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The causes of deterioration of Sundarban mangrove forest ecosystem of Bangladesh: conservation and sustainable management issues

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Abstract. The Sundarban forest, located in the southwest of Bangladesh, is one of the largest continuous blocks of mangrove forests in the world. This mangrove forest ecosystem in Bangladesh is now in captious position. Negative natural and anthropogenic impacts and overexploitation of natural resources have caused severe damage to the ecosystem. Growing human population with few alternative livelihood opportunities poses a serious threat to the mangrove forest. The rapidly expanding shrimp farming industry is a significant threat to the mangrove forests of Bangladesh. Due to illegal cutting, encroachment of forest areas and illegal poaching of wildlife, the mangrove forest is losing biodiversity in an alarming rate. This forest ecosystem also has become vulnerable to pollution, which may have changed the ecosystem's biogeochemistry. Further threats arise from global climate change, especially sea level rise. This study seeks to identify the root causes of deterioration of the Sundarban mangrove forest in Bangladesh. It also recommends the application of sustainable management strategies covering needs for an advanced silvicultural system, improvement of scientific research as well as conservation measures.

Key Words: Sundarban, Mangroves, Bangladesh, deterioration, sustainable management.

(In Bangla)

সারসংক্ষেপ। বিশ্বের সবচেয়ে বড় ও নিরবচ্ছিন্ন ব্লকের ম্যানগ্রোভ বন- সুন্দরবন বাংলাদেশের দক্ষিণপশ্চিমে অবস্থিত। বাংলাদেশে এই ম্যানগ্রোভ বাস্তুসংস্থানটি এখন সংকটাপন্ন অবস্থানে রয়েছে। প্রাকৃতিক সম্পদের ঋণাত্মক ও অ্যানথপোযেনিক প্রভাব এবং মাত্রাধিক্য সম্পদ সংগ্রহ করার জন্য এই বাস্তুসংস্থানের মারাত্মক ক্ষতি হয়েছে। সীমিত বিকল্প জীবনযাপনের সুযোগ এবং মানব জনসংখ্যা বৃদ্ধি এই বনের জন্য হুমকি কাজ করছে। বাংলাদেশের ম্যানগ্রোভ বনে চিংড়ি মাছ চাষঅতিদ্রুত বৃদ্ধি একটি অর্থপূর্ণ হুমকির কারণ। বেআইনি বৃক্ষ কেটে ফেলার দরুন, বেআইনি বন্যপ্রাণী ধরা এবং বন এলাকা বেআইনি অধিগ্রহণ এর কারনে এই বনটি একটি উদ্বেগ জনক হারে জীব বৈচিত্র্য হারাচ্ছে। এই ইকোসিস্টেমটি দূষণ এ চরম সঙ্কটপূর্ণ, যেটি বাস্তুসংস্থানের ভূ জৈব-রসায়নে পরিবর্তন করতে পারে। আরও হুমকি হিসাবে কাজ করছে সাম্প্রিক জলবায়ু পরিবর্তন এবং বিশেষভাবে সমুদ্রপৃষ্ঠের উচ্চতা বৃদ্ধি। এই গবেষণাটি বাংলাদেশের সুন্দরবনের ক্রমাগত ধ্বংস হয়ে যাওয়ার মূল কারণ সনাক্ত করতে চেষ্টা করে। এই গবেষণাটি সুন্দরবনের সংরক্ষণ এর জন্য উন্নত সিলভীকালচার পদ্ধতি, উন্নত বৈজ্ঞানিক গবেষণা, সংরক্ষণ পরিমাপের সহনীয় ব্যবস্থাপনা কৌশল সুপারিশ করে ও প্রয়োজন বোধ করে।

মূলশব্দ: সুন্দরবন, ম্যানগ্রোভ, বাংলাদেশ, ধ্বংস হয়ে যাওয়া, সহনীয় ব্যবস্থাপনা।

Rezumat. Pădurea Sundarban, aşezată în sud-vestul Bangladesh-ului, este unul dintre cele mai mari blocuri permanente de pădure de mangrove din lume. Acest ecosistem este acum într-o situaţie delicată. Efectele negative naturale şi antropice şi exploatarea în exces a resurselor naturale au cauzat daune severe la nivelul ecosistemului. Creşterea populaţiei umane cu posibilităţi alternative reduse de trai constituie o ameninţare gravă la adresa padurilor de mangrove. Creşterea rapidă a industriei producătoare de creveţi este o ameninţare semnificativă pentru aceste păduri. Datorită tăierilor ilegale, violării zonelor forestiere şi a braconajului de animale sălbatice, padurea de mangrove pierde biodiversitatea într-un ritm alarmant. De asemenea, acest ecosistem a devenit vulnerabil la poluare, care ar putea schimba biogeochimia ecosistemului. Alte ameninţări sunt generate de schimbările climatice globale, mai ales creşterea nivelului mării. Acest studiu urmăreşte să identifice cauzele de deteriorare a pădurilor de mangrove Sundarban în Bangladesh. Se recomandă, de asemenea, punerea în aplicare a strategiilor de management durabile care să acopere nevoile unui sistem silvic avansat, îmbunătăţirea cercetării ştiinţifice, precum şi a măsurilor de conservare.

Cuvinte cheie: Sundarban, mangrove, Bangladesh, deteriorare, management durabil.

Introduction. The total geographic area of Bangladesh is approximately 14.40 million hectares (ha) of which 13.46 million ha are land surface and 0.94 million ha are rivers and other inland water bodies (GoB 1993; Islam 2005). According to a recent estimate, the country has only 18% (2.58 million ha) of forest coverage. On the basis of geographical location, climate, topography and management principles, the forests can broadly be classified into: hill forests, mangrove forests, plain land sal forests, unclassified state forests, and homestead forests (Motiur 2006). The Sundarban is the largest mangrove ecosystem in the world. This ecosystem contains numerous tributaries of the Ganges delta, strewn along the Bay of Bengal's coastal belt in southwest Bangladesh.

