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Review Article

Paradigm shift in the management of the Sundarbans mangrove forest of Bangladesh: Issues and challenges

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ABSTRACT

The Sundarbans is the largest continuous mangrove forest of the world, which is rich in both the floral and faunal diversity compared to other mangrove forests of the World. It has long historical records of forest conversion and management. The objectives of this study were to synthesis the management interventions for the Sundarbans and to find out the issues and challenges that encountered the management objectives. The conversion, management, and conservation efforts for the Sundarbans during the last 240 years can be grouped into four distinct time periods based on the outlook of resources use e.g. conversion for agriculture 1780 to 1875; timber production for revenue and control for theft 1876 to 1951; inventory based management 1952 to 1992; integrated management & co-management, and project-based overlapping management 1993-2020. This chronology of outlook was the journey towards the conservation of the Sundarbans ecosystem and also explains the importance of this ecosystem on the national to the regional and global scale. Finally, it was relished that involvement of local people/ community in the management in the form of co-management is now obvious for the protection, conservation, and management of the Sundarbans. However, there are some important issues and challenges that are related to the management of the Sundarbans. The important issues and challenges that are over-exploitation of resources, change in vegetation pattern, poor recruitment of important tree species, habitat degradation, invasive species, poaching and wildlife trafficking, salinity, extreme weather events, uncontrolled tourism, pollution, etc., which are dynamic in nature and need to pay strategic attention to the better protection and management of the Sundarbans ecosystem. It is believed that the findings of this study may contribute to adopting effective management interventions for the other mangrove forests of the world.

1. Introduction

The Sundarbans is the world largest single tract of mangrove forest covering about 10,000 km^2 land at the southwestern corner of the Ganges delta of India and Bangladesh. Within Bangladesh, this forest covers an area of 6017 km^2, comprising 4.13% of the total land area and 38.12% of total forest land of the country (BFD, 2017), and extends from the Harinbhanga River on the Indian border to the Baleswar River in the east. This coastal forest ecosystem is dynamic and highly productive and rich in floral and faunal diversity. It contains about 50% of the world's mangrove plant species (Hoque and Datta, 2005; Aziz and Paul, 2015), 505 species of wildlife (Khan, 2013), 261-320 species birds, 177-400 species of fish (Khan, 2013), 5530 species of insects (Mitra et al., 2016) and numerous species of fungi, bacteria, algae, lichen and phytoplankton. (Siddiqi, 2001).

The Sundarbans plays an important role in the regional and national economy and climate (Mukhopadhyay et al., 2018; Sarker et al., 2019a). It provides many direct benefits (e.g. fuelwood collection, fishing, etc.) to the surrounding communities. About one million people are directly or indirectly dependent on the resources of the Sundarbans for their livelihoods. It protects the lives and properties of the adjacent population from the tidal surges and tropical cyclones. This forest traps a portion of sediment that carried into the Bay of Bengal by the Ganges river system and controls coastal and riverbank erosion (Saenger, 2011; Hale et al., 2019). The mangroves provide nursery, feeding, resting and breeding grounds, as well as shelter, for many aquatic organisms and

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supply particulate and sub-particulate organic matter to coastal fish populations. This forest helps in carbon sequestration and storage, and soil nutrient cycling (Rahman et al., 2015; GoB, 2019). There are some rivers and channels are delineated for the navigation and used for transporting goods by domestic and international vessels. The country's second largest seaport, is situated at Mongla at the north edge of the Sundarbans. The forest faces considerable pressure from resource extraction, the impacts of navigation and tourism, industrial development and other anthropogenic activities in the surrounding areas.

The forest areas are criss-crossed by numerous rivers, canals, and tidal creeks, creating a network of mudflats and islands with an elevation of 0.9 to 2.11 m above sea level (Saenger and Siddiqi, 1993; Siddiqi, 2001). The forest ranges about 125 km from east to west and extends by an average 80 km inland (maximum 100 km). The waterways cover about 1874 km^2, about 30% of the total forest area. The width of the waterways varies from few meters to 10 km (BFD, 2017). The forest boundary follows the natural river channels. In 1770, the total area of the Sundarbans was 19,508 km^2 including the waterbodies. It is now significantly reduced to 10,217 km^2 (the combined Bangladesh and Indian parts). However, the land area (excluding water) recorded during inventories of the Sundarbans has varied slightly: between 390,550 ha in 2013 (minimum) (RIMS 2013) and 414,246 ha (maximum) in 1983 (Chaffey et al. 1985). These changes were mostly associated with the technologies used for area determination, erosion and accretion, and the way in which mud flats were classified.

This Sundarbans mangrove forest has a long experience of conversion to management initiatives since 1780. Primarily, a large portion of this forest was converted to agricultural land and human settlement. The vicinity population was highly dependent on the resources of the Sundarbans for their livelihood and household consumption (Bhattyacharyya, 2011). Forest Department had started the management for the Sundarbans considering the peoples' dependency and contribution to the national economy. A total of 10 plans was prepared for the Sundarbans starting from 1875 to 2020. Some of these plans were implemented, some were modified and again rejected considering the consequences. The objectives of these plans were shifted from timber production to integrated resource management with the involvement of the community. At the same time, there are some issues and challenges were identified that can affect the performance of the management plans as well as the sustainability of the Sundarbans. It is highly important to know the different management interventions, management prescriptions, challenges during the implementation, and causes of revision and rejection of those management plans for the future management of Sundarbans. Therefore, the present study aimed i) to synthesis the past management plans to identify the shift of objectives and interventions for the management of the Sundarbans over time ii) to identify the possible challenges and issues related to the management of the Sundarbans.

2. Management history of the Sundarbans

The Sundarbans was formed 7000 years ago by the deposition of sediments from the foothills of the Himalayas through the Ganges river system (Chaudhuri and Choudhury, 1994; Allison et al., 2003; Aziz and Paul, 2015). From 1200 to 1750, this region was a frontier zone (Eaton, 1990): an economic frontier for communities of wet rice farmers who brought technologies with them; a political frontier for large centralized states expanding from North India - the Delhi Sultanate (1206-1526) and the Mughal Empire (1526-1761); and a cultural frontier (particularly the southwest region of Bangla) for the expansion of the religion of Islamic.

