Affected area (Ha)	Seedling* at present (No.s)	Seedling* after SLR (No.s)	Changes in seedling (No.s)
8	13,807	35	4,832	142,035,370	74,743,504	-67,291,866
18	12,676	30	3,803	39,929,400	41,104,465	+1,175,065
49	11,548	55	6,351	25,176,950	48,518,345	+23,341,395
51A	3,460	25	865	4,373,440	6,607,735	+2,234,295
51B	6,075	55	3,341	8,687,250	25,523,809	+16,836,559
52	11,773	60	7,064	74,113,390	82,194,377	+8,080,987

*** Note- seedling of all species without Goran** **Seedling loss=15,623,565 Nos**

Note: Present seedling number was obtained from forest inventory 1998.

Only in compartment 8, the number of seedling will be lost whereas other compartments will gain seedlings in moderate saline water zone. The positive and negative sign indicates gain and loss of seedling respectively.

The Sundari species, especially the seedling of Sundari is very sensitive to salinity. The number of Sundari seedlings decreases as salinity increases. Due to sea level rise, the future stock of Sundari will be reduced. The following table number 6.6 shows the situation that may happen due to sea level rise.

Table 6.6: Effect of 88cm SLR on Sundari seedling at low saline water zone

Compartment to be affected	Area (Ha)	Percentage to be affected	Affected area (Ha)	Seedling at present (No.s)	Seedling after SLR (No.s)	Changes in Seedling (No.s)
11	5,661	7	396	14,156,746	8,741,716	-5,415,030
15	5,576	20	1,115	80,771,706	51,458,674	-29,313,032
29	4,427	5	221	8,006,230	3,920,330	-4,085,900
30	5,231	20	1,046	31,624,534	18,529,248	-13,095,285
32	5,545	80	4,436	133,106,616	78,565,996	-54,540,620
35	6,579	100	6,579	92,902,059	49,395,132	-43,506,927

Sundari seedling loss=149,956,794 Nos

Note: Present seedling number was obtained from forest inventory 1998.

From the above table it is seen that, Sundari seedling is very sensitive to salinity compared to other species. Due to transformation of a part of low saline water zone to moderate saline water zone, the low saline water zone will lose approximately 149,956,794 numbers of Sundari seedlings whereas according to table 6.4 the total number seedling will be reduced by 96,223,780.

In similar fashion a portion of moderate saline water zone will be transferred to high saline water zone. Following table shows loss of Sundary seedlings in moderate saline water zone.

Table 6.7: Effect of 88cm SLR on Sundari seedling at moderate saline water zone

Compartment to be affected	Area (Ha)	Percentage to be affected	Affected area (Ha)	Seedling at present (No.s)	Seedling after SLR (No.s)	Changes in Sundari seedling (No.s)
8	13,807	35	4,832	102,399,616	48,522,630	-53,876,985
18	12,676	30	3,803	20,884,978	18,854,282	-2,030,695
49	11,548	55	6,351	254,056	641,491	+387,435
51A	3,460	25	865	0	87,365	+87,365
51B	6,075	55	3,341	0	337,466	+337,466
52	11,773	60	7,064	7,155,629	17,489,969	+10,334,339

Sundari Seedling Loss = 44,761,075 Nos

Note: Present seedling number was obtained from forest inventory 1998.

From the above table it can be seen that due to sea level rise, the Sundari seedling of moderate saline water zone will be reduced and the number will be about 44,761,075. When we consider seedling of all species then total number of loss of seedling is lower than the seedling of only Sundari species. Because number of seedlings of few species will be increased dne to zone transfer where the number of Sundari seedling will be decreased for same reason. The Sundarbans will loss approximately 194,717,869 numbers of seedling of Sundari species due to 88cm sea level rise.

6.2 Vulnerability analysis

Vulnerability is the degree to which a system is likely to experience harm as a result of exposure to perturbations or stress. Vnlnerability is a function of exposure, sensitivity and adaptive capacity. Potential impacts are a function of exposure and sensitivity. Therefore, vulnerability is a function of potential impacts and adaptive capacity. Vulnerability assessment requires some information which falls into three basic categories: resource distribution, stressor distribution, and forecast changes. The vulnerability of the ecological entities from sea level rise is discussed below.