The anthropogenic impact on mangroves has increased rapidly over the past decades. That is why so many countries are showing losses of 50-80% or more (73% for Bangladesh; WRI 1996) compared to the mangrove forest cover during the 1960s. Mangrove wetlands are regularly felled to make way for aquaculture, development of coastal cities, and beaches. According to studies carried out at different times by the Forest Department, British ODA and UNDP/FAO sponsored Forest Resource Management Plan, the mean volume ha^{-1} of the *Heritiera fomes* (Aiton, 1789) (local name Sundari) was 34.5 m^3 in 1959. The volume was reduced to 19.9 m^3 in 1983 and 17.8 m^3 in 1996. In the case of *Excoecaria agallocha (*Linnaeus 1758) (local name Gewa) the mean volume ha^{-1} was 8.7 m^3 in 1959, which was reduced to 4.6 m^3 in 1983 and 2.1 m^3 in 1996. The rapid decrease is blamed on overexploitation, legally and illegally clear cutting and pollution. Mangroves are under pressured by many threats such as human encroachment (including reclamation), shrimp farming and other forms of aquaculture, grazing, agriculture, diseases and natural disasters e.g. storms, floods, cyclones, coastal erosion and natural changes in hydrology, sea level rise and inadequate regeneration. There were also impacts of degradation due to the development of two main seaports at Khulna and Chittagong, which handle most of Bangladesh's imports and exports, respectively. This study seeks to identify the root causes of deterioration of the Sundarban mangrove forest and to propose adequate recommendations for sustainable management and conservation of this unique UNESCO World Heritage site for both people and nature.

Study Area. Sundarban forest, located in the southwest of Bangladesh, is one of the largest continuous blocks of mangrove forests in the World, lieing between 21°30′ N and 22°30′ N and 89°00′ E and 89°55′ E (see Figure 1). Total geographic area is approximately 6017 km^2 which represents 23% of total forest area of Bangladesh (Anon 2000). This wetland consists of about 200 islands separated by about 400 interconnected tidal rivers, creeks and canals (Banglapedia 2010).

Biodiversity of Sundarban Mangrove Forest. Sundarban has extremely rich diversity of aquatic and terrestrial flora and fauna. Mangroves are associated with flowering plants, palms, ferns, bryophytes, fungi, algae, lichens and bacteria. Chaffey et al (1995) recorded about 334 plant species, including 35 legumes, 29 grasses, 19 sedges, 18 euphorbia and 50 true mangrove plant species. It is noted that mangrove forests are habitats to about 500 species of wild vascular plants (FAO 2004). A mentionable amount of economically important plants are found in this forest. Fauna have been poorly studied in comparison to flora (Macintosh & Ashton 2002), but according to FAO estimates, Sundarban mangrove forest is home to ca. 840 species of wild animals, including. 419 Royal Bengal tigers (MoEF 2004). Within the forest habitats, there are ca. 50 species of mammals, ca. 320 species of inland and migratory birds, ca. 50 species of reptiles, eight species of amphibians, ca. 400 species of fish, as well as insects. Mangroves are also the nursery and/or breeding grounds for several commercially important species of aquatic fauna (Saenger 2002). Among the invertebrates some molluscs and crustaceans constitute important fisheries resources. About 20 species of shrimps, 8 species of lobsters, 7 species of crabs, several species of gastropods, and 6 species of pelecypods have been reported from the Sundarbans (Pasha & Siddiqui 2003). Among the shrimps *Penaeus monodon* (Fabricius, 1798) and *Metapenaeus monoceros* (Fabricius, 1798) and

the mud crab *Scylla serrata* (Forsskal, 1775) are commercially important. Over 120 species of fish are said to be commonly caught by commercial fishermen (Seidensticker & Hai 1983). The shallow swamps around the mangroves sustain an ideal breeding and nurshing ground for fishes, juvenile shrimps and endangered species such as olive ridley turtle (*Lepidochelys olivacea* (Eschscholtz, 1829)), gangetic dolphin *(Platanista gangetica* (Roxburgh, 1801)), hawks bill turtle *(Eretmochelys imbricate* (Linnaeus, 1766)) and King Crab *Carcinoscorpius rotundicauda* (Latreille, 1802). A large number of economically important plants are found in the forest. Mangrove forests are not only abundant in plant species but also crucial for local populations (Table 1).

