Mangrove Ecosystem of Sundarbans, India: Biodiversity, Ecology, Threats and Conservation.

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Abstract

Mangrove ecosystem, an unique, fragile, highly productive ecosystem in the sea- land interphase, is the conglomerations of plants, animals and microorganisms acclimatized in the fluctuating environment of tropical intertidal zone. This ecosystem is a highly valued ecosystem in terms of economy, environment and ecology. Mangrove ecosystem of Sundarbans, India, (between $21^0$32' – $22^0$40' north and between $88^0$85' – $89^0$00' east) a World Heritage Site, is a unique tidal wetland from the point of view of its biodiversity and ecology. This tidal dominated deltaic complex is the largest of its kind and covers an area of 1,000,000 ha of land and water, the major part (60%) of which is situated in Bangladesh while the remaining western portion (40%) lies within India. The mighty Indian river, the Ganges and its associated estuaries like Muriganga, Saptamukhi, Bidyadhari, Haribhanga, Matla, Thakuran etc open into the Bay of Bengal having a north – south direction of water flow. The silt and loam carried by these estuaries were deposited on the salt marsh eventually leading to the formation of mosaic of 102 deltaic islands of which 54 have been reclaimed for human habitation. A number of geo-morphological and resultant hydrological changes have contributed for shapping and reshapping of this estuarine complex making it a very dynamic system. This ecosystem (representing worlds' one of the most productive ecosystem) harbours thousand of flora and fauna in its diversified habitats and niche. The biodiversity includes true mangrove plants (34 species) and their associate plant species (40), 150 species of algae,163 species of fungi, 32 species of lichen, 250 species of fishes, 7 species of amphibian, 59 species of reptiles, around 200 species of birds, 39 species of mammals, besides numerous species of phytoplankton, zooplankton, ichthyoplankton, benthos, soil inhabiting micro arthropods and mangrove plants dependant insects. Species composition, and their distributional pattern, population dynamics and community structure of different groups of fauna experience wide range of changes spatially and temporally because of the prevailing fluctuating environmental condition. Temperature, rainfall and tidal mixing mostly make this environment unstable with a wide range of variation of major ecological parameters like salinity, pH, dissolved oxygen, nutrients, turbidity etc. from east to west in different periods of year. This ecosystem maintains rural economy by providing timber, fuel wood, faunal resources like fishes, honey etc and protects coast from soil erosion, buffer cyclone, stormes etc, mitigates flood and maintain estuarine flow. However, the biodiversity and basic fabric of ecosystem functioning are being threatened because of several reasons like reclamation of deltaic island for human use, deforestation, erosion and unwanted accretion, salinity invasion, nonjudicious exploitation of fishes, floral and other faunal components, ecotourism, bioinvation and pollution. Further the impact of global climate change has aggreviated the problem. The paper discusses the biodiversity conservation strategies which are being adopted giving due importance to the success and failure of previous ones..

Key words: Mangrove Ecosystem, Sundarbans, Biodiversity, Deltaic Island, Conservation.

I. Introduction: The term mangroves collectively refers to woody halophytic angiospermic trees inhabiting in the intertidal zone of coastal-estuarine regions in the tropics and subtropics, especially between 25^0 N and 25^0 S where the winter water temperature remains not less than 20^0 C. Abundance of mangroves declines gradually with increasing latitudes (Connoly and Lee 2007). Mangrove ecosystem represents one of the most productive natural wetlands found in the intertidal zone of tropical and subtropical regions of the world (Chaudhuri and Choudhury,1994). This specialized ecosystem, dominated by intertidal salt tolerant halophytic vegetation and enjoying the influences of two high and two low tides a day, offers a unique environment for bioresource development on one hand and maintains ecological balance through the protection of coastal line on the other (Chakraborty, 1995). This detritus based coastal ecosystem is highly productive having a productivity of about 20 times more than the average oceanic production (Goudha and Panigrahy, 1996).The importance of mangrove ecosystem for its potential for fisheries and aquaculture development has received wide acceptance all over the globe mainly due to two reasons: Firstly , large quantities of energy, in the form of mangrove plants contributed detritus, are exported from the mangrove forest to open water bodies (Odum and Heald, 1975) and positive correlation in between the extent of mangroves and total fisheries yield from adjacent water (Macnae, 1974,Lee,1995), Secondly, profitable regional and international markets for high quality aquaculture products are available. Owing to difficulties in accessing rigorous mangrove ecosystems, in depth ecological researches are limited in comparison to such studies on some other coastal ecosystems like coral reefs. However, their geographical distribution, floral and faunal surveys and potential for fisheries prompted more research on mangroves in the last couple of decades (Ellison et al, 1999). The present paper deals with the diversity, distribution, zonation, succession, ecological interactions of mangrove flora and fauna of Sundarbans mangrove ecosystem of India with special emphasis on different threats and conservation strategies of this ecosystem.

II. Physiography of Sundarbans Mangrove Ecosystem, India

The Mangrove dominated estuarine networks represent the major feature of coastal environment of West Bengal. The Indian Sundarban having 102 deltaic islands, (42 virgin and 54 reclaimed) is located between $21^0 30'$ - $22^0 15'$N & between $88^0 10'$ - $89^0 10'$ E mostly within South 24- Parganas Districts of the state of West Bengal (Fig.-1). This largest tidal wetland and only mangrove tiger land on the earth, declared by IUCN, 1997 as 'World's Heritage Site', represents a highly valued ecosystem in terms of economy, ecology and environment. It includes a Tiger Reserve (2585 km^2, 1970), 3 wild life sanctuaries (Lothian, 3,800 ha; 1948; Sojnekhali, 35,240 ha; 1960 and Holiday Island, 595 ha; 1976) and one National Park (1330 km^2; 1972). However, the landscape of the Indian Sundarban has changed remarkably because of several natural and anthropological activities like land reclamation, drainage control, sediment control, protective measures against tidal flooding, neotectonic movement, international treaty on sharing of fresh water etc over past centuries. The cumulative effect of all those changes led to alter physicochemical properties of this ecosystem (salinity invasion, massive shoreline erosion coupled with unwanted accretion, shifting of mudflats and sand dunes, increased turbidity, temperature, tidal amplitude and decreased transparency, nutrients, pH etc). Such changes have resulted to modification of species composition of biotic communities leading to the decline and loss of mangrove dependant detritivores, herbivores and other carnivores.

III. Global distribution of Mangroves:

Mangrove has a world wide circumtropical distribution, the highest concentration being located in the IndoPacific region. The mangrove dominate almost 1/4th of worlds tropical coastline. The total mangrove area which spans 30 countries including varius islands nations is about 1,00,000 km2 (Annon, 2003).

Global distribution of mangroves are determined by an array of interlinked and interdependent factors like edaphic factors (soil texture, nutrients and microbial load), geomorphologic factors (rate of sedimentation, stabilization of deposited sediments by flora and fauna in the process of deltaic island formation), physical factors (amplitude and intensity of tides, micro and macrotidal cycles, current of water , salinity and other water parameters) climatological conditions (rainfall, temperature etc) and biological factors (flora, fauna, and microbs). So far 69 vascular plant species of mangroves having several specific adaptations to thrive well in the rigorous and dynamic coastal marine-estuarine environment have been documented (Blasco, 1975; Chapman, 1976; Kathiresen and Bingham,2001) These mangroves and their associated plant species support the life of a diversified form of other faunal components (crustacean, molluscs, polychaetes, finfishes etc), algal (benthic and planktons) and microbial diversities (Chaudhuri and Choudhury, 1994; Annon, 2003). Another 80 species of plants, both herbaceous, and woody, being recognized as mangrove associates have been recorded (Cannolly and Lee, 2007) and they do not have special adaptations for living in the intertidal environment. More than 41% of the world's mangrove occur in South and South east Asia of which Indonesia alone accounts for 23% (Gopal and Chauhan, 2006). A further 20% of the total mangrove area lies in Brazil,Australia and Nigeria (Spalding et al 1997). However, largest chunk of the world's mangrove occur in Ganga- Brahmaputra-Meghna Deltaic system of Sunderbans jointly shared by two countries - Bangladesh and India.

IV. Geological past and estuarine networks of India.

The Sundarbans mangrove – estuarine system is comparatively recent in origin. Deltaic formation of Ganga- Brahmaputra system was supposed to have been initiated at the end of Miocene and reached to its present form, only 10,000 back (Pleistocene to recent). Several geomorphological changes since Tertiary period because of tectonic movements, especially in northwestern Punjab and the southestern flow of the River Ganga resulted in the deposition of sediments in the Bengal basin and development of the Sundarban Delta (Wadia,1961; Gopal and Chauhan,2006). The sediments brought in by the Ganga- Brahmaputra system during post – pleistocene period probably bypassed the deltaic part for a great extent which contributed to the rapid growth of Bengal deep sea fan (Biswas, 1991). During 12th and 16th Century, neotectonic movements in the Bengal Basin forced the Ganga river to change its course towards eastwards leading to its joining with Brahmaputra and deltaic portion of Bengal Basin to shift towards east (Morgan and McIntire, 1959). Such continuous tectonic activities considerably influenced the hydrology of the Bengal Basin because of changes in the sedimentation pattern and shifting of fresh water flow eastward towards Bangladesh, imposing salinity invation in the Hoogly- Matla estuarine complexes of Indian Sundarbans (Hazra et al, 2002; Gopal and Chauhan, 2006).

The entire Sundarbans is criss-crossed by a number of estuaries.This estuarine complex of the tropics occupies an important place in the global map and can be categorized as River- Delta estuary as advocated by Odum (1971) in addition to Pritchard's (1967) four categories of estuarine system.

The estuarine network of Indian Sundarbans include seven major estuaries viz. Hoogly, Muriganga, Saptamukhi, Thakuran, Matla, Bidyadhari, Gosaba and Harinbhanga and they flow from west to east **(Fig.- 1).** Out of these seven estuaries, five (Muriganga, Saptamukhi, Thakuran, Mtla and Gosaba) have lost their connection with the main flow Ganga river because of siltation and their estuarine character is now maintained by the monsoonal run off alone (Cole and Vaidyaraman, 1966). Thus the delta building process has nearly ceased in the west but has accelerated in the eastern part (Gopal and Chauhan, 2006). In 1960's, the total area of the Indian mangrove was estimated as 6,81,976 ha, in which nearly 45% occurs in Sundarbans and the islands of Bay of Bengal (Blasco 1975, 1977). In addition, 1/6th of the mangrove of the country is available in Andaman and Nicobar Islands (Chakraborty and Naskar, 1988). Later Saengar et.al. ,(1983) recorded the total mangrove area as 3,56,500 ha and according to a survey in 1992, the total area of Indian Mangrove is 4,37,400 ha , which include A & N islands. Deforestation and over exploitation of mangrove have resulted into the formation of open marshy land of approximately 1,00,000 ha. Mangroves along the west coast of India are considered as highly degraded areas (Blasco 1975, 1977). The coastal areas like Gulf of kutch, Bombay coast and Cochin Backwaters are the glaring examples of deforestation, reclamation and pollution as well as population pressure (Untawale, 1984).