6.2.1 Vulnerability to ecological zone

To calculate vulnerability due to transfer of ecological zone, a two step assessment is needed, one for transformation of low saline water zone to moderate saline water zone and the other for transformation of moderate saline water zone to high saline water zone. The following table shows the vulnerability to transformation of ecological zone.

Table 6.8: the vulnerability to transformation of ecological zone

Base condition		88 cm scenario	Loss	Vulnerability
Zone	Area (Ha)	Area (Ha)	Area (Ha)	
Low saline water zone	183,956	147,046	36,910	0.2
Moderate saline water zone	203,292	189,820	13,472	0.07
High saline water zone	20,714	71,796		

From Table 6.8, it is seen that the vulnerability due to transfer of low saline water zone to moderate saline water zone is 0.2 while the vulnerability due to transfer of moderate saline water zone to high saline water zone is 0.07. So the vulnerability to transfer of low saline water zone to moderate saline water zone is higher than the vulnerability to transfer moderate saline water zone to high saline water zone. It can be said that low saline water zone is more sensitive than the moderate saline water zone to salinity. If we go to calculate the vulnerability to transfer of ecological zone then it is 0.12.

6.2.2 Vulnerability to production

With low salinity, trees show better growth, whereas if the salinity drastically increases there is a reduced rate of growth. In similar way to ecological zone transfer, we can calculate the vulnerability to production due to 88cm sea level rise. The following table shows the vulnerability to production for each zone transfer.

Table 6.9: The vulnerability to the production

Zone Transfer	Production (Cum) at base condition	Production (Cum) at 88cm scenario	Loss (Cum)	Vulnerability
From low saline water to moderate saline water zone	637,694	590,082	47,612	0.07
From moderate saline water to high saline water zone	228,131	213,133	14,998	0.06

The study found that due to 88cm sea level rise, the fresh water and moderate saline water zone will lose their production. The vulnerability will be about 0.07 and 0.06 respectively for transformation of small portion of low saline water zone to moderate saline water zone and transformation of small portion of moderate saline water zone to high saline water zone. The vulnerability to production for whole Sundarbans will be 0.07 due to 88cm sea level rise.

6.2.3 Vulnerability to regeneration

A significant decrease in regeneration is noticed with an increase in the level of salinity. It indicates that salinity plays a vital role in the distribution of species in the Sundarbans as germination is linked to salinity. The following table shows the vulnerability to regeneration for low saline water zone and moderate saline water zone.

Table 6.10: The vulnerability to Regeneration of each zone

Zone Transfer	Regeneration (No. s) at base condition	Regeneration (No. s) at 88cm scenario	Loss (No. s)	Vulnerability
From low saline water to moderate saline water zone	431,919,928	335,696,148	96,223,780	0.22
From moderate saline water to high saline water zone	294,315,800	278,692,235	15,623,565	0.05

The regeneration of fresh water mangrove species is more sensitive to salinity than moderate saline water zone. The vulnerability to regeneration at fresh water and moderate saline water zone will be 0.22 and 0.05 respectively while the vulnerability to regeneration for whole Sundarbans will be 0.15.

The regeneration of Sundari, most dominant species in the Sundarbans, is highly sensitive to salinity. Due to 88cm sea level rise the number of regeneration of Sundari will be reduced more than other species in both fresh water and moderate saline water zone. The following table shows the vulnerability of Sundari species in both zones.

Table 6.11: The vulnerability to the regeneration of Sundari in each zone

Zone Transfer	Regeneration of Sundari (No. s) at base condition	Regeneration of Sundari (No.s) at 88cm scenario	Loss (No. s)	Vulnerability
From low saline water to moderate saline water Zone	360,567,891	210,611,096	149,956,794	0.42
From moderate saline water to high saline water zone	130,694,279	85,933,203	44,761,075	0.34

Due to 88cm sea level rise, the vulnerability to regeneration of Sundari species at low saline water zone and moderate saline water zone will be 0.42 and 0.34 respectively. So 88cm sea level rise will be more threat to the Sundari species in the Sundarbans specially at low saline water zone because it is distributed more in low saline water zone than other zones. The vulnerability to regeneration of Sundari species in the Sundarbans will be 0.40.