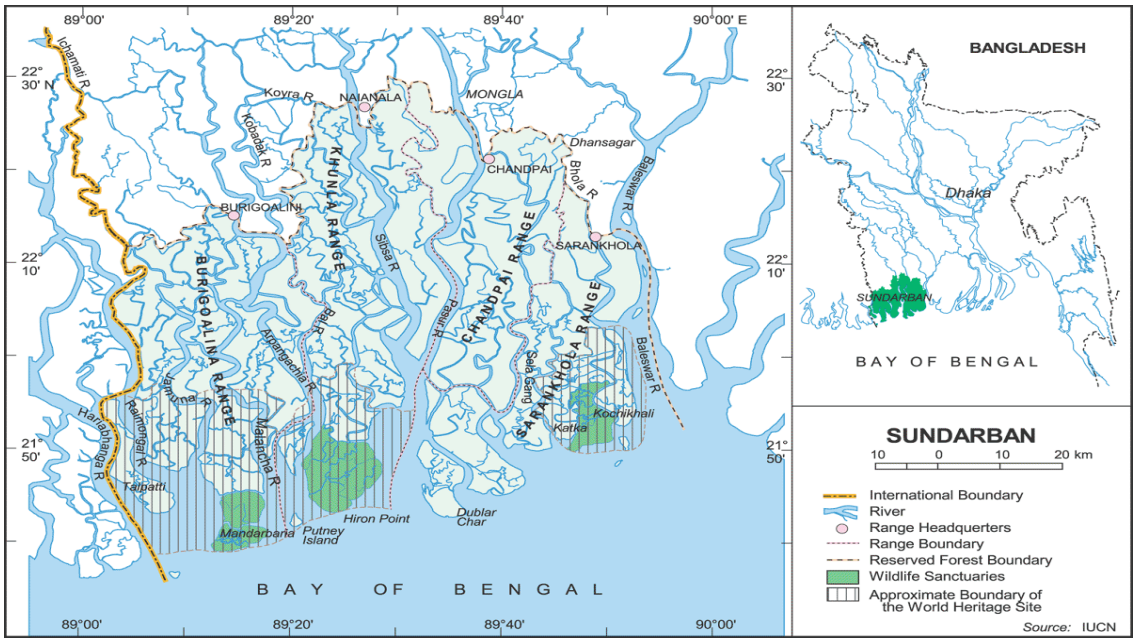

Figure 1. Map showing the distribution of mangrove forest of Sundarban in Bangladesh.

Table 1

Economically important plants of the Sundarban and their uses (after Siddiqi 1998)

Family	Scientific Name	Type of Plant	Main Uses
Avicenniaceae	*Avicennia officinalis*	Tree	Fuel wood, Anchor
Combretaceae	*Lumnitzera racemosa*	Small tree	Fuel wood, Posts
Euphorbiaceae	*Excoecaria agallocha*	Tree	Matchsticks and Raw material for newsprint
Leguminosae	*Cynometra ramiflora*	Small tree	Fuel wood, Charcoal
Malvaceae	*Xylocarpus mekongensis* *Xylocarpus granatum*	Tree	Furniture, Bridges, house
Palmae	*Nypa fruticans*	Recumbent Palm with underground stem	Thatching for houses
	Phoenix paludosa	Thorny palm	Post and rafters for huts
Rhizophoraceae	*Bruguiera spp.*	Tree	Furniture, Bridge and house construction
	Ceriops decandra	Shrub or small tree	Fuel wood, House posts, Charcoal
Sonneratiaceae	*Sonneratia apetala*	Tree	Packing boxes, Paneling
Sterculiaceae	*Heritiera fomes*	Tree	House construction Hard boards

The Causes of Deterioration of Sundarban Mangrove Forest. Sundarban mangrove forest is the most threatened habitats in the world (Rahman 2009). The increased population with few alternative livelihood opportunities poses a serious threat to the Sundarban as it is the main cause of mangrove destruction (Ong 1995; FAO 2003; Ali et al 2006). Excessive exploitation and negligence of restocking are the main cause of overall depletion of growing stocks of Sundarban forest (Ali et al 2006). The growing stock of the Sunderban forest has depleted from 20.3 million m^3 in 1959 to 10.9 million m^3 in 1996 (FAO 2000).

Mangrove forests in Bangladesh are deteriorating due to over-exploitation, deforestation, land reclamation and pollution. Large areas of mangroves have been cleared for fish and shrimp farming. Agricultural practices and industrial development, urbanization, over-logging in coastal areas as well as unregulated discharge of liquid and solid wastes are the most serious threats. Overall, the causes of deterioration of Sundarban mangrove forest ecosystem could be classified into:

1. anthropogenic
2. natural
3. other (or miscellaneous)

1. Anthropogenic Causes

Over-exploitation and Illegal Forest Cutting. Over-exploitation of forests to meet the growing requirement of the people is one of the main problems facing the Sundarban. Encroachment and illicit removal of timber and firewood from the forests and the absence of sustainable management practices are the major forest conservation problems in the area. The main reason of illicit removal of timber are: wide gap between the demand and supply of wood and almost permanent unemployment in rural areas, which results in compelling dependence on gathering of wood from the forests for subsistence; existence of organized groups of mongers who professionally indulge in illegally cutting and removing of valuable trees. Mangroves are partially in the district of Khulna, which is also the site of a government paper mill. The factory relies on nearby legal timber supplies, but with the Sundarban so close, illegal loggers have been making forays into the inner regions of the forest. Sundarban have been exploited for timber, fuel wood, bark tannin, animal fodder, native medicines and food (fish, shellfish, honey and wild animals) for centuries, but population pressure has greatly increased the rate of exploitation, leading to serious degradation.Due to illegal cutting, continuous encroachment of forest areas and illegal poaching of wildlife, the mangrove forest is quickly disappearing and as a result biodiversity of the area is reducing in an alarming rate.

Shrimp Farming. The rapidly expanding shrimp farming industry possesses the crucial cause for deteriorating the mangrove forests in Bangladesh (see Figure 2). Moreover, recently, mangroves have been used for fish, shrimp and especially giant tiger prawn *Penaeus monodon* (Fabricius, 1798) farming (Chowdhury & Ahmed 1994). The Chokoria Sundarban has been completely destroyed in recent years because of shrimp farming (Iftekhar & Islam 2004). There are 14 different fishing methods and gears used by the fisherman inside the Sundarbans. These may be clustered into three major groups based on target species and fishing gear. Shrimp fry fishing in particular is considered to be very destructive. Post-larvae (PLs) are being collected at unsustainable levels to supply shrimp grow-outfarms and massive clearance of large areas of mangroves is taking place to construct shrimp ponds, contributing to degradation and loss of mangrove habitats. Shrimp farms are primarily located in the south-western part of the country, in the districts of Khulna (19%), Satkhira (19%), and Bagerhat (29%); farms in the south-eastern part of the country exist primarily in thedistrict of Cox's Bazar (31%). Shrimp aquaculture in Cox's Bazar annually uses 620 tons of urea, while introducing 15 tons of waste to the water on a daily basis. Large amounts of natural and synthetic chemicals, including dichlorides, malachite green, debris root, and tea seed cake are used in coastal aquaculture worldwide for the control of pests and diseases (GESAMP 1991). Saclauso (1989) listed 14 chemicals and drugs commonly used in brackish water aquaculture ponds of Bangladesh.