These combined effects ultimately shaped the sparse distribution of human settlements in the Sundarbans area from 1200-1750. The hostile environment and the frequent attack by Portuguese and Arakans pirates were the major causes of depopulation (Hunter, 1875; Sarkar, 2012). The British government considered that the Sundarbans was a "jungle" full of deadly diseases and man-eating animals like snakes, crocodiles, and tigers. At the same time, frequent tiger attacks were widely reported and those attacks were also considered as the major hindrance to human habitation and development in those areas. Government appointed hunters and also announced rewards for the killing of tigers. Those initiatives were believed as the major causes of the sharp decline of the tiger population in the Sundarbans (Hunter, 1875). However, a recent study reported that a total of 1259 tiger deaths were recorded from 1881 to 2006 (Adam, 2009). These statistics conform the destruction of the forest and wildlife as well. Massive destruction of the forest occurred following the leasing of land by the Mughal kings, and the British continued this process in their early colonial period. In 1764, the East India Company appointed Commissioner William Dampire and Lieutenant Hodges to survey and demarcate the boundaries of Sundarbans. It was the first survey for the Sundarbans and the British Surveyor-General prepared the first map of Sundarbans in 1769 (Bhattyacharyya, 2011).

The objective of developing the first map was to estimate the amount of revenue to be gained through leasing out the land. Subsequently, land began to be allocated to *Talukders* (aristocrats who formed the ruling class during the Mughal and British times) and Zaminders. In 1828-29, the Sundarbans was surveyed and mapped again by William Dampier and Lieutenant Alexander Hodges, based on revenue records. The Forest Department was established in 1860 and proposed a plan to regulate tax and flow of timber from the Sundarbans. Dietrich Brandis was appointed as Inspector General of Forests 1865 and took steps to conserve the forests of Bengal, and so the Sundarbans came under the management system of the Forest Department (Bhattacharya, 2011). Human settlement around the Sundarbans increased greatly with the establishment of circuit embankments during the 19th century to protect land from tidal inundation (Chakraborty, 2005). Afterward, the Sundarbans has gone through a series on management objectives like timber production, supply of raw materials for wood based industries, and finally integrated management and co-management initiatives. However, the management initiatives of the Sundarbans can be divided into different paradigm shift. The paradigms are conversion for agriculture, timber production for revenue collection, inventory based management and integrated management and co-management (Figure 1).

2.1. Conversion for agriculture (1781 to 1875)

Before the British colonial period, there was no real thought given to the management, protection and conservation of the Sundarbans mangrove forest. Even so, the British were not particularly concerned about the environment. Between 1781 and 1875, they converted considerable areas of the Sundarbans to cultivable land. The concept of protecting the Sundarbans emerged when this conversion appeared to be unprofitable due to the hostile environment and lower production capacity of the soil compared to other areas. The Forest Department realized that it would be more profitable to use the Sundarbans as a sustainable source of timber, fuelwood, and revenue (Hunter, 1875; Eaton, 1990; Ghosh, et al. 2015), which was reflected in their annual progress report of 1867-68. Considering this fact, the Forest Department decided to control the flow of forest resources from the Sundarbans through a tax system that was the first initiative for the protection of timber resources of the Sundarbans. Afterward, a management division was established in 1869 for the protection and preservation of the Sundarbans (Rahman and Danda, 2019). The tax system was introduced only for the extraction of *Heritiera fomes* based on the diameter classes, which was proposed by the first plan prepared by A.L. Home during 1871.

In 1875, Sir William Wilson Hunter (Inspector General of Statistics of India) reported different wood (timber and construction wood) and non-wood resources (fuelwood wood, thatching materials, wildlife, fish and shellfish, etc.) of the Sundarbans, and their uses, abundance and occurrence in his book "*A statistical Account of Bengal, Volume 1*". This account can be considered as the first forest inventory of the Sundarbans. At the same time, Mr. Wilhelm Schlich (Conservator of Forests)

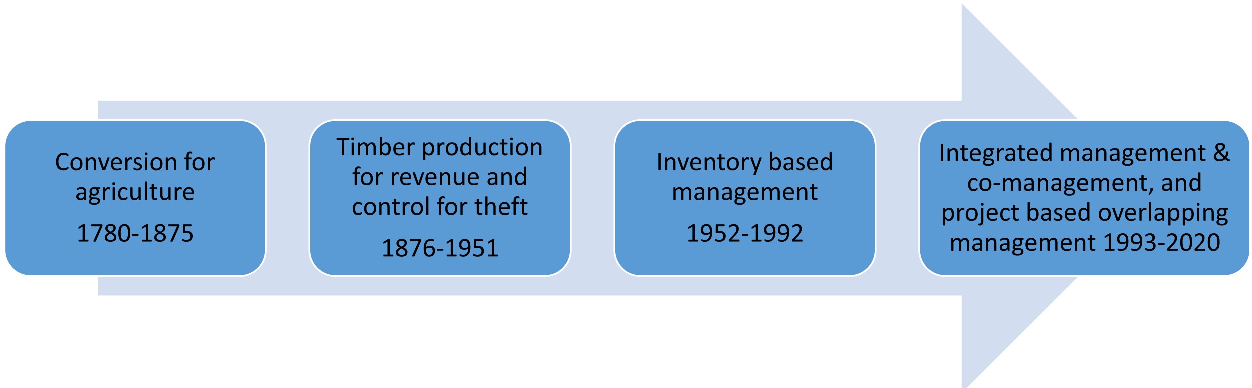

Fig. 1. Paradigm shift in the management of the Sundarbans

wrote an article "*Remarks on the Sundarbans*", which was published in the 1st volume of "Indian Forester" during 1875. This is probably the first scientific article on the Sundarbans. This article described the importance of the Sundarbans in supplying timber, thatching grasses, and fuelwood; peculiarities of the ecosystem, large-scale clearance by the woodcutters; and uncertainty in natural regeneration in the cleared areas of this forest. Schlich recommended that the "*Sundarbans should be taken under forest management without delay, instead of extensive cultivation towards the south without considering to what extent the permanent yield of forest produce may be curtailed by it*". The statement intended to control indiscriminate extraction from the Sundarbans and provided the first framework for 19th century scientific mangrove forestry.