6.3 Risk characterization

Risk characterization is the final phase of ecological risk assessment and is the culmination of the planning, problem formulation, and analysis of predicted or observed adverse ecological effects related to the assessment ecological entities Completing risk characterization allows risk assessors to clarify the relationships between stressors, effects, and ecological entities and to reach conclusions regarding the occurrence of exposure and the adversity of existing or anticipated effects.

6.3.1 Risk estimation

Risk is the function of probability and vulnerability. To estimate ecological risk of 88cm sea level rise to the Sundarbans mangrove forest the probability of 88cm sea level rise and vulnerability to each ecological entity are needed. The vulnerability of 88cm sea level rise to each ecological entity has been calculated and according to EPA, the probability of 88cm sea level rise is 20 percent. Ecological risk of each entity is described below:

6.3.1.1 Risk to regeneration

Regeneration of the Sundarbans is an important determinant of its future stock. The regeneration of different species of Sundarbans is sensitive to salinity. From the following table it can be seen as how much risk the Sundarbans regeneration will face in future.

Table 6.12: Risk to the Regeneration in each ecological zone

Ecological Zone	Probability of 88cm SLR	Vulnerability to the Seedling	Risk to the Seedling
Low saline water zone	0.2	0.22	0.044
Moderate Saline Water Zone	0.2	0.05	0.01

The risk of 88cm SLR to the regeneration of different species except Goran of fresh water and moderate saline water zone will be 4.4 percent and 1 percent respectively while the risk to regeneration of whole Sundarbans will be 3 percent. From this table we can say that the fresh water loving species is more sensitive to salinity than moderate and high saline water zone. So they will be under more threat due to sea level rise. Figure 6.1. shows the risk to regeneration in both low and moderate saline water zones.