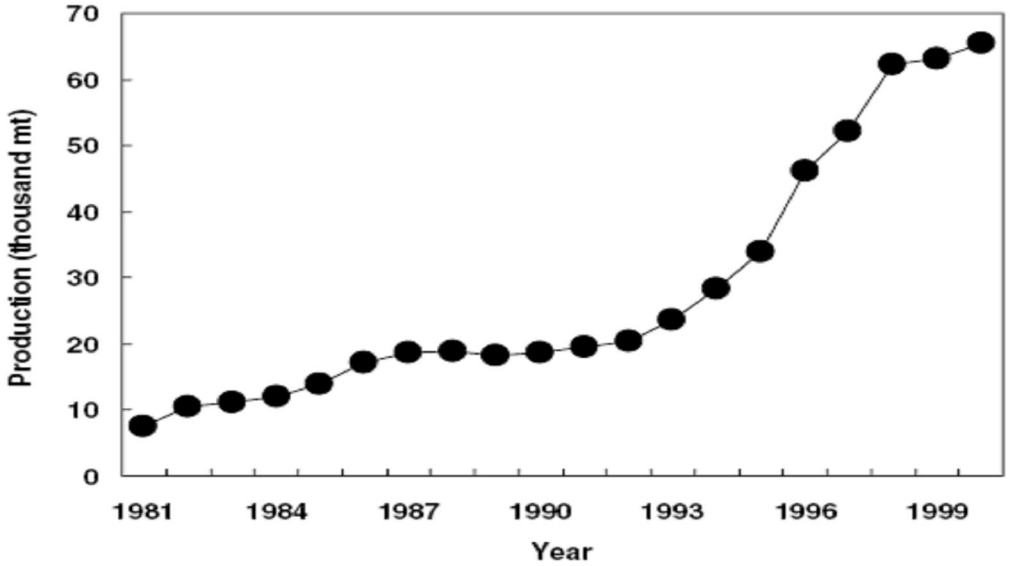

Figure 2. Production time-series of farmed shrimp over the last two decades in Bangladesh (after DOF 2001).

Pollution. Industrial development, agriculture and aquaculture near the river basins, population increase along with attempts to improve or modernize the living standards in coastal areas, has led to the production of huge amounts of garbage, waste water, pollutants and other effluents being discharged to the mangrove wetland (Rahman et al 2009). The Sundarban mangrove forest ecosystem also has become vulnerable to pollution such as oil spillage, heavy metals, agrochemicals–especially pesticides and nutrient enrichment–which may have changed the mangrove ecosystem's biogeochemistry (Rahman et al 2009). Oil pollution is a serious threat in the Sundarban and could be especially damaging to aquatic fauna and seabirds. Sources of oil pollution are potentially the port at Mongla at the north edge of the mangroves and the numerous large shipping vessels passing through the Sundarban each day via the north-east shipping route (ESCAP 1988; Scott 1989). Mongla sea port is situated three Km away from the Sundarban forest. Approximately 400 ships, numerous mechanized river crafts and fishing boats are handled annually at this port. These vessels release waste oil, spillage, balast water and bilge washings. Crude oil and its derivatives are the most dangerous pollutants which enter to the mangrove forest due to oil transportation (Iftekher 2004). Increased traffic also increases noise and air pollution and the potential hazard of oil spills and industry effluents (newsprint mill, match factory, hardboard, boat building, furniture making) can easily degrademangrove ecology (Islam 2001). The oil attached on the leaf surface can block up stomata and affect photosynthesis, respiration, and water metabolism of mangrove plants (Peng 2000). Table 2 shows the response of mangroves to oil pollution. Reported Organic pesticides and high concentration level of heavy metals such as Zn, Cd, Cr, Pb, Cu have been reported in mangrove sediment (Rahman et al 2009).

Table 2

The response of mangroves to oil pollution
(after Iftekher 2004; Rahman et al 2009)

Foliage and canopy	**Reproductive structures**
• Reduced leaf number, leaf area index, twisting or curling • Altered leaf maturation sequences • Change in leafing and shading pattern • Abscission of immature leaves • Spotty chlorosis or necrosis	• Absent or grossly excessive flowering • Change in timing of flowering or fruit set • Developmental failure of fruit • Abortion of flowers or immature fruit • Deformed seed or propagules • Failure to change floating orientation
Trunks and branches	**Regeneration**
• Top dying and lowering of canopy height • Mortality in outer most sun branches • Cessation of terminal shoot growth • Fissuring and creaking of bark • Expanded or more numerous lenticels • Shortened internodes distances • Appearance of trunk sprouts	• Failure to establish primary root system • Failure to initiate primary branching • Failure to geotropic orientation in propegules • Abnormal growth forms in young seedlings • Chlorosis or necrosis of propagules
Aerial root structures	**Gross physiology**
• Proliferation of undersized prop roots • Twisting or curling the pneutophores • Presence of adventitious aerial roots • Death of prop root tips fissuring or pealing of periderm • Abnormal branching of prop tips	• Abnormal increase or decrease in osymolyts • Increased stomatal resistance • Decreased stomatal conductance • Reduced transpiration and CO_2 uptake • Delayed chlorophyll activation • Abnormal increase or decrees in respiration • Reduced rate of sap flow in primary trunk • Increase salt concentration in soft tissues • Increase concentration of abscisics acid in tissues • Mutation • Death

Management Failure. The mangrove forest is disappearing because of the three main management failure reasons: lack of skilled and well trained officials and failure of institutions to effectively manage coastal mangrove resources and conflicting activities, poor planning and knowledge of coastal land use and implementation of development plan that does not include environmental protection principals.