2.2. Timber production for revenue collection (1876 to 1951)

The timber resources of the Sundarbans were the major attraction for the house building in the vicinity cities for their durability and availability, which caused indiscriminate extraction of timer resources from the Sundarbans. The Schlich's 1875 planned to restrict the extraction of forest trees by imposing increased tax. However, the tax collection was increased to twenty times 1876 and 1892. Surprisingly, illicit felling also increased considerably at the periphery of the forest areas, which resulted the failure of the Schlich's plan. The concern of Schlich and the policy of Temple during 1874 resulted in the establishment of 4095 km^2 of reserved forest in Khulna and 4480 km^2 of protected forest in 24 Parganas during 1890 under the Indian Forest Act of 1878 (Presler, 1991; Bhattacharyya, 2011).

The first formal forest policy was adopted in 1894. It covered the forest resources under state control, revenue generation as a major objective, and stressed the importance to greater agriculture. It led to the preparation of six working or management plans between 1876 and 1951 each of which modified the approach to forest protection and management (Balooni and Singh, 2007; Bhattacharyya, 2011).

The Sundarbans Forest Division was established at Khulna during 1889 for the protection and management of the Sundarbans. This was the first step in the decentralization of forest administration for the management of the Sundarbans. The first formal "Working Plan" was prepared by Heinig in 1903 with the objective to protect valuable timber species like *H. fomes, Xylocarpus mekongensis, Sonneratia apetala* and *Aglaia cucullata* through adopting a rotation system for extraction. This system reduced the amount of timber extraction compared to Schlich's plan by about seven times, the extracted amount of fuelwood was remain same (Bhattacharyya, 2011). However, there were two major drawbacks 1) this drastic reduction of timber flow influenced the timber market and 2) livelihood of the dependent population.

A revised working plan was prepared by W.F. Lloyd for five-year period from 1903-04 to 1907-08 and continued to be used until 1913. He proposed the improvement or strengthening of the forest administration and a ban on the felling of *H. fomes, X. mekongensis* and *S. apetala* from the western part of the Sundarbans. It also recommended issuing a permit for resource extraction only for specific coupes (areas to be cut). The number of staff was increased to intensify patrolling. Lloyd proposed three management zones in the Sundarbans: the south-western zone with mangrove species; central zone with *H. fomes;* and coastal zone with savanna. Another modification of Heinig's 1903 plan was introduced by Farrington for 1906-1912. This modification aimed to improve the growing stock of important timber species (*H. fomes, X. mekongensis, Aglaia cucullata, Bruguiera spp., Sonneratia* spp.). The permitted felling DBH (Diameter at Breast Height) of *H. fomes* was increased to 33.4 cm. Practicing of the hammer mark before the tree felling and the introduction of a transit rule were important modifications to control illegal felling of trees.

Trafford prepared a working plan in 1911 which was implemented for 20 years (1912-13 to 1931-32). The plan divided the Sundarbans into two working circles for *H. fomes*: eastern and western. The eastern working circle consisted of coupes under Bagerhat and Khulna areas, with two blocks combined into a single felling series for a 40-year cycle. The western circle was dedicated to fuelwood cutting. However, a survey of Curtis in 1931 identified that the previous conservation initiatives for the major tree species such as *H. fomes* and *X. mekongensis* has done little to improve stocks. Rather, felling had not been controlled and there had been a depletion of these tree species. Curtis also reported a lack of age gradation in these species.

Curtis prepared another working plan for the period from 1931 to 1951. This plan was a revolution for the management of the Sundarbans. It aimed to strengthen forest administration and ensure sustainable supplies of forest resources (timber, fuelwood, thatching material). The silvicultural system was attuned to species characteristics and site qualities. The Sundarbans administration was decentralized into six ranges with administrative sub-divisions. The ranges were divided into five working circles for the management of five important major species and based their ecological character. Felling was allowed according to species requirements. A modification of Curtis's plan was proposed for 1937-51 by S. Chawdhury. He prescribed a block-specific and selection-cum-thinning silviculture system, and an area-based yield for felling cycle of 20 years. The collection of *Nypa* leaves was also permitted in addition to fuelwood.

2.3. Inventory based management (1952 to 1992)

After 1947, in the then East Pakistan, the Sundarbans were managed under short-term plans until 1960, based mostly on the Curtis plan. The Forest Policy of Pakistan (1955, revised 1962) allowed for huge extraction of resources with rights of the local community denied. A detailed inventory of Sundarbans, based on aerial photography, was conducted in 1960 by a Canadian company (Forestal Forestry and Engineering International Limited). This led to the preparation of a comprehensive management plan for the Sundarbans, prepared by A M Chowdhury for the period of 1960-1980, which was continued till 1985. Based on site qualities, this plan prescribed exploitable DBH classes (26.9 cm, 21.9 cm and 16.8 cm) for three classes (I, II and II, respectively) for the harvesting of timber for all species. Chowdhury prescribed a 20 year felling cycle for all species and emphasized timber production for industries developed in Khulna (e.g. Newsprint Mills and Hardboard mills).

After the independence of Bangladesh in 1971, the management of the Sundarbans received special pace through the promulgation of Wildlife (Conservation) (Protection) Act 1974, establishment of three wildlife sanctuaries in the Sundarbans during 1977, establishment of Mangrove Silviculture Division of Bangladesh Forest Research Institute at Khulna in 1977, establishment of permanent sample plots in the Sundarbans for continuous inventory, forestry extension program in 1980, development of wildlife management plan during 1984 and the forest inventory during 1980-85. This inventory report of The UK Overseas Development Authority (ODA) indicated depletion of growing stock of important species like *H. fomes* and *E. agallocha* by 40%, and 45% respectively compared to the inventory of Forestal in 1960, and resulted depletion of growing stock in the forest, which fell from 20.3 m^3 to 13.2 m^3 during 1960 to 1985 respectively (Chowdhury and Hossain, 2011).