V. Climate:

Seasons are well defined in this coastal environment each with four months duration- premonsoon (March to June) with highest temperature (42^{o}C) and almost no rainfall; monsoon (July to October) with high rainfall (2000 ml) and moderate temperature; and postmonsoon having lowest temperature (10 ^{o}C) with occasional rainfall. Winds blow with higher intensity diving May to September from south –east to south-west directions. During early phases of premonsoon (February to April), winds blow from the south and south-west. The postmonsoon (late October to January) experiences mainly clam period having winds flowing from north-west (Annon, 2003).

VI. Tidal levels, volume and duration.

The inter tidal zone represents that part of the continental shelf which remains in between two tidal marks – highest high tide level and lowest low tide level depending on the different tidal amplitudes during different phases of tidal cycles developed in tune with the seasonal and annual variation of the location of sun in relation to moon and earth. The intertidal zone can be divided into three different sub- zones – high tide level (HTL), mid-tide level (MTL) and low tide level (LTL). HTL is the upper most part of the inter tidal zone, the extent of which is determined by the difference in between the two tidal marks – the highest tidal level during maximum spring tide of the year and the lowest tide level during the maximum neap tide of the year. The LTL represents the lower most part of the inter tidal zone, the extent of which is also determined by the difference in between two tidal marks – the lowest tidal level during maximum spring tide of the year and the lowest tidal level during the maximum neap tide of the year.The MTL, therefore enjoys the maximum area of any intertidal zone ranging from upper most border of the LTL to lower most border of the HTL. The flood and ebb tide have semi-diurnal nature (12 hrs interval) and occurs twice a day (Chakraborty et al. 2009).

According to Morgan and Mc Intire (1959), the Bengal Basin and this part of the deltaic plain is gradually tilting towards east. This has probably caused the main fresh water discharge to shift gradually eastward (through Bangladesh) imposing severe stress on freshwater budget for Hooghly- Matla estuary. The tide dominated estuarine system exhibits typical flow separation with downstream freshwater flows along the right bank and upstream saline water tide flowing along the left bank (eastern) of the channel. The Hooghly- Matla estuary experiences a higher rate of freshwater discharge than its eastern counterpart and therefore is less saline and comparatively well mixed (Hazra et al 2002).

VII. Soil quality:

Most of the soils derived from alluvial deposits are a zonal with little or no profile development (Chaudhuri and Choudhury, 1994; Sarkar et al., 1999). Clay loam is the predominating soil type in the Sundarban, though silty and sandy loams also occur in many areas. Numerous tidal flats have been formed after the headwater flow through the deltaic distributaries of the River Ganga was silted up. The parent deposits are either rich in calcium or magnesium, or consist of half decomposed organic matter. The coastal soils are usually classified as saline, non-saline and alkali soils (Annon, 2003).

Texture analysis of Sundarbans mangrove soils (Gupta, 1987) revealed that the soil was mainly silty-clay. The percentage of sand particles varied from 3.81% in Prentice island to 42.62% in Sagar island while that of silt-clay percentage varied from 57.65% in Sagar island to 94.96% in Prentice island. Water holding capacity on silt-clay soil is more (59.03% in Lothian island) than comparatively higher sandy soil (43.16% in Sagar island).regarding mangrove soil nutrient status, both the percentage of organic carbon (0.45% to 1.86%) and human carbon (0.04% to 0.24%) in surface layer were higher than those in subsurface due to the confinement of organic residues in this layer. Available N (85 ppm to 116.4ppm). P (10 ppm to 42 ppm) and K (331 ppm to 630 ppm), were present in appreciable amounts (Sahoo et al, 1985). pH of the mangrove soil varied from 6.5 to 8.1 (Gupta, 1987). Soil temperature, salinity, organic carbon and sand content were found to be higher during premonsoon, while available potassium, available nitrogen and available phosphorous were maximum during monsoon. The postmonsoon season was characterized in having lowest temperature, available phosphorous, available potassium, available nitrogen and moderate level of other parameters

VIII. Water Quality Parameters

The hydrology of the estuarine networks of Indian Sundarbans are goverened mainly by the freshwater flows from Rivers Ganga, Brahmaputra and their associated tributaries which exhibit very high seasonal variation in their discharge, and the tides which range in height from 2 to 5.94 m. The freshwater flows from the rivers and the tidal ingress result in a gradient of salinity that varies both spatially and temporally. During the past few decades, however, the sources of all rivers in the western part of the Indian Sundarban have progressively silted up, disconnecting the inflow of fresh water into the mangrove delta. The reduced freshwater flow in western parts of the Sundarban has resulted in increased salinity of the river waters, and has made the rivers shallower over the years. At the same time, during ebb tides, the receeding water level causes scouring of top soil and creates an innumerable number of small creeks. The receding water carries large volumes of silt which is deposited along the banks of rivers and creeks during high tides. This results in increasing the height of the banks as compared to the interiors of the islands. Over time, such eroded channels extend further inwards into the islands and form muddy banks which may check the penetration of high tides to the interior of the islands. Different physicochemical parameters displayed wide range of temporal and spatial variation. Water temperature, salinity, pH, conductivity, turbidity, dissolved oxygen (D.O.) and biological oxygen demand (B.O.D.) were found to be higher during premonsoon, while silicate, phosphate phosphorous (PO_4), nitrite nitrogen (NO_2), ammonical nitrogen (NH_3) and nitrate nitrogen (NO_3) were maximum during monsoon.

The postmonsoon season was characterized in having lowest temperature, moderate salinity and other parameters (Chakraborty et al, 2009).

IX. Distribution of Microbial load in Water

In the estuarine networks of Sundarbans, salinity along with total dissolved solid and total suspended solid have been found to play a unique role as ecological gradients in determining the distributional pattern of microbial components. The low microbial load was recorded in Matlah estuary which always experienced low salinity level in comparison to two other estuaries viz. Hooghly and Saptamukhi. But simple correlation analyses revealed that the temperature showed significant positive correlation with miocrobial groups in Hooghly estuary and Saptamukhi estuary whereas significant negative correlation in Matlah estuary (Chakravarty et al , 2004). Lipp et al. 2001. advocated that both the salinity and temperature display inverse relationships with the pathogenic micropopulations but findings of Chakravarty et al (2004) may be interpreted by the facts that salinity alone could not impart their role, as dumping of effluents especially sewage from adjoining municipalities and tourist complexes(Bokkhali, sagar Island, Diamond Harbor etc.) enabled the microbial components to flourish in Hooghly estuary followed by Saptamukhi and Matlah estuary. This means that the variation of microbes did not reflect any seasonality , on the other hand it was determined by the location of the estuary in question (Chakravarty et al , 2004).

X. Why Mangrove ecosystem is one of the most productive ecosystems of the world?

During high tide major parts of the forest subsystem get inundated and received the major inputs from estuarine water in the form of moisture recharging of the bottom soil deposition of sediments, and supply of nutrients (macro, micro and trace elements) for forest subsystem. During low tide, the receding water takes away huge amount of mangroves litter contributed detritus to the adjoining aquatic subsystem. The nutrients released from detritus are utilized by phytoplankton along with plenty of water and sunlight available in the open water system. Mangrove being a perennial evergreen plant, produce huge amount of leaf litter throughout the year which after falling on the moisture rich surface of silt- clay loaded bottom soil are broken down by a galaxy of benthic fauna (crabs, gastropods, microarthropods etc.) into smaller pieces providing more scopes for microbial communities (bacteria, fungi, protozoa) to act upon them for detritus production through litter decomposition. The deposit feeders (viz. crabs, molluscs, polychaetes, nematodes etc) through their feeding activities turn over the surface sediment layer, thereby exposing new litter surfaces to microbial actions Three main decomposition processes as outlined by Heal and French (1974) are the release of carbon in gaseous form by micro flora and fauna (respiration), leaching out of soluble materials and corrosion (physical break down) by fauna and physical factors.

Therefore two interlinked subsystems of mangrove ecosystem exchange biotic and abiotic components in between them and get the benefits in respect of higher biological productivity. The shallow water forest subsystem exports energy and nutrients to deeper water of estuary and adjacent coastal shelf. The plankton and nekton which move freely between the two fixed subsystems producing, converting and transporting nutrients and energy while responding to diurnal tidal and seasonal periodicities (Odum, 1971).

Hitherto, productivity of mangrove ecosystem had been attributed to four reasons: (1) three types of primary production units (marsh vegetation, benthic algae and phytoplankton); (2) ebb and flow of water movements resulting from tidal action; (3) abundant supplies of nutrients and (4) rapid regeneration and conservation of nutrients due to the activity of microorganisms and filter feeders (Schelake and Odum, 1962). A number of operating food chains for this ecosystem may be categorized into two distinct types. Firstly, the grazing food chain that begin with the consumption of live plants (both phytoplankton and mangrove vegetation) by herbivorus consumers and then by carnivorus consumers. Secondly, the detritus food chain that begin from the dead organic matter reach into microorganisms and then to detritivores and their predators. These different food chains are inter connected with one anothers to produce a very complicated mangrove estuarine food web. The physical, chemical and biological processes operating in mangrove ecosystems to sustain high levels of productivity are due to the wide range of interactions among different structural components (viz. soil, water, flora and fauna) of the ecosystem **(Fig-II).**

The degrading plant litters are consumed by a wide variety of organisms and they release a considerable amount of nutrients to mangrove ecosystem for recycling. The litter fall in Sundarban mangrove forest is higher than 550 gm dry wt./m2/year as found in mangroves at Rookery Bay by Lugo and Snedaker (1974) and 876 gm dry wt/m2/year as observed by Heald (1971) of mangrove at Everlade Park area in Florida (Jadav and Choudhury, 1985).

XI. Biodiversity of Indian Sundarbans:

Owing to wide range of temporal and spatial variation of different ecological parameters (salinity, pH, temperature, railfall, nutrients, etc) and ecological processes (duration of tidal exposure and inundation, volume of water, fresh water inflow and mixing with saline water, erosion and accretion, etc) in different creeks and tributaries, salt marshes, sandflats and mudflats, the Sundarbans mangrove estuarine complex supports a rich diversity of flora and fauna in varying ecological niche and habitats.