Poor Knowledge of Mangrove Ecosystem and High Dependence of Local Population on its Products and Services. The people who live near the mangrove forest and depend on the mangroves for their livelihoods do not have enough knowledge and education regarding the value of mangroves. They do not know how to conserve the mangrove forest thus they lead to the destruction of the forests resources.

Other Uses. Mangrove wet land have been used for other natural resources. Population is increasing day by day putting under pressure food production; mangroves are often converted to salt pans, agricultural fields and aquaculture farms. A mentionable amount of mangrove forest has been converted into salt production area in Mohesh Khali, Cox's Bazar. Many natural mangrove stands are also degrading from overgrazing. Mangrove leafs are excellent food for domestic animals such as goat, cattle, sheep and cow and local people can easily put their livestock for feeding to the mangrove forest.

Diseases. "Top dying" is the disease of the dominant Sundari trees (*Heritiera fomes*) one of the big causes for deteriorating the forest. At least 5-6% of the total *H. fomes* across the Sundarban is now suffering from the disease and around 50% of them have already been affected in most areas of high salinity. According to the Forest Department, spreading of "top dying" started on a large scale since 1980 (see Figure 3). Recent index also shows that approximately 70% of *H. fomes* stems are moderately or severely

affected by "top dying" (Islam & Wahab 2005). A survey conducted by the Forest Department of Bangladesh from 1994 to 1996, showed that on an average 134291.701 m^3 of *H. fomes* die from the disease every year and thus the disease poses a significant cause in terms of economic and biodiversity losses. According to the Forest Department Research Centre of Bangladesh, accepted salinity levels in the rivers and canals are 5-10% and in rivers and canals in the Satkhira Range of the Sundarban is 27-33%. Rising salinity in rivers, canals and other water bodies in the mangrove forest is one of the big threat for the death of trees.

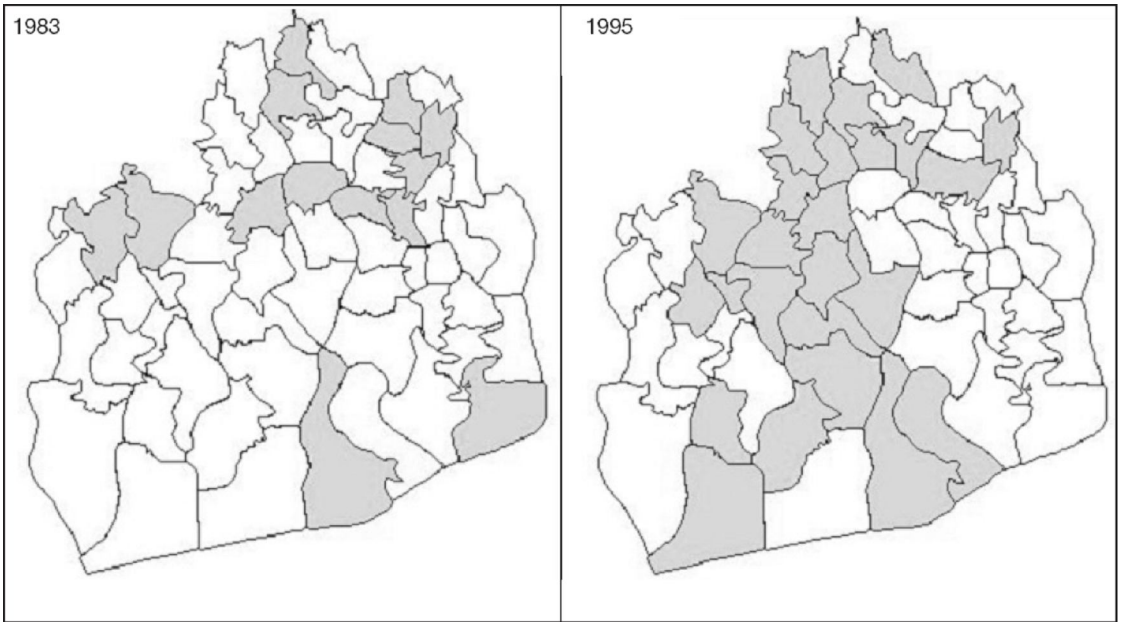

Figure 3. Compartment map showing the spreading of "top dying" disease affecting *H. fomes* from 1983 to 1995 (shaded areas) (after Iftekhar 2004).

A number of diseases has been identified as chief causes of population decline of the tree species *Avicennia* spp*., Rhizophora spp., Heritiera* spp*., Pandanus* spp*., Phoenix spp*. and *Acanthus* spp*.*. Data are scarse on disease problems of *Nypa* spp*., Ceriops* spp*., Excoecaria* spp*., Bruguiera spp*. and *Sonneratia* spp. Certain important diseases of Sundarban mangroves are leaf blight (*Alternaria alternata* (Keissl, 1912)), Dieback (*Phytophthora nicotianae* (Breda de Haan, 1896)), stump and collar rot (*Fomes* spp*.*) and damping off (*Pythium* spp*.* and *Phytophthora* spp.) affecting *Avicennia spp*.; Leaf spot (*Cercospora rhizosphorae*), trunk gall and decline (*Cylindrocarpon didymum* (Wollenw, 1926)), prop root rot (*Capillataspora corticola* (Hyde, 1989)) and seed rot (*Fusarium* spp.) affecting *Rhizophora* spp.; Wilt (*Fusarium oxysporum*), quick decline and lethal yellowing (Mycoposma like bodies), leaf blight (*Gliocladium versoeseni*), bleeding disease (*Ceratocystis ulmi* (Brisman, 1918)), leaf necrosis (*Pestalotia* spp.). Affecting *Phoenix* spp.; Dieback (*Fomes* spp.) and other diseases affecting *Heritiera* spp.; Leaf spot (*Alternaria tenuis* (Nees, 1817)), anthracnose (*Glomerella cingulata* (Spauld. & Schrenk, 1903)), leaf blight (*Botrydiploida theobromae* and *Phyllosticta* spp.), sootymold (*Meliola* spp.), leaf and fruit rot (*Erwinia carotovora* var *carotovora*), Cadang cadang (Unkonwn aetiology) affecting *Pandanus* spp.; Mosaic (virus), leaf blight (*Septoria acanthii*), powdery mildew (*Oidium* spp.), rusts affecting *Acanthus spp*. and sooty mold affecting *Aegiceras spp.*(Banerjee et al 1991).