Considering the depleting trend of forest resources, Bangladesh Government imposed a ban on harvesting of timber from the Sundarbans during 1989. In another way, the Sundarbans was declared a RAMSAR site (a wetland of international importance under the Ramsar Convention - the Convention on Wetlands) during 1992 as strategic conservation initiatives.

2.4. Integrated management, co-management and project based overlapped management (1993-2020)

2.4.1. Integrated management initiative

The first Forest Policy and the Forestry Master Plan in the independent Bangladesh were promulgated during 1994 and 1996 respectively, which influenced to take integrated management and conservation initiatives for the Sundarbans. Meanwhile, the Sundarbans was declared as the 798th World Heritage Site (WHS) by UNESCO Sundarbans during 1997. This declaration was the important initiative for conservation.

The first integrated approach to the management of the Sundarbans began in 1988 under a 12-year plan 1998-2010 prepared by Canonizado J.A and Akbar Hossain. This plan not only focused on timber production but also dealt with the integration of nature conservation objectives as principles of integrative forest management. This management plan was based on an inventory conducted in 1996 under the FRMP (Revilla et al., 1998) and forecasted the timber harvest and growth up to 2020. This plan prescribed regulatory measures for both the forest and aquatic resources of the Sundarbans. The major prescription was to increase the exploitable diameter for timber harvest and reduced the annual allowable cut compared to Curtis' plan (1931-51) and Chowdhury's plan (1960-1980), which were the indications of more conservation attitude. This management plan also prescribe to improve the infrastructural development at the field level and logistic support to facilitate the management capacity for the protection of forest resources and improvement of tourism facilities inside the Sundarbans (Canonizado and Hossain, 1998). However, this management plan failed to get approval from the concern authority hence was not implemented in the field.

The present 10-year (2010-2020) Integrated Resources Management Plan (IRMP) for the Sundarbans was prepared under the Nishorgo support project. It is a revision of the Integrated Forest Management Plan (1988-2010) of Canonizado J.A and Akbar Hossain, and the Conservation Management Plan of the three Wildlife Sanctuaries (1997-98 to 2002-03) (BFD, 2010). This management plan was based on an inventory conducted by Latif in 2009. It contains resource-specific objectives and management guidelines along with monitoring and evaluation criteria. This plan prescribes 10 strategic management programs e.g. habitat protection; wildlife sanctuaries management; sustainable forest management; food security and wetland management; climate change mitigation; climate change adaptation; ecotourism; facilities development; conservation outreach conservation research; participatory monitoring and capacity development; administration and budget (BFD, 2010).

This plan included a co-management approach to incorporate local resource users in decision-making processes as well as to increase accountability and sharing of responsibility for the management of the Sundarbans. This is the major paradigm shift towards the integrated management of the Sundarbans with the expectation of more equitable and sustainable resource conservation and management backed by resource users, management authorities, and other relevant stakeholders (Chowdhury et al., 2010). Co-management of the Sundarbans contains a three-tiered co-management structure that been in practice since 2011. The three tiers are VCF (Village conservation forum at the community level), PF (Peoples Forum at the Forest Range level) and CMC (Co-Management Committee at the Forest Range level). However, the overarching structure of co-management is the Co-Management Councils (CM Council also at Forest Range level), while their executive body is known as Co-Management Committees (CMC) (GIZ, 2017).

2.5. Project based management

The consecutive inventories of the Sundarbans indicated that the sustained yield approach did not work well for the management of the Sundarbans. It is believed that illicit felling of trees, lack of protection and conservation measures and inappropriate monitoring of the forest resource harvesting operation and improper assessment of the resource bases can be responsible for the failure of sustainable yield basis management of the Sundarbans (BFD, 2010). The failure of sustainable yield basis efforts has resulted in the depletion of 50% growing stock during the four decades (1960-2000). Over-extraction and changes in salinity have been identified as contributory causes for this depletion of the forest resources. The deterioration of the Sundarbans became a concern and resulted in the launching of sixteen (16) development projects since 1993 with specific objectives. The implemented project emphasized the issues relating wildlife, fisheries, apiculture, tourism, forest extension, employment diversification, women's development and livelihood and poverty alleviation as well as timber management and biodiversity conservation. The objectives of these 16 development projects were overlapped with the objectives of different management plans (Conservation Management Plan of the three Wildlife Sanctuaries- 1997-98 to 2002-03; Integrated Forest Management Plan-1988-2010; Integrated Resources Management Plan-2010-2020) of the Sundarbans for the period of 1988-2020. However, the name of the projects, implementation period, funding sources, and the specific objectives of these development projects have been presented in Table 1.

3. Challenges and issues related to the management of the Sundarbans

3.1. Over-exploitation of resources

The inventory of ODA in 1985 reported that the volume stock of *H. fomes* and *E. agallocha* had been reduced considerably in comparison to the inventory of Forestal (1960). This reduction in volume stock may be related to the over exploitation, which is reflected in the different inventories of the Sundarbans (Table 2). Recently, a study reported that density of *H. fomes, E. agallocha* has increased to 331 and 228 stem/ha respectively (GoB, 2019), which was higher compared to all the inventories since 1960 (Table 2).

Felling of best quality saplings of important species was frequent to fix fishing nets and boat decking by fishermen and wood cutters respectively, which resulted loss of about 2 million poles annually. This loss considered as over-exploitation and resulted serious implications on the

Table 1
List of important implemented project in the Sundarbans.