A. Diversity, distribution , zonation and succession of floral components:

Mangroves are an 'artificial assemblage' of trees and shrubs i.e. species are not taxonomically related with one another, which demonstrate special adaptations for life in the intertidal zone (Tomlinson,1986).The adaptability of mangrove plants to thrive well in the stressful ecological condition is ensured by the possession of pneumetaphores and trap roots, sunken stomata, viviparous germination, thick lignin coating on leaves etc.

69 species of true mangroves belonging to 26 genera and 20 families have been recognized by Duke (1992) while Kathiresan and Bingham (2001) considered 65 species (22 genera and 16 families) as to be true mangroves. Another 80 species of plants, both herbaceous and woody showing no special adaptation for living in the intertidal environment have been recorded as mangrove associates and they bridge the gap between, mangroves and terrestrial vegetation (Duke, 1995). Sundarbans mangrove ecosystem harbours 34 true mangrove species, out of the above mentioned ones, a total of 163 species of fungi (Chaudhuri and Choudhury 1994), 150 species of algae (Naskar et al

2004) and 32 species of lichens(Santra 1998)   40 species of mangrove associate (Annon, 2003).

Table-I: The floral diversity of Indian Sundarbans.

Groups of plants	No. of species	Reference
True mangrove	34	Chaudhuri and Choudhury, 1994
Mangrove associates	40	Annon, 2003. Chaudhuri and Choudhury, 1994
Mesophytic invasive species	10	Bhakat et al, 2004
Algae	150	Naskar, 2004
Lichens	32	Santra,1998
Fungies	163	Chaudhuri and Choudhury, 1994

Out of the true mangrove plant species, special mention may be made of *Rhizophora apiculata, Sonneratia apetala, Avicennia marina, Excoecaria agallocha, Bruguiera cylindrica, Acanthus ilicifolius* etc. The mangrove associated plants are represented by species such as *Sarcolobus carinatus, Suaeda maritima, Pandanus tectorius* etc. Some examples of the mesophytic bioinvasive plants occurring in the three study sites are *Casuarina equisetifolia, Alternanthera* sp. etc (Bhakat et al 2004). Important phytoplankton species include *Nitzschia* sp., *Peridinium* sp., *Ceratium* sp., Thalassiosira sp., Planktoniella sp, Gosslorilla sp., Rhizosolenia sp., Ditylum sp., Triceratium sp., Fragilaria sp., Gyrosigma sp., Diploneis sp., Navicula sp., Dynophysis sp., Oedegonium sp etc (Annon, 2003). The algal community provide a novel source of nutrients to the whole ecosystem. The algae remain in the mangrove forest subsystem as an epiphytic assemblage living on the stems, pneumatophores of mangrove trees and on the surface of the sediment as epibenthic form. Besides, a number of algae remain in the water subsystem as phytoplankters and play a great role in the total productivity and energy flow of the system (Gopalakrishnan, 1972; De et al, 1987). This mangrove ecosystem harbours 48 bacterial strains from the decomposed litter (Bhowmick et al, 1985) which play the key role in the total nutrient cycle of the ecosystem by their exo-enzymatic activities leading to degradation of cellulose, hemicellulose, pectin, chitin,lignin etc(Biswas, et al. 1986). Out of 150 species of algae recorded from Indian Sundarbans, 50 species belong to Cyanophyta, 39 species belong to Chlorophyta, 2 species belong to Pheophyta, 44 species belong to Chrysophyta of which 42 species are diatoms and 15 species belong to Rhotophyta (Naskar et al. 2004). The occurrence, distribution and succession of mangrove species are determined by virtue of the adaptive ability of different species with the fluctuating ecological conditions.

In Sundarbans, there is a distinct zonation of different mangrove species along the intertidal slope reflecting their adaptation to different prevailing ecological factors viz. duration of tidal inundation and exposure, salinity, sediment characteristics etc. Mudflats are developed in some sheltered areas on the deltaic islands of the Sunderbans due to higher sedimentation load and lower velocity of water. The finer sediment constituting the thick mudflats are rich in organic content and ideal for penetration by plant roots. The surface of these flats are initially covered by thick algal mat. Consequently luxuriant growth of mangrove vegetation occur, showing distinct zonation pattern. Ginsburg and Lowenstam (1958) reviewed the evidence of stabilizing and salt trapping powers of filamentous algal and marine phanerograms (mangroves) in shallow sheltered waters. The species replacement of mangroves in a particular mudflats consolidates, elevates the substratum and creates shades and makes way for another (Paul et al, 1987). The zonation of mangrove vegetation in Sundarbans showed that the seaward edge of the forest is endowed with saline grass *Porterasia coarctata* which are followed towards landward by *Avicenia officinalis, Suaeda maritima, Bruguiera gymnorhiza, Sonneratia apetala* and *Ceriops roxburghiana*. Different floral and faunal community display different zonation pattern reflecting their adaptation to different degrees of terrestriality, duration of inundation and exposure, salinity gradients, textural and nutrients components of the soil, biotic association etc (Chakraborty and Choudhury, 1992). *Heritiera fomes* requires more freshwater and occur together with *Phoenix pelludosa* and *Nypa fruticans*, generally above the mid tidal level. The mangrove species like *Excoecaria agallocha*, *Ceriops* *decandra, Rhizophora apiculata* and *Bruguiera gymnorhiza* are found to inhabit in relatively higher saline zones experiencing higher intensity of currents and longer exposure. Lugo and Snedaker (1974) inferred that zonation patterns in mangroves represents steady state adjustment rather than successional stages.

The succession of group of vegetations as observed in the Sundarbans, covering around 70% of forest area is as *Porteresia coarctata, Phagmites karka, Sesuvium portulacastrum, Avicennea officinalis* →*Acanthus illicifolius*, *Aegiceras corniculatum, Avicennia alba, A. marina, Sonneratia apetala* → *Bruguiera gymnorhiza, Salicornia brachiata, Ceriops dacandra*→ *Heritiera fomes, Rhizophora apiculata, Xylocarpus mekongenesis* →*Ceriops dacandra, Excoecaria agallocha, Phoenix pelludosa, Suaeda maritime.*

B. Diversity, distribution and zonation of faunal components

Highly productive Mangrove ecosystem supports a high abundance and diverse variety of faunal components (Ong, 1995). The faunal biodiversity includes 215 species of fishes, 7 species of amphibia, 59 species of reptiles, more than 200 species of birds, 39 species of mammals, besides numerous species of phytoplankton, zooplankton, ichthyoplankton, benthos, soil inhabiting and mangrove plants dependant insects (Chaudhuri and Choudhury, 1994; Annon, 2003). Species composition, and their distributional pattern, population dynamics and community structure of different groups of fauna experience wide range of changes spatially and temporally because of the prevailing fluctuating environmental condition.More distinct zonations have been revealed by different macrobenthic fauna especially brachyuran crabs, molluscs and polychaetes (Chakraborty and Choudhury, 1992). Mangrove ecosystem of Sundarbans supports a rich estuarine fauna in hundreds of creeks and tributaries, salt marshes, sandflats and mudflats in the form of plankton, benthos and nekton. Zooplankton, an important biotic component of mangrove aquatic subsystem, constitutes the secondary and tertiary trophic levels of mangrove food web (**Fig-II and Table-III**). The faunistic composition of zooplankton in this system includes copepods as principal component of the total zooplankton (67.8% to

90%). A total of 36 copepod species belonging to 19 families and 21 genera have been recorded (Sarkar et al, 1986). Other zooplanktonic forms are mysidacea, sergestidae, amphipoda, cladocera, ostracoda, cumacea, chaetognatha, hydromedusea etc (holoplankters) and polychaete larvae, nauplius, zoea, megalopa, fish eggs and larvae, echinoderm larvae etc (meroplankters) (Annon, 2003, Chakraborty et al.2009).

Icthyoplankton, the juvenile stages of fin fisheses constitute an important planktonic group and include hundred of species under 29 families. The major families are Clupeidae, Megolopidae (Chakraborty et al, 2009). A hoard of benthic fauna, both infauna (sessile, semisessile and burrowing) and epifauna (crawlers and creepers) are the happy residents of these habitats which are subjected to various oscillatory exposures of hydrological parameters (Chakraborty et al, 1992; Chaudhury and Chaudhury, 1994). Most of the benthic organisms have evolved various behavioural and physiological adaptation to cope with the stress due to varying ecological conditions (Vernberg and Vernberg, 1972). Besides, benthic fauna are divisible into three broad groups based on their body sizes—macrobenthos, meiobenthos and microbenthos. There is a distinct zonation of different microbenthic species along the intertidal slope reflecting their adaptation to different prevailing ecological parameters (Chakraborty and Choudhury, 1985; Chakraborty and Choudhury, 1992). Among the intertidal macrobenthic fauna, brachyuran crabs constitute a dominant faunal component of ecological and economic significance. 26 species of brachyuran crabs belonging to 15 genera and 5 families have been recorded from the deltaic Sundarbans estuarine complex (Chakraborty et al, 1986). A total of 69 species of polychaetes under 45 genera and 25 families have been documented from this ecosystem (Misra,1986). Subba Rao et al, (1986) recorded 110 species of benthic mollusca from the intertidal zones of Sundarbans, India which are distributed under class gastropoda (59 species) and bivalvia (40 species). These salt marshes also harbour a rich abundance of benthic insects in its different categories of soils. A total of 24 dipteran species belonging to 5 families and 11 genera (Roy and Choudhury, 1989) and 14 coleopteran species (Poddar et al, 1990) have been reported. Phytophagus insects living on mangrove plants are noticed in abundances which include 2 species of hemiptera, 1 species of hymenoptera, 8 species of hemiptera, 1 species of homoptera, 16 species of coleopteran, and 30 species of diptera (Chakraborty and Naskar, 1988). Actiniarian, sipunculans, echiurans, hemichordates, globid fishes etc are other important benthic faunal groups. Dey et al, 2010 recorded 44 species of microarthopods belonging to six major taxonomic groups viz. Acarina, Collembola, Coleoptera, Diptera, Isoptera, and Hymenoptera. 80 species of nematodes belonging 26 families have been documented (Chaudhuri and Choudhury 1994). Rao and Misra,1983 studied meiofaunal abundance in Sagar Island, Sundarbans and found that nematodes constitute the most dominant group followed by copepoda, polychaeta, ostracoda etc. An ecological survey on the distribution of subtidal and intertidal foraminiferan faunal components revealed the occurrence of 58 species belonging to 31 genera under 21 families and 4 suborders from the coastal belts of West Bengal, especially in and around Sundarbans mangrove ecosystem (Majumder et al, 1996)