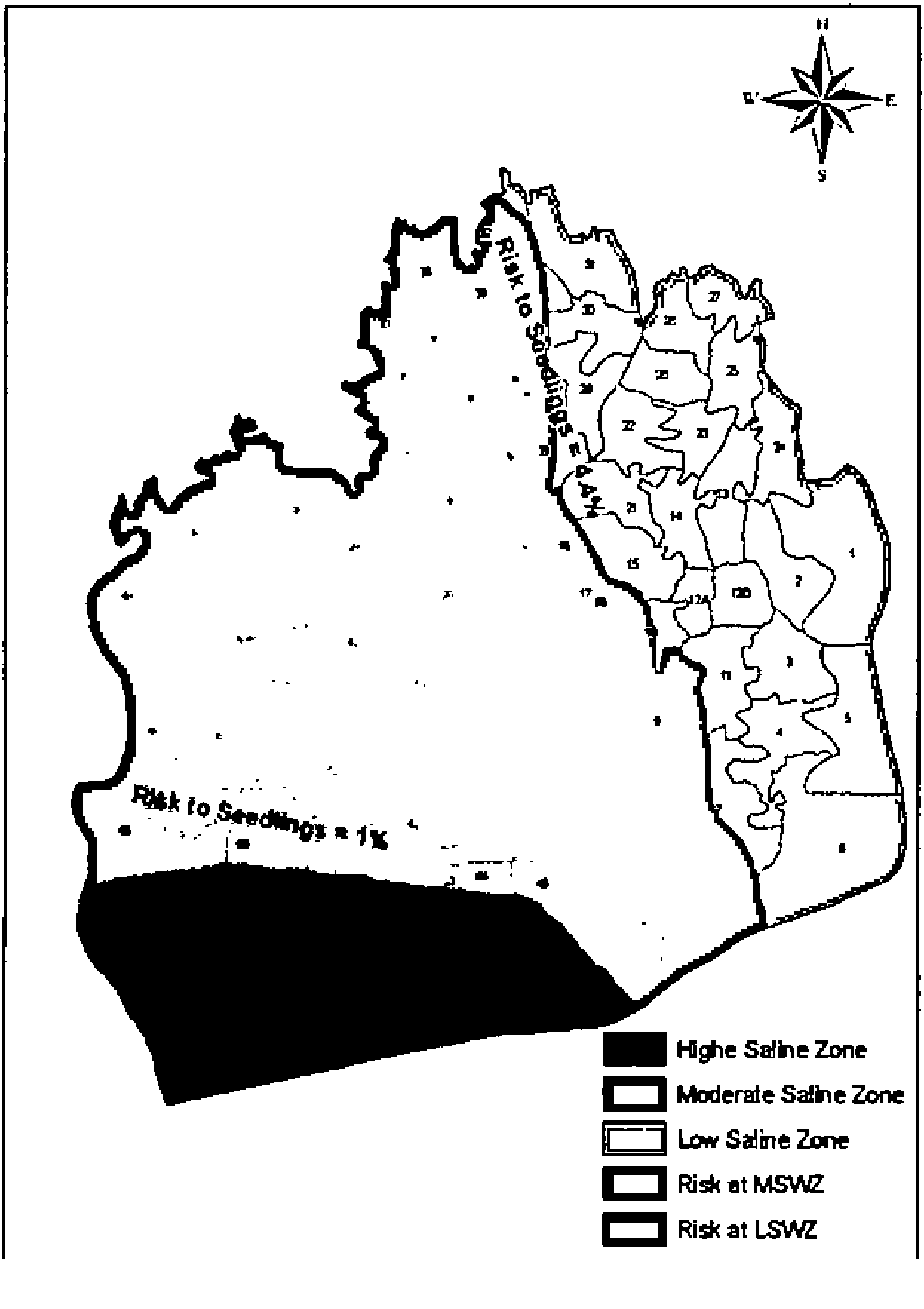


Figure 6.1: Regeneration risk map of Sundarbans

Note: Number in the map indicates compartment. MSWZ - Moderate Saline Water Zone and LSWZ - Low Saline Water Zone.

Following figure shows the risk to the sundari seedlings.