Sl No.	Name of the project	Period of Implementation	Funded by	Objectives
1	Integrated Resources Development of Sundarbans Reserved Forests FO DP/BGD/84/056	1993 to 95	UNDP	This was a technical assistance programme of FAO which aimed to assist government in formulating a development programme for the Sundarbans to increase its productivity.
2	Development of Wildlife Conservation and Management	1995 to 97	GoB	
3	Forest Resources Management Project	1992-2000	IDA GoB	Its main objectives were to develop the management plans for forests and prepare conservation management plans for three wildlife sanctuaries with more emphasis on biodiversity
4	Sundarbans Biodiversity Conservation Project	1999 -2005	ADB GoB	This project attempted to bring a paradigm shift in the management of Sundarbans by introducing a powerful management authority and creating additional forest divisions – the Aquatic Division, and Wildlife and Tourism Division to take special care of fisheries and tourism potential, respectively.
5	A study on behavior and Ecology of Tigers in the Sundarbans Reserved Forests	2002-2006	USAID	
6	Sundarbans Reserved Forest Management Support Project	2005-10	GoB	
7	Integrated Protected Area Co-management Project (IPAC Nishorgo)	2010-13	USAID GoB	The objectives were to introduce the co-management through the involvement of local communities in Sundarbans management in order to address the threats of illegal harvesting, wildlife poaching and crime in the Sundarbans, and also provide alternative sources of income to the dependent population.
8	Support to Essential Management Capacity in the Sundarbans World Heritage Site following the Passage of Cyclone SIDR phase I	2008	UNESCO	
9	Support to Essential Management Capacity in the Sundarbans World Heritage Site following the Passage of Cyclone SIDR phase II	2010 to 11	UNESCO	
10	Sundarbans Environmental and Livelihood Security (SEALS) Project	2012-15	EU GoB	It was aimed to improve the productivity of ecosystems with environmental and social integrity.
11	Strengthening Regional Cooperation for Wildlife Protection	2011-16	IDA GoB	
12	Biodiversity Conservation and Ecotourism Development	2011-14	GoB	
13	Sustainable Development and Biodiversity Conservation in Coastal Protection (SDBC Sundarbans)	2012-15	GoB GIZ	
14	Climate Resilient Ecosystem Livelihood Project	2012-18	USAID	This aimed to address environmental challenges by protecting forests and watersheds in Bangladesh. The project worked to strengthen community organizations through training to the vulnerable and resources-dependent communities around the Sundarbans. It also encouraged co-management and support communities in playing their role in safeguarding the Sundarbans resources.
15	Expanding the Protected Areas System to Incorporate Important Aquatic Ecosystems (EPASHAE)	2016-20	GEF	It focused on conserving dolphins and has identified areas for three new dolphin sanctuaries and hotspots.
16	Sundarbans Suroakkha Project or "Sundarbans Security project"	2020-2024	GoB	This project value is 18.57 million US$. This project mainly focus on the capacity building of the Forest department personnel involved in the Sundarbans management, infrastructure development and maintenances of the existing facilities inside the Sundarbans for the management purposes of the Forest department, use of information technology, improved the connectivity for the for monitoring and patrolling inside the Sundarbans, census of wildlife, stock assessment of the aquatic resources, characterization and assessment of the protected areas and ecosystem, and research activities (climate change, and soil and water salinity) linking the forest management, plantation activities in the Sundarbans Impact Zone (20 km from the Sundarbans). This project also involves the community people of 19 Upozila at the periphery of the Sundarbans to improve their livelihood.

diameter-class distribution of trees (IUCN, 2012). Presently, Forest Department is imposing strict monitoring on the felling of sapling from the Sundarbans. At the same time, the fishermen have to carry the required number of bamboo poles for fixing their fishing net to get the fishing permit. These combined efforts have able to reduce the over-exploitation of good quality saplings from the Sundarbans. Over-exploitation of *Ceriops decandra* as the main fuelwood species can be noticed. The density of this species (collar diameter ≥ 2.5 cm) was lower (2704 stem/ha) during 1998 (Revilla et al., 1998), while it was 4741 stem/ha (Latif, 2010). It is believed that ban on harvesting of *C. decandra* since 2007 may be responsible for this increasing trend. Similarly, overexploitation of *Nypa fruticans,* honey and wax are also reported to about 30% and 3.5 times higher than the officially recorded (Revilla et al., 1998; IUCN, 2012).

The annual harvested amount of aquatic resources (bony and cartilaginous fish, dry fish shrimp, crabs and mollusks) from the Sundarbans between 2001-02 and 2018-19 shows an increasing trend which

Table 2
Comparative estimation of *Heritiera fomes* and *Excoecaria agallocha* density and volume stock (m^3).

Inventories	*Heritiera fomes* N/ha	V10/ha (m3)	*Excoecaria agallocha* N/ha	V10/ha(m3)	*Other species* N/ha	V10/ha(m3)
GoB (2019)	331	58.42	228	26.44	102	12.89
Latif (2010)	205	48.2	62	7.8	30.4	11.2
Revilla et al. (1998)	106	17.8	20	2.1	20	7.5
Chaffey et al. (1985)	125	19.9	35	2.7	20	7.1
Forestal (1960)	211	33.6	61	5.0	24	5.9

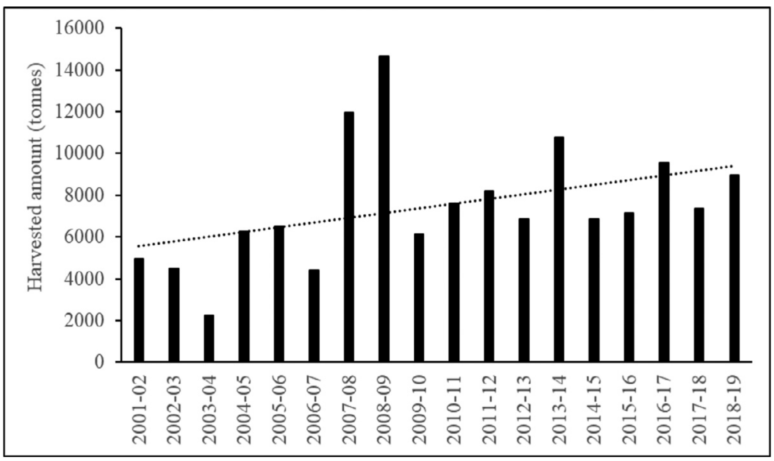

Fig. 2. Yearly (2001-2002 to 2018-19) harvested amount of aquatic resources (bony and cartilaginous fish, dry fish shrimp, crabs and mollusks) harvest from the Sundarbans, Source: (BFD 2020a).

indicates the over-exploitation of aquatic resources (Figure 2). About 40,000-70,000 boats are operated yearly in the Sundarbans for fishing (Shah et al., 2010). There is no scientific monitoring and data recording of the harvested amount of the aquatic resources. The over-exploitation is thought to be related to the use of destructive fishing gear, fishing and crab collection during the bas season, post larvae collection and poison fishing (IUCN, 2012). The recent management plan "Integrated Resources Management Plans for the Sundarbans (2010-2020)" considered the causes of the over-exploitation of aquatic resources and proposed guidelines for the conservation of these resources as well as suggested to reduce the number of Boat License Certificate (BLC) to 12,000 (BFD, 2010).