The outwelling hypothesis of Odum, (1971) in respect of transportation of detritus contributed nutrients to aquatic subsystem assisted prolific development of fisheries (Manson et al 2005). The finfishes and shell fishes constituting nektonic fauna of this mangrove estuarine system can be divided into two broad groups—residents and transients or migrants. The resident species according to their salinity tolerance are grouped into three categories. First category (salinity from 6.2% to 32.86%) includes Mullets- *Liza parsia* and *L. tade*; thread fins – *Polynemus tetradactylus* and *P. indicus*; *Sciaena miles* and *Sciaenoides biauritus*; Perches – *Lates calcarifer;* Ribbonfish – *Trichiurus savala*; Clupeids – *Hilsa sinensis* and *Coilia bornunsis*; Catfish – *Tachysurus jella* and *Plotosus canius*. Second category (salinity from 4% to 32.86%) includes *Harpodon nehereus, Setipinna taty* and *Ilisha elongate*. Third category (salinity 32.86%) includes *Pama pama, Coilia ramcarati, Polynemus paradiscus, Setipinna phasa, Sillaginopsis panijus*. The migrant species usually enter the estuarine zone for breeding and feeding. These species can be broadly divided into three categories. Firstly, marine forms that migrate upstream and spawn in fresh water areas of the estuary are: *Tenulosa ilisha, Polynemus paradiscus* etc. secondly, fresh water species which spawn in saline areas of the estuary are: Pangasius pangasius and the prawn Macrobrachium rosenbergi. Thirdly, marine fishes that spawn in the saline areas of estuary are: *Tachysurus jella, Polynemus indicus, Penaeus indicus, P. monodon* etc. A total of 172 species of fishes has been recorded from the Hoogly Matlah estuarine complex of which 73 occupy the less saline zone and 99 the higher salinity zone (Jhingran, 1991). A total of 26 species of prawns and shrimps spread over in 5 families occur in these estuarine water bodies of Sundarbans (Gopalakrishnan, 1971). Chaudhuri and Choudhury (1994) mentioned the occurrence of 250 species of fishes in the estuaries of Sundarbans. However, Naskar et al (2004) listed 137 fish species from Indian Sundarbans of which 13 belong to chondrichthys and rest to Ostichthys.

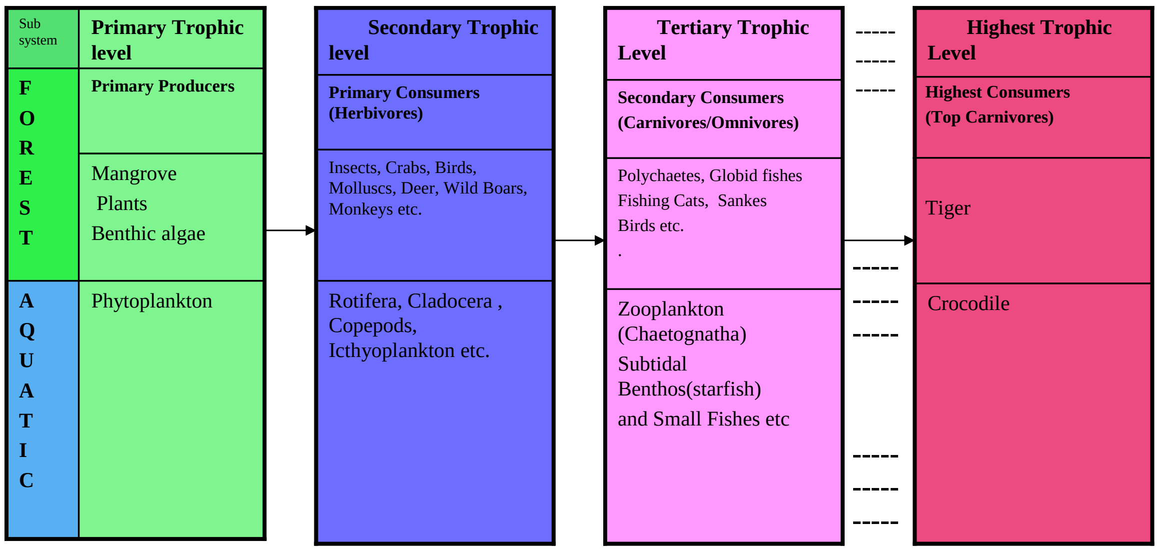
XII. Ecology:

The ecology of mangrove ecosystem includes the interactions among its different structural components viz. plants, animals, microbes, soil and water.

A. Trophic Relationships:

The trophic relationships among different biotic components of mangrove ecosystem reveal that 3 different types of green plants (mangrove plants, benthic algae and phytoplankton) represent the first trophic level as primary producers which are taken up as food by primary consumers representing secondary trophic level (insects, intertidal crabs, molluscs, forest inhabiting deers, wild boars, birds, monkies etc) The fauna belonging to tertiary trophic levels are mainly carnivores and also omnivores. Such flow of energy through some other trophic levels, mostly represented by carnivores and omnivores (larger finfishes, dolphins, leopard cats, turtles, water monitors and different birds) ultimately end to highest trophic level, represented by top carnivores like Royal Bengal tiger(Panthera tigris tigris), crocodile (Crocodylus porous) etc.

Fig-II Trophic relationships in Mangrove Ecosystem



B. Role of Physicochemical parameter:

Different physico-chemical parameters of soil and water determine the temporal and spatial variation of biodiversity components, govern their distribution and succession, and also ensure biological productivity by maintaining the energy flow and decomposition cycle. Fluctuation of all ecological parameters, mainly because of the changes in the meteorological conditions like temperature, precipitation, wind flow etc coupled with marine and estuarine physical processes like tides, waves and current of water, make this environment very much unstable and force the biological components to restrict their own territory in different parts of Sundarbans.

C. Ecology of flora:

The change in the distribution of plants species reveal a distinct shift in their species composition from east to west parts of Sundarbans. A study shows the occurrence of 24 true mangrove species, 21 mangrove associated plants and 9 mesophytic bioinvasive plants in the north-east, while 17 true mangrove species, 19 mangrove associated plants and 10 mesophytic bioinvasive plants are found in South-west parts of Sundarbans. The central part is represented only by 16 true mangrove plants and 8 mangrove associated plants (Chakraborty et al 2010). It has been observed that such distributional patterns are determined by salinity, cations exchange capacity, water holding capacity and textural composition of soil (Chaudhuri and Choudhury 1994).

Maximun density and diversity of phytoplanktonic species have been recorded during premonsoon followed by monsoon and postmonsoon. Species richness was found to reach its maximum during monsoon and came down to minimum during premonsoon ((De et al. 1987; Chaudhuri and Choudhury , 1994).

Smith (1992) reviewed factors and mechanisms that may determine local forest structure of mangroves: (1) land building processes driving autogenic succession of mangroves; (2) response of species to geomorphologic influences such as sea level rise; (3) physiological adaptations to stress gradients such as soil, salinity in the intertidal zone; (4) dispersal patterns of mangroves propagules in accordance with size and rooting time; and (5) post disposal processes determining propagule establishment, such as predation and competition.

Different mangrove species have different optimal requirements in salinity, nutrient abundance and soil characteristics (Hatchings & Saenger, 1987), translating to correlations between soil properties and species recruitment, establishment and dominance (e.g. McKee, 1995a; Lovelock et al. 2005). Availability (e.g. proximity to parent tree, tidal dispersal) and retention of propagules also influence the initial community structure (McKee, 1995; Patterson et al. 1997).

Table- II: Major mangrove species of Indian Sundarbans.

Sl. No.	**Families**	**Major species**	**Status**
1.	Rhizophoraceae	1. *Rhizophora mucronata* Lamk *2. R. apiculata* Blume 3. *Bruguiera gymnorhiza* (L) Lamk *4. B. cylindrical* L 5. *Ceriops tagal* (Perr). Robinson 6. *C. decandra* (Griff) Ding Hou 7. *Kandelia candel* (L) Druce	Tree Tree Tree Tree Tree Tree Tree
2.	Avicenniaceae	1. *Avicennia officinalis* L. *2. A. alba* Blume 3. *A. marina* (Forsk) Vierh	

3.	Sonneratiaceae	*1.* *Sonneratia apetala* Buch Ham 2. *S. caseolaris* (L) Engler	
4.	Combretaceae	1. *Lumnitzera racemosa* Willd	
5.	Meliaceae	1. *Xylocarpus granatum* Koen 2. *X. mekongensis* Pierre P	
6.	Arecaceae	*1.* *Nypa fruticans* (Thunb) Wurmb *2.* *Phoenix paludosa* Roxb	Threatened because of less fresh water and highland inhabitat preferred home of Tiger
7.	Sterculiaceae	*Heritiera fomes* Buch Ham	Tree
8.	Myrsinaceae	*Aegiceras corniculatum* (L) Blanco	Shrub
9.	Rubiaceae	*Scyphora hydrophyllacea* Gaertn. F	Shrub
10.	Euphorbiaceae	*Exoecaria agallocha* L.	Tree
11.	Acanthaceae	*Acanthus ilicifolius* L.	Shrub
12.	Malvaceae	*Thespesia populnea* (L) Solander *Hibiscus tiliaceus* L	Tree Tree
13.	Tamaricaceae	*Tamarix dioica* Roxb	Tree
14.	Fabaceae	*Derris indica* (Lamk). Bennet	Tree/ Climber
15.	Convolvulaceae	*Ipomoea pes-caprae* Sw	Creepers. Sand binders pioneer species in Dune formation
16.	Chenopodiacea e	1. *Suaeda maritima* (L) Dumort 2. *Salicornia brachiata* Roxb	Herb Herb
17.	Poaceae	1. *Porteresia coarctata* Takeoka 2. *Phragmites kakra* Trin Ex Steud 3. *Cynodon dactylon* (L) Pers	Grass Grass Grass

D. Ecology of Fauna:

Mangrove animals have been studied mostly for their trophic and bioturbating roles and their capacity for commercial fishing production (Connolly and Lee, 2007). Ecology of two major faunal groups viz. plankton and benthos of Sundarbans Mangrove Ecosystem India, have been studied extensively during last three decades by different researchers. Sarkar et al, (1986) reported that copepods being the most dominant zooplanktonic group enjoyed bimodal type of population fluctuation with relatively higher population density during mansoon and also with a slight peak of population during last phase of winter. Some species under both chaetognatha and cladocera, the two other major zooplanktonic groups experienced their maximum population density during higher saline periods i.e. premonsoon period: (Chaudhuri and Choudhury,1994).