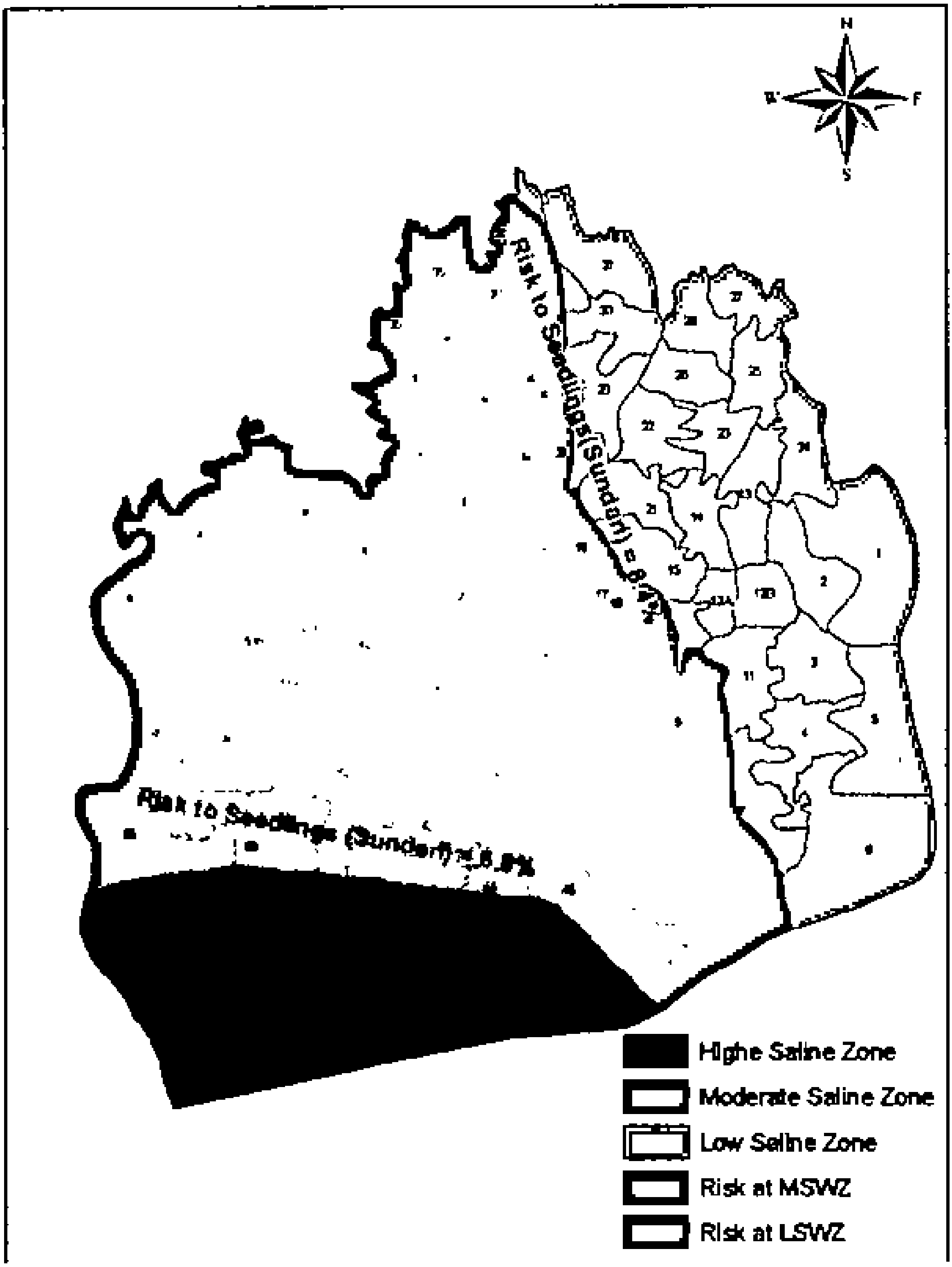


Figure 6.2: Risk map of only Sundari Seedlings in Sundarbans

Note: Number in the map indicates compartment, MSWZ - Moderate Saline Water Zone and LSWZ - Low Saline Water Zone.

Table 6.13 represents the risk only to the Sundari seedling that it may face in future due to 88cm sea level rise.

Table 6.13: Risk to the regeneration of Sundari in each ecological zone

Ecological Zone	Probability of 88cm SLR	Vulnerability to Sundari Seedling	Risk to the Sundari Seedling
Low saline water zone	0.2	0.42	0.084
Moderate Saline Water Zone	0.2	0.34	0.068

Table 6.13 shows that the risk to the Sundari seedling of low saline water zone due to 88cm sea level rise is 8.4 percent while it is 6.8 percent in moderate saline water zone. The risk to the Sundari seedling due to 88cm sea level rise for whole Sundarbans then the risk will be 8 percent.

6.3.1.2 Risk to production

The following table shows the risk of 88cm SLR to the production of the each zone of the Sundarbans. The risk to the production of low saline water zone will be 1.4 percent where the risk to the production of moderate saline water zone will be 1.2 percent.

Table 6.14: Risk to the Production in each ecological zone

Ecological Zone	Probability of 88cm SLR	Vulnerability to the Production	Risk to the Production
Low saline water zone	0.2	0.07	0.014
Moderate Saline Water Zone	0 2	0.06	0.012

The risk to production of whole Sundarbans for 88cm SLR will be approximately 1.4 percent. Figure 6.3 shows the risk to the production in both low and moderate saline water zone.