Fire. Fire may have caused some of the most serious damage of the mangrove ecosystem in recent years. Trees in an area around one km^2 at Napitkhali under Chandpai range of the world's largest mangrove forest are burning rapidly, posing a threat to natural habitat for many rare species including the famous Royal Bengal tiger.

On March 20, 2010, trees and animal habitats of around 250 ha of the forestland were destroyed by fire. In the last three years, 12 incidents of fires occurred in the Sundarban (MAP 2010). The mangroves are the main source of honey and wax in Bangladesh. The technique of honey and wax collecting is very ancient. Das & Siddiqi (1995) reported that 200 metric tons (MT) of honey and 55 MT of wax are collected annually from the forest The Sundarban inhabit numerous species of trees that produce abundant nectar and pollen and these floral resources are used by honey bees (Islam & Wahab 2005), in order to remove the honey bees from the nest, fire has to set up. However, sometimes the fire spreads destroying the larger areas of the forest.

2. Natural Causes

Natural Disasters, Climate Change and Sea Level Rise. Various natural calamities like cyclone, flood, storms, coastal erosion, naturally shifting hydrology, climate change and sea level rise may destroys trees and animals even faster. The damage to Sundarban caused by recent cyclone Sidr has been preliminary assessed at $142.9 million. It has left 26 % of the forest severely damaged (Saadi 2010). Climate change is set to damage biodiversity of the Sundarban increasing the immersed areas and salinity of water in coastal areas. As a result, a wide range of impacts on socio-economic scale and on the mangrove ecosystems is anticipated, including the increased damage to crops, fisheries, forests and livestock. A report by UNESCO, entitled "Case Studies on Climate Change and World Heritage", has stated that an anthropogenic 45 cm rise of sea level (likely to happen by the end of the twenty-first century, according to the Intergovernmental Panel on Climate Change), combined with other forms of anthropogenic stress on the Sundarban, could lead to the destruction of 75 % of the forest (UNESCO 2007). Natural resources of the Sundarban, especially various species of trees, are seriously threatened due to sea level rise. Low areas of the mangrove forest are flooded by tidal waters every year because of sea level rise along with and massive silt deposition. Rising seas are said to have flooded 7,500 ha of mangroves in the Sundarban (WWF 2007). Mangrove forests require stable sea levels for long-term survival. They are therefore extremely sensitive to current rising sea levels caused by global warming and climate change. Rising sea levels have submerged two islands in the Sundarban, and a dozen more are under threat of submergence. Global warming is expected to cause changes such as higher temperatures, sea level rise and changing rainfall patterns, as well as more abrupt effects, such as an increase in the intensity and frequency of extreme events such as floods, storm surges and cyclones and sea level rise. Climatologists so far agree that sea level will increase 9-88 cm over 1990 levels by the end of the century. Dasgupta et al (2007) reported that the largest percentage share of land area impacted by sea level rise was evident in Bangladesh throughout south Asia (Figure 4).

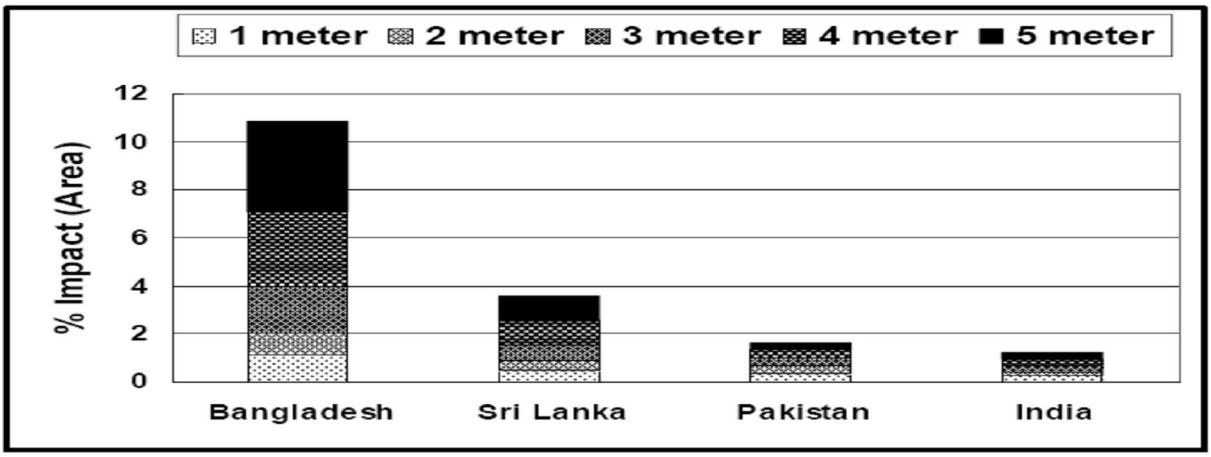

Figure 4. Percentage of land area impacted by sea level rise among south Asian countries (after Dasgupta et al 2007).

3. Other Causes

Other Causes behind mangrove forest deterioration are loss of soil fertility, geomorphological changes, high salinity ecological succession, inadequate regeneration and low yield (Akhtaruzzaman 2000).