Different macrobenthic faunal groups viz. brachyuran crabs, polychaetes, molluscs in Sundarban mangrove ecosystem displayed varying fluctuation trend of seasonal population density and community structure. The fiddlers crab's population density displayed its maximum during premonsoon followed by postmonsoon while many species of polychaetes have been found to occur in maximum density during monsoon. The species diversity indices taking into consideration of total benthic faunal groups were maximum during premonsoon and minimum during monsoon. However , such indices with polychaetous and molluscan faunal components registered maximum values during monsoon. (Chakraborty et al 1992; 1992 A; Chakraborty and Chaudhury , 1993; Chakraborty and Chaudhury , 1994; Chakraborty and Chaudhury , 1997; Chakraborty et al, 2009). Several researchers have put forward their views regarding the influence of different ecological parameters on such spatial and temporal variation of density and community of macrobenthic species. Barnes (1967) stressed the importance on osmoragulatory abilities of macrobenthos pertaining to their distribution in time and space. Teal (1958) and Kinne (1963) advocated the role of temperature affecting the animal distribution in the brachish water zone. Abele (1974) mentioned that substrates are important in determining the species composition of the various habitats. A species can use one substrate as a shelter, another as a feeding site and other as a source of nutrition, thus reducing competitive interactions for each one resulting in appositive co action in community existence. Thus greater number of species can inhabit in a narrow intertidal belt, resulting in the change of species diversity. Sanders (1968) postulated the role of sediments and opined that most diverse communities will always be found in the tropics and deep sea because of the constancy of their soil environments. Nutrient enrichment in the littoral zones of the mangrove ecosystem play vital role in determining the settlements, growth , population fluctuation and community interactions of fauna (Heald and Odum 1970). Owing to the highly buffered nature of sea water, pH has no limiting effect on marine organisms (Michael, 1984).

E. Bioturbation and nutrient cycling :

Bioturbation, the disturbance through the stiring or mixing of sediments layers by biological activities viz. mobility, feeding, burrowing etc. of benthic animals, affects the geochemistry of sediments and their interstitial water (Woodin et al 1998). Brachyuran crabs, polychaetes, and globid fishes represent the major agents of bioturbation of Sundarbans and its adjoining coastal environments. Burrows and other bioturbatory structures like pseudo-pelletes, sand balls, mud balls, sand pyramids, semidome, chimney, hood etc. have been documented highlighting seasonal variations on the rate of sediment distabilisation, intensity of soil excavation, pumping of water and oxygen within soil, etc. Adaptive behavioural strategies out of such activities have also been hypothesized (Annon, 2003: Chatterjee et al. 2008).

One of the major bioturbatory activities is on the microbial degradation rate of sediment organic materials by microbial and benthic community. In mangrove ecosystem, macrobenthos along with several microarthropods (Dey et al. 2010) primarily acted upon mangrove litters for their ready conversion into detritus by microbial activities. Detrital export from mangrove forests is a source of nutrients and energy to nearby ecosystems such as Biscayne Bay, FL (Fleming et al. 1990). Bosire et al. (2005) have studied litter degradation and CN dynamics in reforested mangrove forest in Kenya. Raulerson (2004) studied the leaf litter processing by macrodetritivores in natural and restored Neotropical mangrove forests.

Many species of mangrove plants produce viviparous propagules that develop to substantial sizes before dispersal, a behaviour that has been hypothesized as an adaptation to their intertidal habit (Tomlinson 1986). The large , energy-rich propagules attract grazers both before (insects,e.g. Murphy 1990) and after(grapsid crabs, Smith 1987) abscission.

The microbial activities in the mangrove forest for litter decomposition depend on temperature and moisture of soil (Gupta, 2002). However, during monsoon excessive rainwater and water run off create water logging condition and thereby preventing the penetration of atmospheric oxygen and lowers the activities of microbes and other soil inhabiting detritivores. During premonsoon, higher air temperature enhances the diffusion of oxygen in soil which in turn increases the redox potential, a measure of the electron pressure or availability in a solution (Mandal et al. 2009). Oxidation occurs not only during the uptake of oxygen but also if hydrogen is removed or more generally, a chemical gives up an electron. Reduction is the opposite process of giving up oxygen gaining hydrogen or gaining an electron (Mitsch and Gosselink, 1986).

A case study, dealing with the role of microarthropods in nutrent cycling of an mangrove ecosystem, adjoining to Sundarbans highlighted their gradual occurrence and succession in respect of decomposition of the organic plant litter. The succession was initiated with the occurrence of Collembola followed gradually by acarina, coleoptra, diptra, isopoda, hymenoptra and others, resulting in the generation of maximum nutrients after 6 months of decomposition of mangrove litters (Dey et al. 2010).

XIII. Threats to Biodiversity:

Several natural and anthropogenic threats have been inflicting their impact on biodiversity of West Bengal Coast in several ways which are mentioned below

Non judicious exploitation of mangrove bioresources to meet the demand of steadily increasing local human population. An estimate shows that 50,000 people enter the Sundarban forest areas daily to extract rersources for their livelihood. During the dry season, this figure becomes double. The sundarban serves as a strong lifeline to the poor people living on the forest fringing settlements. Following types of resource utilization are found in the Sundarban at present for the livelihood of poor people (Paul, A 2009).

- Collection of timbers by felling trees (mangroves),
- Collection of fuel wood from the forests,
- Collection of Golpara (Nypa) leaves for thatching roofs,
- Fishing in the rivers and tidal creeks and crab potting in the mud flats,
- Collection of honey from forests (bee-hives),
- Catching shrimp fry and tiger prawns from mangrove fringed channels,
- Collection of Goran (Ceriops) sticks for fencing and fixed netting,
- Grass cutting from tidal flats for fodder supply.

- Considerable changes of land use pattern for the development of aquaculture, fisheries and agriculture promoted large scale reclaimation of land of virgin deltaic islands leading to deforestation (Hazra et al 2002).
- Large scale destruction of juveniles of hundred of species of different fishes, and shell fishes for the collection of shrimp juveniles, especially juveniles of *Peneaus monodon* to be used in semi intensive aquaculture.An estimate shows for the collection of one juvenile of *Peneaus monodan*, juveniles of other aquatic fauna having a range of 27.41 to 31.77 at different sites of Sundarbans were destroyed (Annon 2003).
- Fishermen camps often lead to disturbances to the coastal ecosystem functioning because of the release of different waste materials as well as operation of increased number of nylon nets having small mesh size to the death of marine turtles, migratory birds and threatened fish species (Chakravorty et al 2004).
- Changing flow pattern of Ganga river during last centuries because of faulty neotectonic movements has influenced the hydrology of deltaic region and modified the sedimentation patterns and reduction of fresh water inflow leading to salinity invasion. (Gopal and Chauhan 2007; Hazra et al 2002)
- Indiscriminate use of agrochemicals (fertilizers and pesticides) in the catchments of Ganga and Brahamaputra rivers, their numerous tribularis as well as in agriculture fields close to the mangroves, pollute both the water ways and the land mass and thereby affect the vegetation and fauna directly.
- From seaward side, major pollution occurs through oil spills that cause damage especially to aquatic fauna and seabirds (Qasim et al, 1988). Besides, thousand of mechanized boats for carrying passengers and fishing, are the major source of oil pollution (Paul A, 2002).
- Construction of embankment and dredging of riverbeds hamper the water circulation, distabilise bottom sediments, increase turbidity and affects settlement of flora and fauna (Paul A, 2002).
- Ecotourism to different parts of Sundarbans (Segar Island, Bakhali, Sajnekhali etc) contribute profusely for the ecodegradation of the West Bengal coast (Chaudhury and Chaudhury, 1994).

- **Growing Industrialization** of the area around Kolkata and Haldia industrial complex and industries situated on the wastern side of the Hoogli estuary, contribute significantly to the pollution load and hence to the degradation of mangroves. (Chakravorty et al, 2004)

- **Errosion and Accretion pattern in Sundarbans:**

  A time series analysis of the change in the shape, size and geomorphic features of the island over the part 32 years (1969-2001) show some important changes like degradation of mangrove swamps and mudflats, increase in salinisation and development of saline banks within mangrove swamp.

  Twelve sea facing southern islands including the World's largest delta, the Sagar Island are more prone to erosion problems. Total erosion over the thirty years time span is estimated to be 162.879 km sq in contrast to land accretion (82.505 km sq) over the same period which has been taken place mostly in the inner estuary along eastern and northern margin of islands (Hazra et al, 2002).

- **Disastrous cyclones of Sundarbans-** During the previous centuries, although 17 disastrous cyclones had struck the different parts of Sundarbans, but due to vast expanse of Sundarban forest, those storms could not cause much damage on the coastal habitations. Strong waves of the previous centuries generated on the Bay of Bengal have pushed upward along the natural passage of the Sundarban rivers and produced damages to the banks. Other disturbances are recorded as :a) rise of water level in the rivers, b) shifting of depositional bars and shoals, c) change of river courses, d) inundation and flooding over the inland tracts, e) embankment breaches etc (Paul, A.K. 2009)

- **Global warming-** The coastal environment of West Bengal representing a very sensitive, vulnerable and productive coastal - mangrove ecosystem is subjected to the impact of global warming mediated environmental consequences. A steady rate of increase of water temperature (0.05^{0}C/year) in this coastal environment over the past 27 years has had a profound impact on other physical parameters of estuarine water and enhanced the salinity (~6 psu over last 30 years), evaporation, free CO_2, precipitation, fresh water runoff and intrusion of sea water and decreased pH (0.015 per decade). Global warming accelerates the process of erosion by elevated sea- level rise coupled with high tidal amplitude having increased intensity of currents. Besides, depletion of forest cover because of oscilating and unpredictable environmental condition also contribute to the higher erosion and sedimentation process leading to turbidity. The overall rate of decrease of transparency for Indian Sundarbans has been found as 7-9 cm over last 27 year or about 2.3 cm per decade (Mitra et al, 2009). Alongside, the changes in the abiotic parameters, the sea level rise, salinity invasion, higher turbidity, low pH, and lower primary productivity are expected to impart their impact on the biodiversity of this dynamic ecosystem. The major indicatons of the sea level rise in the Sundarban have been documented with field obsertvations since 1984 and satellite image data analysis since 1973 to 2006. These include- shoreline erosion, bank erosion, re-shaping of the island drifting; increase of saline blanks in the mangrove swamps, and significant storm impacts on mangrove shorelines; embankment failures by the wave thrust on the river mouths; shifting of estuarine mudflats and salt marshes; increased tidal datum in the Hoogli estuary and river valleys, filling up of sediments transported by tidal currents and storms and river floods (Paul, 2009).