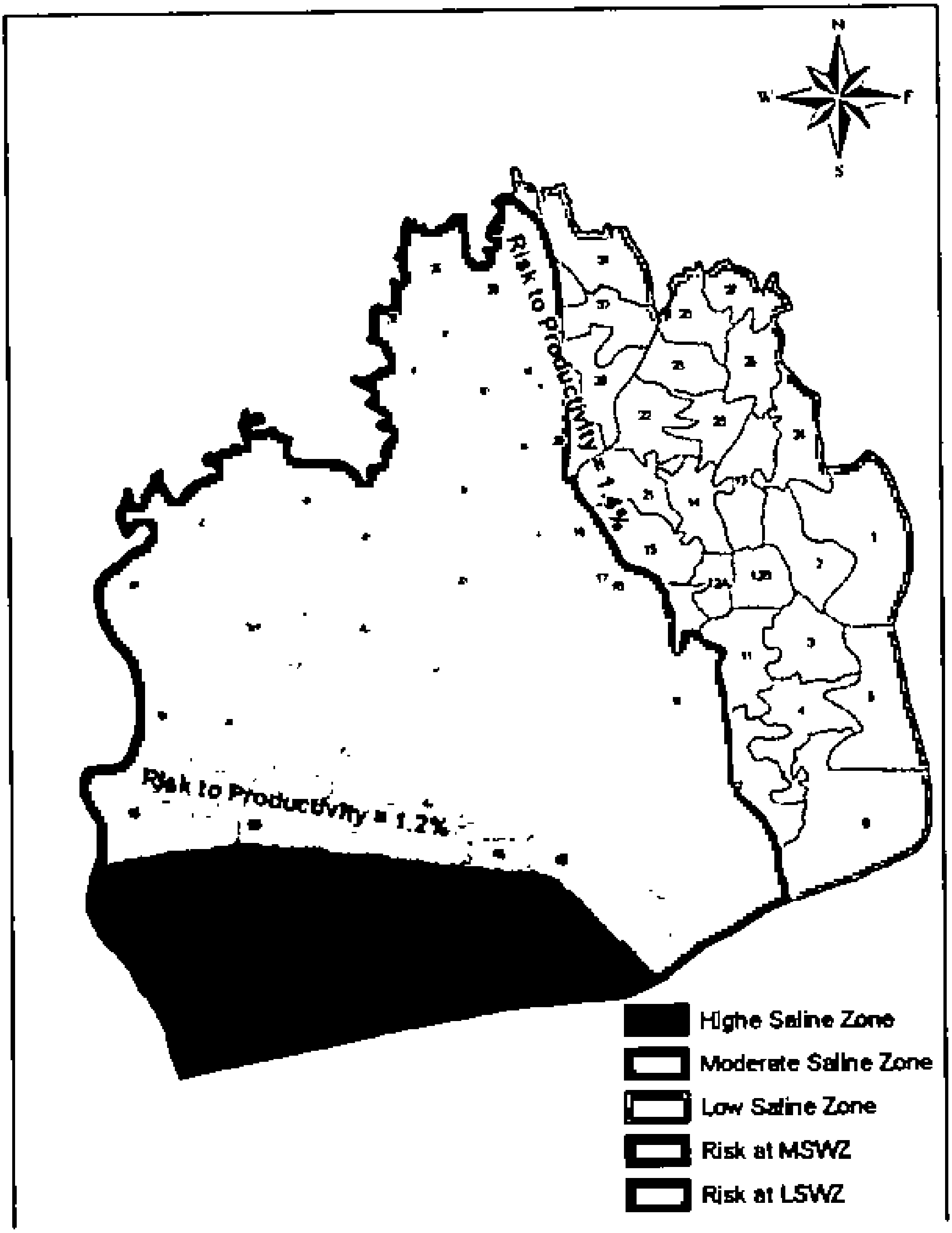


Figure 6.3: Risk to production in Sundarbans

Note: Number in the map indicates compartment. MSWZ - Moderate Saline Water Zone and LSWZ - Low Saline Water Zone.

6.3.1.3 Risk to ecological zone

The study found the vulnerability of low saline water zone to transfer to moderate saline water zone and vulnerability of moderate saline water zone to transfer to high saline water zone are 0.2 and 0.07 respectively. EPA said the probability of 88cm sea level rise is 0.2. The following figure shows the zone transfer risk of 88cm SLR to each zone of Sundarbans.