Present Mangrove Management in Bangladesh. The management history of the Sundarban mangrove is very old. Mangrove forests of India and Bangladesh, were managed since 1769 and detailed work-plans were prepared during 1893–1894 (Chowdhury & Ahmed 1994). Forestal forestry carried out a detailed scientific inventory of the mangroves of Sundarban. Choudhury prepared the working plan based on inventory of Sundarban for the period 1960 to 1980 (Choudhury 1997). The main objective was to manage the forest on a sustained yield basis. In 1993, the Forestry Master Plan suggested two sanctuaries. The first one proposed annual planting target of about 18,000 ha during 1993–2002 and 21,000 ha during 2003–2012 (MOEF 1993). However, sufficient attention has not been given to the use of quality planting material, site preparation and post-establishment maintenance. Due to financial and legal constraints enough protection of plantations from fire, grazing, illegal removal and encroachment has not been provided (GoB 1993). The second sanctuary paid attention to the development of wildlife sanctuaries; consequently, three areas of the Sundarban Forest Division have been declared wildlife sanctuaries. However, the total area of these sanctuaries is not sufficient to provide long-term protection to the wildlife (Islam & Wahab 2005). An integrated management plan for the Sundarban is being prepared through a FAO project. The major objective is to achieve sustainable management of the mangrove in order to yield different important recourses including wood, fish, wild life as well as recreation services and non-wood products (Choudhury 1997). However, mangroves are now degrading rapidly. Forest cover, species diversity and ecosystem function have declined, even though several forest policies, laws and management plans have been enacted to protect them. The effectiveness of these policies and plans is limited by the poor implementation capacity (Iftekhar & Islam 2004). In addition to natural forest, mangrove plantation programme has been undertaken over an area of 170,000 ha since 1966. *Sonneratia apetala* (Buch.-Ham 1822) and *Avicennia officinalis* (Linnaeus, 1775) are the principal planting species for the coastal afforastation. But neither tree cutting moratorium nor participatory forestry have seen any success. Moreover, negligence and corruption among the personnel of government forest department along with the collaboration of local political leaders with the encroachers is adding to the management failure (Akhtaruzzaman 2000). Although governmental bodies (e.g. Bangladesh forest department) tried to undertake certain conservation planning initiatives such as Environmental Policy, National Conservation Strategy and National Environmental Management Active Plan to protect mangrove ecosystems since 1960 to 2001, management strategies based on logical and scientific basis have not been developed until today. Adequate research efforts have not yet been paid to find out effective management policies (Islam & Wahab 2005).

Examples of Sutainable Mangrove Management in South Asia. The Matang mangroves in Malaysia is the best example of mangrove management in the world. Comprehensive management objectives and a ten-year working plan have contributed to its success. The 90% of total area is now covered by natural regeneration and repopulation is assisted by artificial planting (Chan 1996). In Vietnam, the "3.2.7 project" and the "5 million haproject" are examples of national projects under auspice of the government. Today, 10 million haof reforestation including mangrove and other plants is being undertaken (Kogo & Kogo 2004). In China, Hong Kong, Shenzhen, Fujian, Dongzhai and Guangdong provincial governments introduced sustainable management practices during the last few years (Chen et al 2004). Forty years ago, Jiulongjiang estuary mangrove forest was completely destroyed by human activities. However, the Chinese government took the initiative to regenerate the mangrove forest. Chinese Mangrove Protection Project (CMPP) works on mangrove issues is all China's coastal provinces which have mangroves including Zhejiang, Fujian, Guangdong, Hainan and

Guangxi. Activities include awareness raising , investigation, scientific research, communication, interpreter training, data accumulation, web construction, afforestation and the Greenwild Mangrove Fund (GWMF) in order to promote mangrove conservation and management of Chinese mangrove ecosystems (MAP 2007). As a direct result of these comprehensive measures, Jiulongjiang estuary mangrove forest is now a large mangrove wetland; Moreover, the government introduced sustainable management system (Chen et al 2004; Peng 2000). Wang Mangrove Reforestation Contract Project in the Philippines archived the highest success of sustainable management of the resource. In Indonsia, a new approach called *Tambak empang parti* (channel fish ponds) has been introduced to the north cost of west Java to take socio-economic factors in account (Soegiarto 2004). The ''Perrum Perhutani'' is another positive management example in Indonesia. Almost 3,000 ha of damaged mangrove forest have been rehabilitated in Cilacap on the south coast of Java. In addition, Thailand, Ghana, Senegal and Tanzania provide success stories of community based management of mangrove resources.

Conservation and Sustainable Management Issues. Internationally, forest ecosystem management attention seems now to have generally been shifted from management for a single objective (often wood production) to a sustainable ecosystem approach that tries to incorporate the principles of equity in resource utilization and participation for sustained production of multiple outputs into forest management by recognizing the hopes and aspirations of different stakeholders interested in the future of the natural forest resources. Environmental destruction in a country or region affects other regions. Conservation of nature at local level strengthens and contributes towards regional and global nature conservation. At international and national policy level, it is today accepted that Sustainable Forest Management (SFM) depends upon several factors such as: 1. integrated management for all forest values–wood and other items and services, 2. meaningful participation of all stakeholders 3. landscape level planning and management and 4. comprehensive monitoring, evaluation and reporting on indicators of sustainability. Most of the mangrove forests in Bangladesh are now substantially degraded and poorly stocked. In this crucial time it is needed to review the current management strategy of mangrove forest ecosystem for the future betterment. The future of this ecosystem depends on wether sustainable planning and management can be effectively implemented (see Figure 5).