XIV. Conservation Strategies:

A. In- Situ conservation of Wildlife:

From time immemorial, the resource base of virgin mangrove forest of Sundarbans attracted the attention of people which led to the reclaimation of forest land cultivation and exploitation of fishes, honey, timber etc. An integrated approach for the conservation of Sundarbans Mangrove estuarine complex in general and its flora and fauna in particular is very much needed. Several conservation stratiegies like declaring Lothian Island (3,800 ha) as Wildlife Sanctuary in the 1948 and Sojnekhali Wildlife sanctuary (35,240 ha) in 1960 were adopted. Subsequently, giving due importance to IUCN declaration (1970) on Bengal tiger, *Panthera tigris tigris* as an endangered species, Government of India established a Tiger Reserve in the Sundarbans, covering a total area of 2,585 sq km of which 1,330 sq km were treated as core areas. Another 241 sq km were later demarcated as a subsidiary wilderness area. The core area (1,330 sq km) was afterwords declared as a National Park. Another wild life sanctuary was established in 1976 on Haliday Island (595 ha). In 1987, The Sundarbans National Park in India and in 1997, parts of Sundarbans in Bangladesh, were inscribed as World Heritage List (IUCN, 1997). The entire Indian Sundarban area, south of Dampier – Hodges line (that demarcates the inward limit of tidal influence) including 5,366 sq km of reclaimed lands, has also been designated as the Sundarban Biosphere Researve, a multi-purpose protected areas with an aim to preserve the genetic diversity of this ecosystem by way of following measures:

- To conserve diversity and integrity of plants, animals and micro- organisms;
- To promote research on ecological conservation and other environmental aspects;
- To provide facilities for education, awareness and training for effective participation of the people living around biosphere reserves.

The major thrust of conservation of wildlife in Indian Sundarban has been based on the ecosystem functioning on which wildlife depend.

B. Participatory management of bioresources:

The stability of ecosystem is individually insignificant but collectively determined cumulative ecological effects are not attributable to any one source or action and can not be regulated in isolation. This requires cross sectional approaches to natural resource management which should take into account the participatory management practices in order to integrate the goals of conservation into mainstream of economic development (Patra et al, 2005; Mishra et al 2009).

C. Integrated coastal Zone Management:

An integrated management scheme for the judicious utilization of coastal resources and also to minimize eco- degradation involves monitoring changes and the handling of much information. These tasks have been aided in recent years by the application of remote sensing techniques and Geographic Information system (GIS) (Paul and Bandyopadhyay, 2009). The systematic collection and analysis of information as mentioned below are required for such management:

- **Biological information of the coastal zone** include type and extent of ecosystem (riverine and flood- plain wetland, coastal wetland, marshes and mangroves, coastal and inland sand dunes); primary productivity, nutrient enrichment; species diversity and abundance; nursery grounds of fishery resources; assessment of fish stock, their breeding period, duration of juvenile phase in order to impose restriction on catching them.
- **Physical information of coastal zone** include geology, temperature, salinity, nutrients, tides, sea level and currents, sediment types and distribution, flooding, erosion/accretion.
- **Socio-economic conditions** require information on human population distribution and growth, economic activities (rice- paddy cultivation, horticulture, vegetable gardening, acquaculture, marine fishing, tourism and recreation, industrial development and salt manufacturing), land use alterations (conservation of marshes and mangroves were converted to fish ponds for the aquaculture of prawns and also converted to saltpans for salt making grounds at the coast. Industrial development, tourism and recreation, construction of ports and harbours and infrastructural development) are needed.

The Ministry of Environment and Forests enacted the CRZ notification in 1991 under the Environment Protection Act to protect coastal areas from over- development and industrialization. The CRZ areas of the country is defined as coastal stretches of sea, bays estuaries, creeks, rivers, back waters, all influenced by tidal action on the landward margins. However, based on ecological sensitivity, geomorphic features and demographic distribution, the CRZ is categorized into four significant areas as:

CRZ-I: (ecologically sensitive and tidally influenced upto 500 m from HTL)
CRZ-II: (Urban built-up areas or densely developed areas along the shoreline)
CRZ-III: (rural coastal dwelling units or developed areas of the coast).
CRZ-IV: (islands surrounded by water bodies and isolated from the main land).

Much of Purba-Medinipur coastal district falls within CRZ-I and CRZ-III . Areas of CRZ-III are further sub-divided. The area upto 200 meters HTL is no construction zone where only repairs of existing authorized constructions are permitted or allowed.

Table-III: Total faunal diversity of Indian Sundarbans

Faunal Categories	**Number of species**	**Major groups**	**Reference**
Chordate Hemichordate	1	*Saccoglossus sp*	Singh and Chaudhury, 1984
Pisces	250	Chondrichthyes I).Pristiformes-33 II). Rajiformes-25 III). Crcharhiniformes -29 Osteichthyes I). Cypriniformes-66 II). Perciformes-32 III). Clupiformes-13 IV). Belomniformes-11 V). Gobiformes-17 VI). Siluriformes- 24	Chaudhuri and Choudhury, 1994 Annon 2003
Amphibian	6	Aneura- 3 Eurodala- 2 Apoda-1	Annon 2003

Reptiles	57	I).Chelonea (12 orders) II). Squamata (44 orders) III). Crocodilia (1 order)	Annon 2003
Aves	>200	I).Galliformes-45 II). Anseriformes-31 III). Turniciformes-30 IV). Piciformes-24 V). Bucerotifornes-12 VI). Upupiformes-06 VII). Cuculiformes-17 VIII). Passeriformes-29 IX). Collumbiformes-12	Chaudhuri and Choudhury, 1994 Annon 2003
Mammals	39	*Panthera tigris tigris* *Felis bengalensis* *Platinista gangetica* *Orcaella brevirostris* *Manis pentadactyla* *Felis viverrina*	Chaudhuri and Choudhury, 1994 Annon 2003
Macrobenthos **Cnideria** Actiniariun	5	I). Edwardsiidae-1 II). Haliactiidae- 2 III). Diadumenidae-1 IV). Actiniidae-1	Chaudhuri and Choudhury, 1994 Annon 2003 Chakraborty et al 2010
Penatulla	4		Chakraborty et al 2009.7
Ctenophores	3		Chakraborty et al 2009.
Brachyuran crab	26	I). Ocypodidae-6 II). Gerapsidae-6 III). Xanthidae-4 IV). Portunidae-4 V). Maiidae-4	Chakraborty et al 1986

		VI). Calappidae-2	
Anomura	3	*Clibanarius padavensis* *Coenobita cavipes* *Diogenes avasey*	Chaudhuri and Choudhury, 1994
Horse shoe crabs	2	*Tachypleus gigas* *Carcinoscorpius rotundicaudata*	Annon,2003
Molluscs	110		Subba Rao et al 1996
Gastropods	24 families 35 genus 59 species	I). Neridae II). Trochidae III). Littorinidae IV). Assiminidae V). Architectonicidae	Subba Rao et al 1996
Bivalves	26 families 40 genus 5 1species	I). Unionoida II). Venoroidae	Subba Rao et al 1996
Polycheates	25 families 47 genus 69 species	I). Hesionidae II). Phyllodocidae III). Nereidae IV). Glyceridae V). Eunicidae VI). Capitellidae	Misra,1986
Oligochaetes	1	*Pontodrilus berosudensis*	Subba Rao et al 1996
Nemerteans	2	*Anopla sp*	Annon,2003
Echinodermata	5 Orders	*Enopla sp*	Annon,2003
Echiurida	3 species	*Anelassor hunchus* *Brachior hynchus* *Anelassor dendrorhychus* *Anelassor meinorhynchus*	Chaudhuri and Choudhury, 1994
Sipanculida		*Phascolosma or chuata*	

Amphipoda	3 families I). Photidae II).Aoridae III). Ampeliseidae		
Nematodes	26 families 80 species		
Benthic **Insects** A). Diptera	7 families 18 species		Ray and Chaudhury 1986
B). Coleoptera	10 families 21 Species		Poddar et al 1986
Protozoa A). Soil Amoeba	3 species	*Acanthamoeba astronyxis* *Acanthamoeba culberstsoai* *Acanthamoeba rhysodes*	Chaudhury & Chaudhury
B). Foraminiofera	3 genera	*Calcarina sp* *Elphidium sp* *Quinqueloculime sp*	
Phytoplankton	24		Annon,2003
Zooplankton			
A). Copepoda		*Canthocalanus parper* *Eucalanus elongates* *Paracalanus dubia* *Paracalanus pavus* *Aerocalanus similes* *Aerocalanus intermis* *Euchaeta marina* *Centropages dorsipinatus*	Annon,2003

		Centropages alcocki *Phyllodiaptomus blanci* *Phyllodiaptomus serricaudatus* *Phyllodiaptomus annadalie* *Phyllodiaptomus binghami*	
B). Cladocera		I). Aloninae II). Bosminidae III). Daphnidae IV). Moinidae	Annon,2003
C). Chaetognatha		*Sagitta enflata* *Sagitta bediti* *Krohnitta sp*	Annon,2003
D).Rotifera		I). Brachionidae II). Asplanchnidae III). Lecanidae IV).	Chaudhuri and Choudhury, 1994
E).Ostracoda	7		Chaudhuri and Choudhury, 1994

XV. Conclusion:

Although, significant measures have been taken up for the conservation of biodiversity of Sundarbans, an integrated action plan is required incorporating the outcome and recommendations of multidimensional researches undertaken during the last four decades. Based on these, proper guidelines are to be framed for future researchers on this globally important environmental sector so that Time Series Analysis and Long Trend Analysis on the natural and anthropogenic stress factors become possible. These will facilitate the process of pointing out problems more distinctly and remedial measures more effectively.