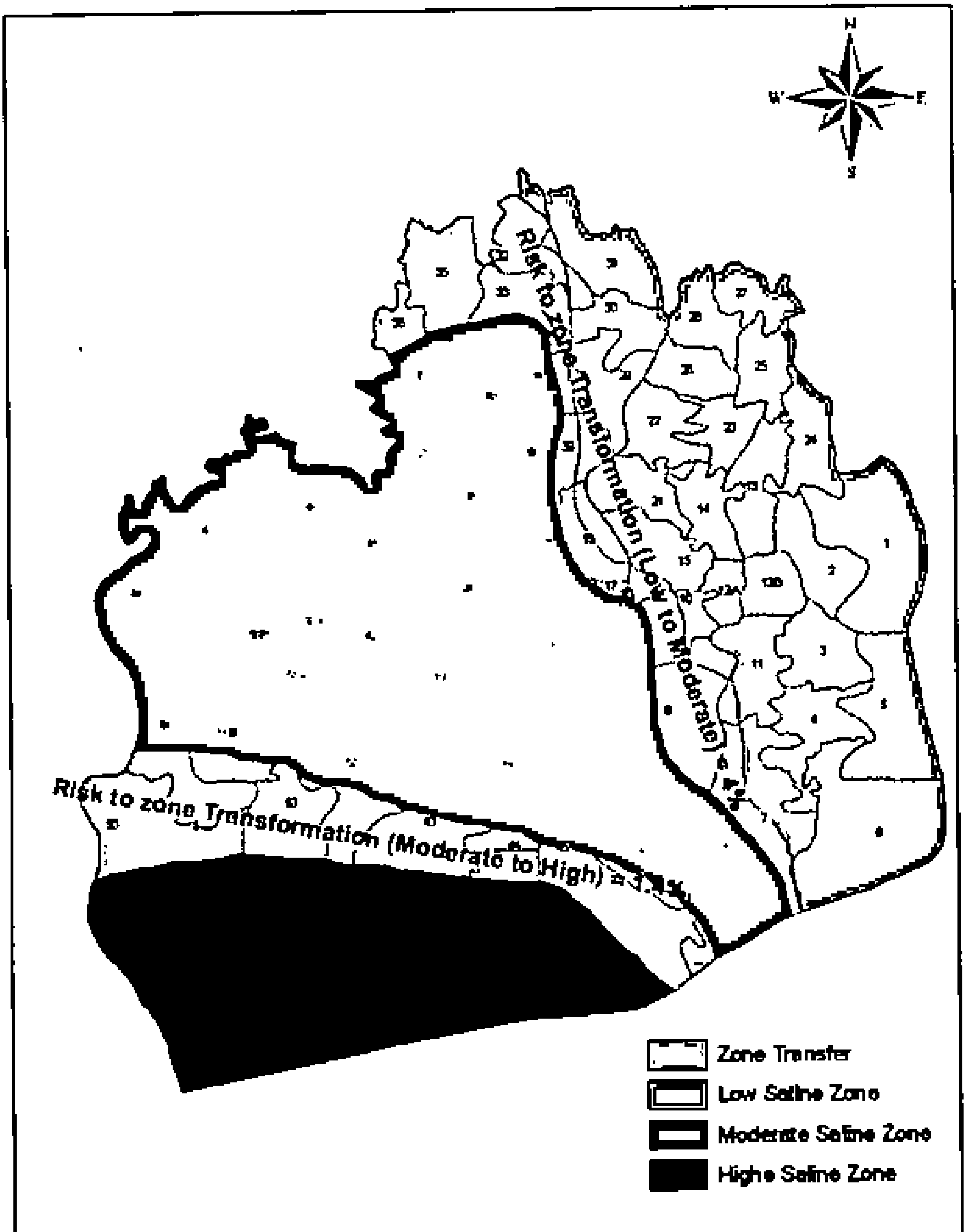


Figure 6.4: Risk map of zone transfer in Sundarbans

Note: Number in the map indicates compartment. MSWZ - Moderate Saline Water Zone and LSWZ - Low Saline Water Zone.

Table 6.15 Shows that the risk to low saline water zone to transfer to moderate saline water zone is 4 percent while the risk to moderate saline water zone to transfer to high saline water zone is 1.4 percent.

Table 6.15: Risk to transformation of ecological zone

Ecological Zone	Probability of 88cm SLR	Vulnerability	Risk
Low saline water zone	0.2	0.2	0.04
Moderate Saline Water Zone	0.2	0.07	0.014

The study found the vulnerability of 88cm SLR to ecological zone to transfer is 0.12 so the risk to ecological zone transfer will be about 2.4 percent

Chapter Seven
Conclusion and Recommendation

7.1 Conclusion

This study aimed to assess the impact of sea level rise and the potential risk to the Sundarbans ecosystem. Two key questions were addressed and these are how the mangroves of the Sundarbans will be affected and how much risk they are going to face in future.