3.2. Change in vegetation pattern of the Sundarbans

The species composition, distribution and species diversity of the Sundarbans as a mangrove ecosystem is highly dependent on various environmental factors such as coastal physiography, elevation, climate, current and wave patterns, salinity, dissolved oxygen, soil and nutrients (Tomlinson, 1986; Hutchings and Seanger, 1987; Siddiqi, 2001). *Heritiera fomes* is the dominant, climax, and a less salt tolerant species (Siddiqi, 2001; Mahmood et al., 2014). Various researchers have reported that the vegetation pattern, density and canopy cover in the Sundarbans has changed over time (e.g. Chaffey et al., 1985; Revilla et al., 1998; Iftekhar and Saenger, 2008; Sarker et al., 2019b). So far, five complete forest inventories have been conducted for the Sundarbans (Forestal, 1960; Chaffey et al., 1985; Revilla et al., 1998; Latif, 2010; GoB, 2019). The first three inventories showed a considerable lower density (number and volume) of trees compared to the inventory of Latif (2010) and GoB (2019) (Table 2). It is assumed that ban on felling as well as conservation-oriented management initiatives would have had a significant influence, allowing to increase the tree density in the Sundarbans.

The canopy closure of the Sundarbans has decreased considerably over the 50 years (1960 to 2010). The first forest inventory during 1960 reported that 78% of the forest having 75% canopy closure or more Forestal (1960), while Revilla et al. (1998) reported 65% of the forest having a canopy closure of 70%. Recent the Landsat image data NDVI shows about 23% of the forest has 60% canopy closure or more during 2010 (Latif, 2010; IUCN, 2012). This indicates rapid decline in canopy closure over 12 years (from 1998 to 2010). This decreasing trend of canopy closure is thought to be correlated with the salinity of the Sundarbans (IUCN, 2012). Further investigations are required before a reliable conclusion can be made. Nevertheless, the area coverage of *H. fomes* vegetation type was 82,845 ha during 1985, which was 16% lower than the first inventory. This coverage was further decline to 74,264 ha during 2013. Interestingly, the area coverage of *C. decandra* vegetation type has increased steadily during the said 53 years (1960 to 2013) from 2,910 ha to 7,831 ha (Table 3). These changes suggest that the Sundarbans might become dominated by the high salt tolerant and less commercially important tree species, which may lead to a more homogenous species composition in near future (Sarker et al., 2019b).

3.3. Poor recruitment of major tree species

The seedling and sampling density of important timber species of the Sundarbans found to fluctuate considerably during 1998 to 2019 (Revilla et al., 1998; Latif, 2010; GoB, 2019) (Table 4). The seedling density increased to 53,806 seedlings/ha during 2009 compared to the study of Revilla et al. (1998) (Table 4), whilst sapling density decreased by 31% over the same period. The lower number of sapling might be a major concern for the sustainability of the Sundarbans (IUCN, 2012). Nevertheless, the seedling density has decrease to 20,942 seedling/ha during the latest inventory (GoB, 2019). Interestingly, the sapling density has increased about 11% compared to the record of 2010 (Table 4). A profusion of seedlings is usually found on the forest flood during the

Table 3
Change in area coverage from 1960 to 2013 of the dominated vegetation types of the Sundarbans.

Vegetation types	Area coverage (ha) Forestal (1960)	Chaffey et al. (1985)	Change (%)	Revilla et al. (1998)	Change (%)	RIMS (2013)	Change (%)
Heritiera fomes	98551	82,845	-16	74,992	-24	74,264	-25
Heritiera fomes -Excoecaria agallocha	92,139	123,247	34	105,967	15	102,264	11
Excoecaria agallocha	12,557	18,556	48	19,909	59	21,454	71
Excoecaria agallocha-Heritiera fomes	58,897	59,973	2	75,704	29	73,505	25
Excoecaria agallocha-Cerriops decandra	32,196	37,593	17	34,604	7	32,575	1
Ceriops decandra- Excoecaria agallocha	42,115	57,597	37	56,536	34	54,655	30
Sonneratia apatala	8,854	3,509	-60	8,287	-6	10,603	20
Ceriops decandra	2,910	8,706	199	8,262	184	7,831	169

Table 4
Comparison on seedlings and saplings density of major species of the Sundarbans: 1998-2019.

Sources	Species	Seedlings (Ht<1.5 m)	Saplings (DBH<2.5 cm)
GoB (2019)	*Heritiera fomes*	10,094	1413
	Excoecaria agallocha	6,923	1823
	Ceriops decandra	1,225	2522
	Aglaia cuculata	815	227
	Phoenix paladusa	524	-
	Cynometra ramiflora	-	64
	Others	1361	151
	Total	*20942*	*6200*
Latif (2010)	*Heritiera fomes*	34776	3044
	Excoecaria agallocha	13235	1266
	Avicennia officinalis	42	0
	Sonneratia apetala	5	5
	Others	5748	1231
	Total	*53806*	*5547*
Revilla et al. (1998)	*Heritiera fomes*	20522	3957
	Excoecaria agallocha	5971	2627
	Avicennia officinalis	23	6
	Sonneratia apetala	5	3
	Others	8203	1495
	Total	*34723*	*8088*

rainy season and a considerable lower number remain during the dry season (Siddiqi, 1988). In other way, the studies of Revilla et al. (1998), Latif (2010) and GoB (2019) were not concentrated solely on the natural regeneration. The sampling designs of these studies were focused to estimate the tree density and volume stock in the Sundarbans. The natural regeneration in the mangroves related with the elevation of the forest floor, tidal inundation, and distance from the canal or riverbank (Tomlinson, 1986; Siddiqi, 1988).The factors related to the natural regeneration were not considered during the sampling scheme of those studies. Therefore, the seedling and saplings density outcome of these studies need to consider carefully before concluding any statement.