References:

1. Abele, L. G (1974) Species diversity of decapod crustaceans in marine habitats. *Ecology* **55**: 156-161
2. Alongi, D.M. (1990). Effect of mangrove detrital outwelling of nutrient regeneration and oxygen fluxes in coastal sediments of the Central Barrier Ruf Lagoon. *Estuarine Coastal Shelf Science*. **31** : 581-598.
3. Annon, (2003). Mangrove ecosystem: Biodiversity and its influence on the natural recruitment of selected commercially important finfish and shellfish species in fisheries. *National Agricultural Technology Project (NATP).* Indian Council of Agriculture Research (ICAR). Principal Investigator: George, J.P.; Co-PI: Chakraborty, S.K. and Damroy, S.N.: 1 – 514.
4. Banerjee, A. and Santra, S. C, 1999. Plankton composition and population density of the Sunderbans mangrove estuary of West Bengal (India). *In: D.N.Guha Bakshi, P. Sanyal and K.R. Naskar (cds). Sunderbans Mangal. Naya Prokash Publication,* Calcutta : 340-349.
5. Barnes, R.S.K (1967).The osmotic behaviour of a number of grapsoid crabs with respect to their differential penetration of an estuarine system. *Journal of Experimental Biology* **47**:535-552
6. Bhakat, R.K. Chakravarty, G., Giri, S and Chakraborty, S. K. (2004). Invasive species in Sunderbans Mangrove Ecosystem, India. *In: Fish Diversity in Protected Habitats, Edts. S.Ayyappan, D.S.Malik, R.Dhanze and R.S.Chauhan, (Publ. by Natcon publication):* 219-240.
7. Bhowmik, S. K, Roy, G. N. and Burman, S. 1985. Alist of 24 strains of bacteria from the decomposed litter of mangrove areas of Sundarbans complex. *National Symposiun on Biology, Utilization and Conservation of Mangroves*: 389- 392
8. Biswas, A, Bhowmik, S.K and Roy, G.n. 1985. Chitinolytic bacteria of mangrove swamps of the Sundarbans. *National Symposium on Biology, Utilization and Conservation of Mangroves*: 382- 384

9. Biswas, S.K. (1991) Classification of Indian sedimentary basins in the frame work of platetectonics. Proceedings of second of second seminar on Petroliferous Basins of India. I : 1-46 (In Biswas S.K. et al - Edts) Indian Petroleum Publishers, Dehradum, India.
10. Blasco, F. (1975). The Mangroves of India. Inst. Francais de Pondichery. *Trans. Sec. Sci. Tech.* Vol **14**: pp. 1-175.
11. Blasco, F.(1977).Outline of ecology, botany and forestry of the mangals of the Indian subcontinent. *In: Ecosystems of world I. West Coastal ecosystems(ed Chapman, V.J.)*:247-262
12. Chakraborty, P. K. and Naskar, K.R. 1988. Role of mangrove in estuarine fisheries development. *Bulletine Central Inland Capture Fishery Research Institute*, Barrackpore **57**:229-33.
13. Cannolly, R.M. and Lee S.Y (2007) Mangroves and Saltmarh in Marine Ecology (Edited by Connel, S.D. and Gillanders, B.M.) Published by *Oxford University Press* : 485-512
14. Chakraborty S.K., Chaudhury, A. (1985). Distribution of fiddler crabs in Sundarbans Mangrove estuarine complex, India. The Mangroves: *Proceedings of National Symposium Biology Utilization Conservation of Mangroves* : 467-472
15. Chakraborty S.K., Chaudhury ,A, and Deb,M (1986) Decapod brachyra crab from Sundarbans mangrove estuarine complex India. *Journal of Bengal Natural History Society* **5(1)**:55-68
16. Chakraborty S.K., Chaudhury ,A (1992). Ecological studies on the zonation of brachyuran crabs in a virgin mangrove island of Sundarbans, India. *Journal of Marine Biological Association India,* **34(1&2):** 189-194
17. Chakraborty S.K., Chaudhury ,A (1992 A) . Population ecology of fiddler crabs(Uca spp) of the mangrove estuarine complex of Sundarbans. India. *Tropical Ecology* **33(1)** : 78-88

18. Chakraborty S.K., Poddar T.K., and Choudhury, A.(1992). Species diversity of macrozoobenthos of sagar island, Sunderbans, India. *Proceedings of Zoological Society* Calcutta, **45 (Suppl, A):** 435-444.
19. Chakraborty S.K., Chaudhury, A (1993). Community organization of macrobenthic molluscs of Sagar Island, Sundarbans, India. *Indian Biologist Vol.* XXV, No. **1**:33-36.
20. Chakraborty, S. K. and Choudhury, A. (1994). Community structure of macrobenthic polychaetes of intertidal region of Sagar Island, Hoogly estuary, Sundarbans, India. *Tropical Ecology*, **35 (I):** 97 – 104
21. Chakraborty S.K. and Choudhury, A. (1994). Population ecology of *Metaplax intermedia* (Brachyura : Grapsidae) of Sagar Island, Sundarbans, India. *Proceedings of Zoological Society, Calcutta* **47**(1) : 41-45.
22. Chakraborty, S.K. (1995). Aquaculture potential of mangrove ecosystem of Sundarbans, India. *Proceedings of Seminar on Fisheries - a multimillion dollar industry.* AFI, Madras: 72-83.
23. Chakraborty S.K. and Choudhury, A. (1997). Occurrence and abundance of benthic polychaetes in Hoogly Estuary, Sagar Island, India. *Journal of the Marine Biological Association of India.* **39** (1& 2) : 140-147
24. Chakraborty, S. K. ; Giri, S.; Chakravarty, G. and Bhattacharya, N. (2009). Impact of ecorestoration on the biodiversity of Sundarbans mangrove ecosystem, India. *Water, Air, Soil Pollution:* Focus **9**: 303-320.
25. Chakraborty, S.K., Giri, S. Chakravarty, G. and Bhattacharya, N. (2009) Impact of eco-restoration on the biodiversity of Sundarbans mangrove ecosystem, India. *Water Air Soil Pollution*: Focus **9**: 303-320.
26. Chakravarty, G., Giri, S., Giri, S and Chakraborty, S. K. (2004). Distribution of coliform bacteria in different estuaries of West Bengal Coast, India. *In: Protected Habitats and Biodiversity*. Edt. A.Kumar, J.R.Dhanze, A.K.Chopra and D.S.Malik, (Publ. by Natcon publication): 395-402.
27. Chapman, V.J. 1976. Mangrove Vegetation. *Journal of Cramer, Vaduz, Germany*. 447 Pp.

28. Chatterjee, S., Bhunia, G and Chakravorty, S. K (2008). Bioturbation of brachyuran crabs and its impact on coastal ecosystem of Midnapore district, West Bengal, India. In *Proceedings of Fourth International Conference on Environmental Science and Technology (II)Houston, Texas, USA*: 133 – 148
29. Chaudhuri, A. B. and Choudhury, A.(1994). Mangroves of the Sundarbans , India. *IUCN-Bangkok. Thailand***. I**, 1-247
30. Cole, C.V. and Vaidyaraman 1966. Salinity Distribution and effect of fresh water flows in the Hoogly River. *Proceedings of Tenth Conference on Coastal Engineering, Takyo (American Society of Civil Engineers, New York)*: 1312-1434
31. De, T.K, Mitra, A and Choudhury ,A (1987) Studies on phytoplankton and productivity around Sagar Island and Prentice Island, Sunderbans, West Bengal. Records *Zoological Survey of India* **81(3&4)**: 81-92
32. Dey, M. K.; Hazra, A. K. and Chakraborty, S. K.(2009). Functional role of microarthropods in nutrient cycling of mangrove-estuarine ecosystem of Midnapore Coast of West Bengal, India. *International Journal of Environmental Technology and Management*, **12(1):** 67 - 84.
33. Dey, M.K., Hazra, A.K. and Chakraborty S.K. (2010) Functional role of microarthopods in nutrient cycling of mangrove-estuarine ecosystem of Midnapore coast of West Bengal, India. International *Journal of Environmental Technology and Management.* **12 (1):** 67-84.
34. Duke, N.C. 1995. Genetic diversity, distributional barriers and rafting continents-more thoughts on the evolution of mangroves. *Hydrobiologia* **295:** 167-181.
35. Duke, N.C. (1992) Mangrove floristics biogeography. In: A.I. Robertson and D.M. Alongi (eds), *Tropical Mangrove Ecosystems. American Geophysical Union, Washington, D.C.*, USA, pp. 63-100.
36. Duke, N.C., E.Y.Y.lo, and Sun M. (2002). 'Global distribution and genetic discontituaties of mangroves-emerging patterens in the evolution of Rhizophora'. *Trees-Structure and Function* **16**: 65-79.

37. Ellison, A.M., Farnsworth, E.J and Merkt, R.E (1999) Origin of mangrove ecosystems and the mangrove biodiversity anomaly; *Global Ecology and Biogeography* **8**:95-11
38. Fleming, M., Guanghuhi, L, da Silveira Lobo Sternberg, L 1990. Influence of mangrove detritus in an estuarine ecosystem. *Bulletin of Marine Science.* **47** : 663-669.
39. Ginsberg, R.N. and Lowenstam, H.A. 1958. The influence of marine bottom communities on the depositional environment of sediments. *Journal of Geology*. **66** : 310-318.
40. Gopal, B. and Chauhan, m. (2006), Biodiversity and its conservation in the Sundarban Mangrove Ecosystem; *Aquatic Sciences*. **68**:338-354.
41. Gopalkrishnan, V. 1971. The biology of the Hoogly-Matlah estuarine system (West Bengal, India) with special reference to its fisheries. *Journal of Marine Biological Association, India.* **13**: 182-194.
42. Goudha, R and Panigrahy, R. C.(1996) . The mangrove of Orissa. *Journal of Indian Ocean Studies* **3(3)** : 228 – 237.
43. Gupta, S.K. 1987. Some mangrove soils of the Sundarbans ecosystem. *UNESCO Regional Introductory Training Course on estuarine Research, Calcutta*. **2** : 105-112.
44. Gupta, S.K. 2002. Methods in environmental analysis, water, soil and air. Agrobios (India) Jodhpur, India : n203-217
45. Hazra, S., Ghosh, T., Dasgupta,R and Sen, G. (2002) Sea level and associated changes in the Sundarbans. *Science and Culture* **68(9-12):**309-321
46. Heald, E. J.(1971) The production of detritus in a South Florida estuary. *Sea Garnt Technology Bulletin (University of Miaoni)* No **6**: 110.
47. Heald, E.J and Odum, W.E (1970) The contribution of mangrove swamps to Florida Fisheries. *Proceedings of Gulf and Carribian Fishery Institute* **22**: 130-135
48. Heal, O.W and French, D.D (1974) Decomposition of organic matter in Tundra , in Holding, A. J. et al (Eds): Soil Organisms and Decomposition in Tundra, Tundra Biome Steering Committee Stockholm: 279-309

49. Hutchings,P.A., and P. Saenger. 1987. Ecology of mangroves. University of Queensland Press, Brisbane.

50. Jadav, U.K and Choudhury, A (1985) Litter production in mangrove forest of Lothian Island in Sundarbans, West Bengal. *Proceedings of National Symposium on Biology, Utilization and Conservation of Mangroves*: 227-229

51. IUCN, 1989. Marine Protected Areas Needs in the South Asian Seas Region. **2** : India.

52. IUCN, 1997. Sundarban Wildslife Sactuaries (Bangladesh): World Heritage Nomination – IUCN Technical Evaluation. http:// whc.unesco.org/archive/advisory_body_evaluation/798.pdf 12

53. Jhingran, V.G. (1991) Fish and Fisheries of India. Hindusthan publishing Corporation (India), Delhi. :1-705.

54. Kathiresan, K. and Bingham, B.L. 2001. Biology of mangroves and mangrove ecosystems. *Advances in Marine Biology.* **40**: 81-251.