According to the TAR of IPCC, mean sea level will continue to rise up to 88 cm by the year 2100. Sea-level rise is the greatest climate change challenge that mangrove ecosystems will face in future. The EPA has calculated the probability of different sea level rise for global aspect. According to EPA, the probability of 88cm sea level rise is 20 percent. Due to sea level rise, salinity of the Sundarbans ecosystem will be increased. As a result, ecological entities of the Sundarbans viz. ecological zone, productivity, regeneration etc will be affected. In case of ecological zones, all saline zones will not be converted completely even all the compartments in each zone will not be affected. The impact on ecological zone will be as follows.

- The low saline water zone will be reduced from 45 percent to 36 percent
- Moderate saline water zone will be reduced from 50 percent to 47 percent.
- High saline zone will be increased from 5 percent to 17 percent.

Due to transformation of ecological zone, the productivity of the affected compartments in low saline water zone and moderate saline water zone will be replaced by the productivity of nearby compartments of moderate saline water zone and high saline water zone respectively. Thus

- Low saline water zone will lose 47,652 cum of mangrove production.
- Moderate saline water zone will lose 14,998 cum of production.

Concerning regeneration of the Sundarbans ecosystem,

- About 96,223,780 numbers of seedlings will be lost at low saline water zone. and
- Moderate saline water zone will lose about 15,623,565 numbers.

- This number is quite higher regarding Sundari seedlings. The loss of Sundari seedlings at low saline water zone and moderate saline water zone is 149,956,794 and 44,761,075 respectively.

- The vulnerability to transfer of low saline water zone to moderate saline water zone will be 0.2 while the vulnerability to transfer of moderate saline water zone to high saline water zone will be 0.07. The vulnerability to transfer of ecological zone will be 0.12 and thus the risk to ecological zone transfer will be 2.4 percent.

- Regarding productivity, the vulnerability will be 0.07 and 0.06 at low and moderate saline water zone respectively whereas it will be 0.07 for whole Sundarbans and the risk to production will be 1.4 percent.

- From the regeneration point of view, for low saline water zone the vulnerability will be 0.22 and for moderate saline water zone it will be 0.05 while the vulnerability to regeneration for whole Sundarbans will be 0.15 and the risk will be 3 percent.

- The risk will be quite higher for Sundari seedling and it is 8 percent.

7.2 Recommendation

Present study identified some gaps in information regarding Sundarbans and sea level rise. Following recommendation can be effective for further study on ecological risk assessment.

- A separate study should be conducted to calculate probability of sea level rise. IPCC did not mention probability of a particular sea level rise.
- There are different mangrove species in the Sundarbans, those have different saline sensitivity. A study on saline sensitivity of mangrove species should also be conducted to assess degree of loss to mangrove species per unit salinity increase.
- Every species must have capacity of recovery. Another study on resiliency of mangrove species should also be carried out to assess recovery rate of different mangrove species at different saline level.

Following actions can be recommended, to protect the world largest mangrove forest against sea level rise:

Increase mangrove resistance and resilience by reducing and removing stresses

Promoting overall mangrove ecosystem health by reducing and eliminating non climate-related stresses, such as pollution, will increase resistance and resilience to sea level. Local communities and leaders must recognize the long-term benefits of mangrove conservation.

Mangrove rehabilitation

Capacities to rehabilitate mangroves (restore, enhance and create mangroves) will compliment other activities taken by people to adapt to mangrove responses to sea level. Restoring areas where mangrove habitat previously existed, enhancing degraded mangroves by removing stresses that caused their decline, and creating new mangrove habitat will help to offset anticipated reductions in mangrove area and increase resistance and resilience to climate change. This can be done by allowing mangrove's landward migration.

Reduction in duration of permanent inundation

To reduce permanent inundation, sedimentation is important. But according to study done by Abdur Rahman, Professor, Forestry and Wood Technology, Khulna University, sedimentation is responsible for top dyeing disease to Sundari species. That's why it is suggested to introduce controlled and guided sedimentation that will have a balancing influence on subsidence process and can help delay permanent inundation of the forest floor.

Reduction in salinity

The most important adaptation strategy will be to reduce the threats of increasing salinity, particularly during the low flow period. This may involve a range of physical adaptations to offset salinity ingress, including: (a) increasing freshwater flows from upstream areas; (b) resuscitation of existing river networks towards improving flow regime along the forest; and (c) artificial enhancement of existing river networks to facilitate freshwater flow regime along the rivers supplying freshwater to the western parts of the forest.

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