3.4. Habitat degradation

Habitat degradation is related to the poor quality of the edaphic factors of a site (Hutchings and Seanger, 1987). Degraded sites of the Sundarbans demand special attention for management interventions, where the general prescriptions will not able to produce or support the desired goods and services that we expect. However, the special management interventions for the degraded sites usually ignored due to the difficulties in application and monitoring. In the Sundarbans, some areas of compartments 1, 21, 25, 27, 28, 36, 45, 46, 47, 48, 51A, 54 and 55 were identified as degraded sites/ habitats (IUCN, 2012). These areas were found to be poorly stocked and less productive and classed as non-commercial cover (NCC) areas, with some climbers and non-commercial species (Siddiqi, 2001). The degraded sites of the Sundarbans are found as raised lands, depressions and vacant canal and riverbanks. The relatively raised lands are found in the northern and north-eastern parts of the forest. They become inundated only in the monsoon during the spring tides for a short duration. No or very little natural mangrove regeneration is observed in the depressed waterlogged land which occur particularly in the middle and western portion of the Sundarbans. Considerable areas along canal or riverbanks are vacant with no mangrove regeneration. Habitat degradation can be tracked by assessing forest cover. The US Geological Survey mapped the Sundarbans in three classes: forest, waterbody and others (bare lands, sandy areas and marshy areas with dwarf vegetation using the satellite images from 1989 and 2014. This study revealed that proportion of the 'others' type had increased between 1989 and 2014. However, further investigation is needed to draw any reliable conclusions.

Mangrove tree species are slow growing. Their growth rate thought to be controlled by soil edaphic factors, light, temperature, wind, and tidal inundation (Tomlinson, 1986; Saenger, 2002). Growth rate is highly variable among different species, and according to the age of the individual and site conditions (Hutchings and Seanger, 1987). Therefore, the growth rate of tree species can be used as an important indicator to assess the habitat quality for a particular species. The Forest Department compared the rate of diameter growth of important tree species of the Sundarbans for three time periods: 1950-1970, 1971-1990 and 1991-2010. This showed that the growth rate of *H. fomes* decreased by about 28% between 1950 and 2010, while the growth rate of *E. agallocha* and *S. apetala* increased considerably of the same period (Table 5). This provides an indication of stressed habitat for the dominant tree species of the Sundarbans.

3.5. Habitat isolation

Genetic clusters have been reported among the tiger population of the Sundarbans (Aziz et al. 2018). It is important to facilitate the normal dispersal of tigers and other terrestrial species to prevent the ge-

Table 5
Diameter growth rate (cm/yr) comparison of major tree species of the Sundarbans, Source: BFD (2010).

Species	Period 1950-70	1971-90	1991-2010
Heritiera fomes	0.1879	0.1466	0.1355
Excoecaria agallocha	0.1498	0.2566	0.2138
Sonneratia apetala	0.2500		1.4498
Avicennia officinalis			0.6352
Xylocarpus mekongensis			0.402
Xylocarpus granatum			0.0005
Bruguiera sexangula			0.3248

netic cluster. The width (range from 1.2 to 4.4 km) of the major rivers (Arpangassia, Sibsa, Passur, Raimangal, Hariabhanga) of the Sundarbans and the human activities (increased movement of seagoing vessels), which prevent the crossing and dispersing of the tiger and their prey (Aziz et al., 2018). It is believed that these factors are responsible for habitat isolation for the tiger and its prey in the Sundarbans (Aziz, 2017) and causes a major barrier to east-west and west-east animal dispersal Aziz et al. (2018). This conclusion is supported by the study of Naha et al. (2016) and Barlow (2009), where the tigers rarely cross the rivers wider than 400 m and 600 m respectively for the Indian and Bangladesh Sundarbans. Considering this situation, it is necessary to limit the intensity of cargo/ seagoing vessel movement at night, minimal use of loud whistles and lights; and the activities that are responsible for widening the rivers across the Sundarbans.

3.6. Invasive species

The abundance of the invasive plant species in the Sundarbans and their aggressiveness towards the valuable species depend on the site suitability or change in site conditions. The invasive plant species can be used as an indicator of degradation. Invasive species can be categorized as highly invasive, moderately invasive and potentially invasive, based on their dominance, abundance, and aggressiveness. There are 23 invasive plant species have been reported in the Sundarbans that include 1 fern, 3 grasses, 4 shrubs, 2 epiphytes, 6 climbers, 2 herbs and 5 trees. Among the, *Derris trifoliate, Eichhornia crassipes*, and *Eupetorium odoratumare* are considered as highly invasive. However all these invasive species in the Sundarbans is under control (Biswas et al., 2007). All the listed species of Biswas et al. (2007) are mangrove associates except *Eichhornia crassipes*, and *Eupetorium odoratumare* (Giesen et al., 2006; Mahmood, 2015).

Prosopis juliflora is an alien species found on embankments close to the Sundarbans near Munshiganj, Shatkhiral of Sathkhira district. This species was planted intentionally or unintentionally in Bangladesh. This versatile and medium-sized tree species is fast growing and can adopt to habitats - from dry to saline condition. It is native to Mexico, South America, and the Caribbean (ILDIS, 2018; CABI, 2020). It was introduced in dry areas of India and Sri Lanka for the production of fuelwood. Nevertheless, this species invaded the mangroves of south India (Walter, 2011; Gunawardena, 2013). Presently, *P. juliflora* is not a stage of invasion in the Sundarbans of Bangladesh, but we need to pay attention for the risk of invasion.

3.7. Forest fires

A total of 24 fire incidence has been recorded in the Sundarbans (BFD, 2021). All the incidences (except Wildlife Scantuary area, Kotka, Chandpai Rage, during 2002) occurred at the northeastern part of the Sundarbans under the jurisdiction of The Sundarbans East Forest Division, which caused damage to 34.61 ha (0.005767% of the Sundarbans) of the forest areas (BFD, 2021). However, the number of fire incidences and the areas affected are likely to be higher than the official records. The causes of forest fires in the Sundarbans are both accidental and intentional. The accidental events are due to careless behavior by woodcutters, local fuelwood collectors, fishermen and honey collectors. Burning cigarette and torches used for honey collection are thrown on the dried forest floor. Intentional fires are caused during illegal clearing areas for cattle grazing, collecting fuelwood, fishing and diverting the attention of the forest officials from the poaching activities and wildlife trafficking.