55. Kinne, O.(1963). The effect of temperature and salinity on marine and brachish water animals. *Oceanography and Marine Biology Annual Review* **1**: 301-340

56. Lee, S.Y (1995) Mangrove outwelling a review. *Hydrobiologia* **295**:203-212

57. Lee, S.Y. 91998). Ecological role of grapsid crabs in mangrove ecosystems: a review work. *Marine and Fresh water Research* **49**: 335-343.

58. Lovelock,C.E.,I.C.Feller, K.L.McKee, and R Thompson. 2005. 'Variation in mangrove forest structure and sediment characteristics in Bocas del Toro, Panama'. *Caribbean Journal of Science* **41**:456-464.

59. Lugo, A. and Snedaker, S.C. 1974. The ecology of mangroves. *Annual Review of Ecology and Systematics*. **5** : 39-64.

60. Macnae, W. 1974. Mangrove forest and fisheries Indian Ocean Programme, 34. Indian Ocean Fisheries Commission, Rome. 1 OFC/DEV/74/34 : 1-35.

61. Majumder, S., Choudhury, A., Naidu, T.Y. and Bandyopadhyay, S. (1996). A reconnaissance survey of recent benthic foraminifera from the mangrove-estuarine sector of Indian Sundarban. *Vidyasagar University Journal of Biological Sciences*. **2** : 40-46.

62. Mandal, S., Roy, S and Ghosh, P. B. (2009). Modelling of the contribution of dissolved inorganic nitrogen (DIN) from litter fall of adjacent mangrove forest to Hoogly-Matla estuary, India. *Ecological Modelling* **220**:2988-3000.

63. Manson, F.J., Loneragan, N.R., Harch, B.D., Skilleter, G.A. and Williams, L. (2005) A broad scale analysis of links between coastal fisheries production and mangrove extent: a case study for north-eastern Australia. *Fisheries Research*. **74**: 68-95.

64. McKee, K.L. (1995). 'Seedling recruitment patterns in a Belizean mangrove forest: effects of establishment ability and physico-chemical factors. *Oecologia* **101**:448-460

65. Misra, A. (1995). Polychaetes. In : Estuarine Ecosystem Series- Part-2 Hoogly-Matla Estuary West Bengal. Published in *Zoological Survey of India*. : 93-155

66. Mitra. A Gangopadhyay, A., Dube, A. , Schmidt Andri, C. K., and Banerjee, K (2009) Observed changes in water mass properties in the Indian Sundarbans (North Western Bay of Bengal) during 1980-2007. Current Science. **97** (10): 1445-1452.

67. Mitsch, W.J., Gosselink, J.G. 1986. Wetlands. Van Nostrand Reinhold Company, New York. Pp. 93-95.

68. Morgan, J.P. and McIntire, W.G (1959) Quaternary geology of the Bengal basin, East Pakistan and Burma, *Bulletin Geological Society of America***70**: 319-342

69. Mukhopadhyay, S.K., Biswas, H, De T. K. and Jana, T.K. 2006. Flexes of nutrients from the tropical river Hoogly at the land – Ocean boundaty of Sundarbans, NE coast of Bay of Bengal. *Journal of Marine System* **62** : 9-21.

70. Murphy, D.H. 1990. 'The natural history of insect herbivory on mangrove trees in and near Singapore'. *Raffles Bulletin of Zoology* **38**:119-203.

71. Naskar, K.R., 1999. Status of mangroves in the Indian Sundarbans in the persepective of Indian and world mangals. In D.N. Guha Bakshi, P. sanyal and K. R. Naskar (eds) *Sundarbans Mangal. Naya Prokash Publication*, Calcutta, : 20-89.

72. Naskar, K. Sen Sarkar, N. Ghosh, A, Dasgupta, M and Sengupta, B. (2004). Status of the mangroves and mangrove ecosystem of Sundarbans in West Bengal : Its Impact on Estuarine Wet lands fisheries. *Bulletine No. 134 CIFRI, Barrackpore, Kolkata* : 1-40.
73. Odum,E.P. (1971) *Fundamentals of Ecology*. W.B. Saunders and Co., Philadelphia, U.S.A.: 1-297
74. Odum,E.P. and E.J. Heald (1975) Mangrove forests and aquatic productivity. In: Haster, A.D. (ed) Coupling of Land, water systems. *Ecological Studies (Springer-Vesllog, New York)*, **10**: 129-136
75. Ong,J.E. (1995) The ecology of mangrove conservation and management. *Hydrobiologia* **295**: 343-351
76. Patterson , S., McKee K.L, Mendelssohn I.A..1997. 'Effects of tidal inundation and predation on Avecennia germinans seedling establishment and survival in a sub-tropical mangal /marsh community'. *Mangroves and Salt Marshes* **1**: 103-111.
77. Patra, M.K., Acharjee, S.K. and Chakraborty, S.K. (2005). Conservation categories of siluroid fishes in North-East Sundarbans, India. *Biodiversity and Conservation* .**14**:1863-1876
78. Pal, U. C., Naskar K. R. and Santra S.C., (1988).A check-list of algal flora of Sundarban delta, West Bengal, India. *Phykos*, **27**: 48-53
79. Paul, A.K., 2002. Coastal Geomorphology and Environment. (Published by-Ajoy Bhattacharya of acb publications). 1-575
80. Paul, A.K. 2009. Man-Environment interactions in the single largest mangrove forest along the shoreline of the Bay of Bengal : A case study of Sundarbans. *Geomorphology in India* (edts H.S. Sharma and V.S Kole): 263-286.
81. Poddar, T.K, Chakraborty, S.K. and Choudhury, A. 1990. Littoral buttes of the sand mudflats of *Hoogly estuary. Annals of Entomology*. **8(1)** : 31-35.
82. Pritchard D.W (1967) What is an estuary, Physical view point. In: Lauff, G. H.(Ed), Estuaries, no83. American Association for the Advancement of Science Publication, Washington, DC, USA: 3-5

83. Qasim, S.Z. Sengupta, R and Kureishy, T.W. 1988, Pollution of the seas around India. *Proceedings of Indian Academy of Science (Animal Science)* **97(2):** 117 – 131.

84. Rao G. C and Mishra, A (1983). Studies on the meiofauna of Sagar Island . *Proceeding of Indian Academy of Science (Animal Science)* **92 (1):** 73-85

85. Raulerson, G.E. 2004. Leaf litter processing by macrodetritivores in natural and restored neotropical mangrove forests. Ph. D. Thesis, Louisiana State University and Agricultural and Mechanical college, USA.

86. Ray, S. and Choudhury, A. (1989) Occurrence and abundance of benthic dipterans in a tidal creek of Hoogly estuary, Sagar island, India. *Tropical Ecology,* **30(2):**303-308.

87. Saenger, P., Heger, E.J., and Davie, J.D.S., (1983) Global status of mangrove ecosystem. Commission on ecology papers No#, Gland, Swizerland. *International Union for conservation of nature and Natural Resources. The environmentalist Supp. No.***3.**

88. Sanders, H.L. (1968) Marine benthic diversity: A comparative study American naturalist. **102**: 243-282.

89. Santra, S.C. 1998. Mangrove lichens, *Indian Biologist*, **30(2):**76-78

90. Santra, S.C., Paul, U.C. and Choudhury, A. 1991. Marine phytoplankton of the mangrove delta region of West Bengal, India. *Jurnal of the Marine Biological Association, India* **33(1-2);**292-307.

91. Sahoo, A.K., Sah, K. D and Gupta, S. K (1985) Studies on nutrient status of some mangrove mud of the Sundarbans. *Ibid* : 375-377

92. Sarkar, S.K. Singh, B.N and Choudhury, A (1986) The ecology of copepods from Hoogly estuary of West Bengal , India *Mahasagar-Bulletin of the National Institute of Oceanography* **19(2):** 103-112

93. Sarkar, S.K, Sing,B.N. and Chaudhury,A. (1986) Composition and Variation in the Hooghly Estuary, West Bengal, India *Proceedings of Indian Academy of Science* **95**: 125-134

94. Sarkar, D., Chattopadhyay, G.N. and Naskar, K.R. 1999. Nature and properties of coastal saline soils of Sundarbans with relation to mangrove vegetation. In:

D.N.Guha Bakshi, P. Sanyal and K.R. Naskar (eds), Sundarbans Mangal. Naya Prokash, Calcutta, pp. 199-204.

95. Schelake, CL and Odum, E.P (1962) Mechanisms for maintaining high productivity in Georgia estuaries. *Proceedings of Gulf Caribb Fishery Institute* ***14***: 75-80

96. Sing, B. and Choudhury, A. 1984. Occerence of an enteropneust hemichodate in the mangrove swamps of Sundarbans, India. *Bulletin of Zoological Survey, India*. **6(1-3):** 1-4.

97. Snedaker, C (1991) Notes on the Sundarbans with emphasis on geology, hydrology and forestry In: J. Seidensticker, R. Kurin and A.k. Townsend (eds). The commons in South Asia. Societal Pressures and Environmental Integrity in Sundarbans. The International Center, Smithsonian Institution, Washington, D.C.

98. Smith, T.J. III (1987). Seed predation in relation to tree dominance and distribution in mangrove forests. *Ecology* **68** : 266-273

99. Smith, T.J. III (1987). Seed predation in relation to tree dominance and distribution in mangrove forests. *Ecology* **68**:266-273

100. Smith , T.J. III (1992). 'Forest structure'. In A.I. Robertson and D.M. Alongi, (eds). *Tropical Mangrove Ecosystems. American Geophysical Union, Washington DC.* : 101-136.

101. Spalding, M., Blasco, F. and Field, C. 1997. World Mangrove Atlas. The International Society for Mangrove Ecosystems, Okinawa, Japan.

102. Subba Rao, N.V. Dey, A and Barua, S. (1995) Mollusca:In Estuarine Ecosystem Series- Part-2 Hoogly- Matla Estuary West Bengal. Published in *Zoological Survey of India.* : 41-91.

103. Teal, J.M. (1958) Distribution of fiddler crabs in Georgia Salt Marshes. *Ecology*. **39**: 185-193.

104. Tomlinson, P. B. 1986. The Botany of mangroves. *Cambridge University Press, Cambridge*: 414

105. Untawale, A. G., (1984). Mangroves of India. In: Present Status and multiple use and practices. Status report submitted to the UNDP/UNESCO Regional mangrove project for Asia and the Pacific, 28pp

106. Vernberg, W.B. and Vernberg, F.J. 1972. Environmental physiology of marine animals. Spinger Verlag, New York.

107. Wadia, D. N., (1961). Geology of India. MC Muller & Co., London.

108. Woodin, S.A., Marinelli, R.L and Lindsey, M.S. (1998) Process specific cues for recruitment in sedimentary environments: Geochemical signals. *Journal of Marine Research* **56**: 535-558