To protect and conserve the Sundarban mangrove of Bangladesh, the following measures should be considered: silvicultural system must be improved to promote effective regeneration. At the same time, sustainable alternatives to forest-based livelihoods such as home gardening, forest product based small cottage industry, bee keeping, poultry farming, tourism and recreation may be explored. The study demonstrated that the traditional resource users possess distinct customary ways to sustainably manage the resources of the Sundarban. Thus these practices should be promoted.Technical and institutional education and training can also create alternative job opportunities. To formulate such management strategies, growth and yield information should be made available through appropriate forest inventory that would allow computation of annual allowable cut that can be extracted from the mangrove forests preserving sustainability of ecological, economical and social values of these forests. Also, an accurate inventory of encroached mangrove forest is required to develop a viable land recovery plan. In addition, it is required to develop comprehensive protection measures to tackle the illicit activities such as forest land encroachment for agriculture, illegal tree felling, wood smuggling, poaching of wildlife etc. There is an urgent necessity to strengthen the management of mangrove forest through recruiting well trained and motivated forestry professionals, allocating sufficient budget and developing infrastructures. The Sundarban mangrove forests must be brought under community reserves where local people could be made partners in conservation and management processes. Ecofriendly, cost effective technology such as phyto-remediation and bio-manipulations should be considered for pollution prevention, control, and remediation. Economical, yet efficient, industrial effluent treatment plants should be utilised to reduce the environmental impact of industrial effluents. Use of mangrove

areas for dispersal of urban and industrial waste should be prohibited. Currently, there is no organized system of harvesting wood, wild medicinal and aromatic plants. There is a need to formulate policies related to rotational harvest of medicinal plants for the benefit of communities thereby controlling excessive pressure on the mangrove forest.

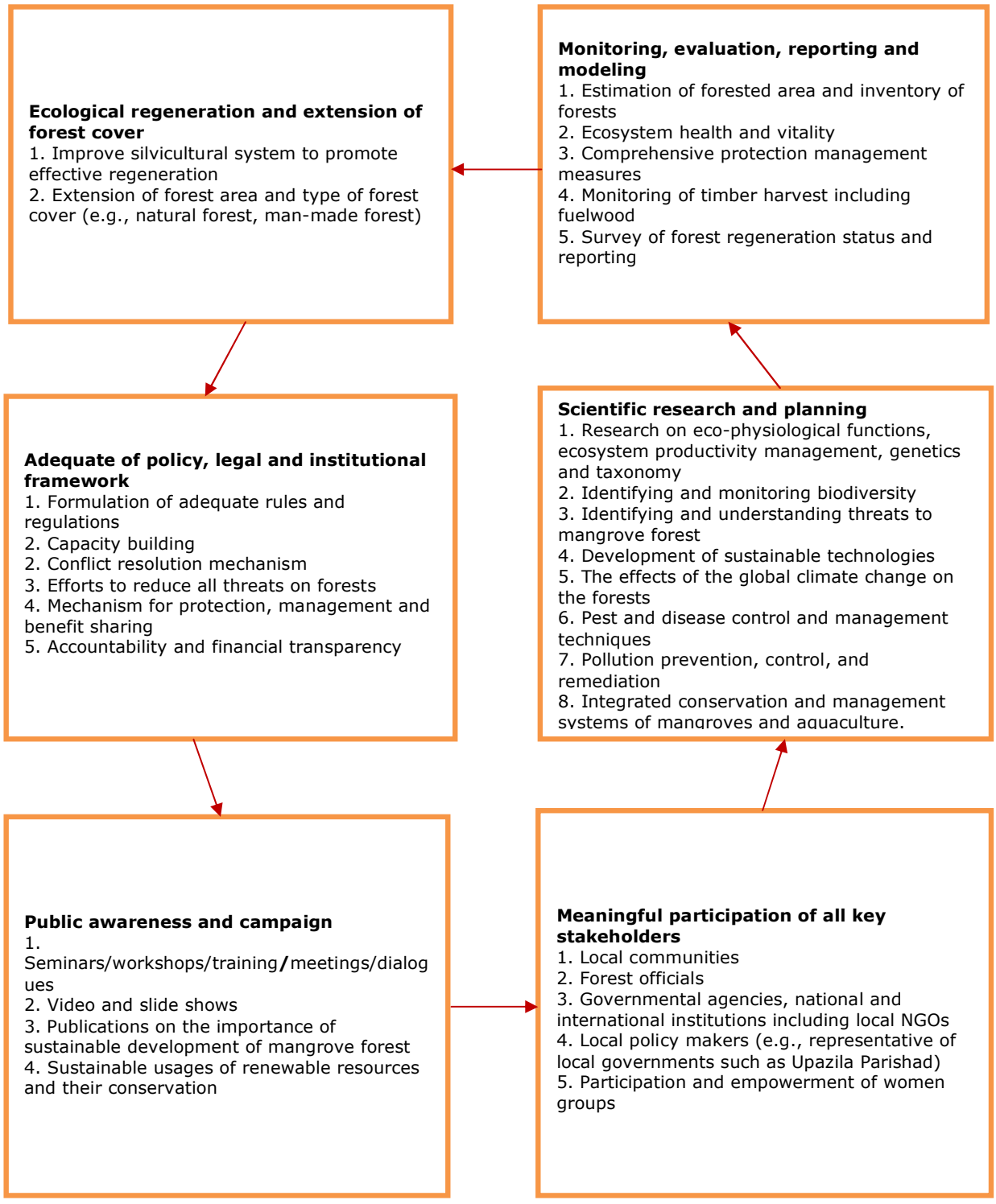

Figure 5. Sustainable management plan for mangrove forest ecosystems.

Conclusions. The deterioration of mangroves can lead to serious consequences, including reduction in biodiversity, species decline, genetic erosion, extinction, increased flooding, and decline in water quality.The future existence of Sundarban mangrove forest in Bangladesh depends on the development and successful implementation of a sustainable management plan to protect and conserve these important resources. The government has attempted to introduce some initiatives to protect these important ecosystems but the sustainability of these resources could not be achieved due to lack of sound management strategies. A sustainable management plan should be developed by involving all beneficiaries and stakeholders and should be effectively implemented to conserve the world's largest mangrove ecosystem for present and future generations.

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