3.8. Poaching and wildlife trafficking

Once upon a time, the government encouraged and declared reward for hunting tiger, and the local elites were engaged in the hunting of wildlife from the Sundarbans as a matter of pride (Hunter, 1875). Now all sort of hunting was prohibited with the enforcement of wildlife conservation initiatives. Wildlife (Preservation and Security) Act 2012, Bangladesh has appeared as major legal instrument to save guard wild and its management. Still, the poachers hunt tigers, deer, snakes, birds, monitor lizards, and other animals for sale locally and internationally. Tiger parts (skin, teeth, bones, meat, tongue, genital organs, claws, fur, and whiskers) are in high dement in the international market for medicinal and personal social status (Samia, 2016). Illegal haunting of deer is mainly carried out by villagers, 'professional' poachers and pirates, using guns, traps and bate. Poaching is mostly done along the peripheries of the Sundarbans with easy and efficient access (IUCN, 2012). The number of death/ killing/poaching of deer is 387 for last 16 years from 2004-2005 with an average of 24 numbers/year. While about 51 tigers are death/ killing/poaching during last 19 years (2001-2002 to 2019-2020) with an average of 3 number/year (Figure 3-4).

Wildlife trafficking is now becoming a serious concern in Bangladesh due to the huge demand in the black market, particularly for the tiger skins and bones in China. A number of seizures of wild animals and birds were reported in the newspapers between 2010 and 2015 and the Forest Department recovered 21,506 live wild animals and birds including tiger and bear cubs. Some of the seizures were destined for local sale, while many were for countries in Southeast Asia. International wildlife trafficker uses Shahjalal International Airport and land borders with India and Myanmar for this purpose (Daily Star, 2015). Frequent trafficking of geckos and monitor lizards from the Sundarbans are also reported locally.

Bangladesh government and the Forest Department has taken local, regional and international initiatives to control the death/killing/poaching and trafficking of wildlife from the Sundarbans. Among the initiatives, Management Plan of the three Wildlife Sanctuaries for the period of 1997-98 to 2002-03; Integrated Resources Management Plan (IRMP) for 1988 to 2010; expansion of wildlife Sanctuary areas; involvement of community people through Co-management Committee (CMC), Village Conservation Forum (VCFs) and Community Patrol Group (CPG); and implementation of Tiger Action Plan (BTAP) for 2018-27; National Tiger Recovery Program (NTRP) for 2017-2022; establishment of Wildlife Crime Control Unit; formation of Tiger Co-ordination committee at national and regional level; structuring 49 Village Tiger Response Team (VTRT); compensation Policy for wildlife victims 2012. As part of regional and international initiatives, Bangladesh has ratified the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and its partners in the International Consortium on Combating Wildlife Crime (ICCWC) during 1982 and 2009 respectively to ensure that international trade in specimens of wild animals and plants does not threaten the survival of the species (WCS, 2018). During, 2011, Bangladesh also involved with the South Asia Wildlife Enforcement Network (SAWEN) to combat wildlife crime in South Asia SAWEN (South Asia Wildlife Enforcement Network, 2021).

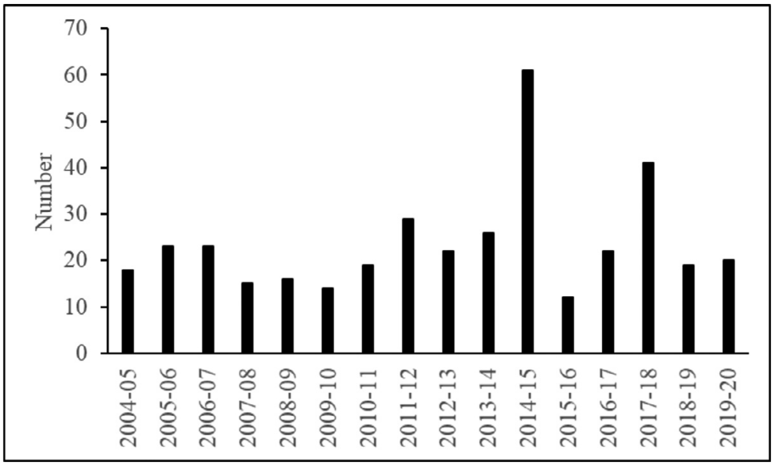

Fig. 3. Number of deer death/ killing/poaching reported for the Sundarbans 2004-2020 (Source BFD 2020b)

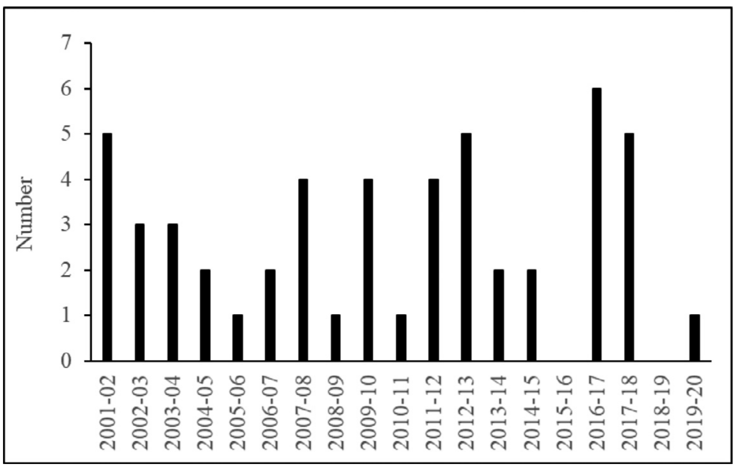

Fig. 4. Number of tiger death/ killing/poaching reported for the Sundarbans 2001-2020 (Source BFD 2020b).

3.9. Salinity in the Sundarbans

The water and soil salinity of the Sundarbans are controlled by the freshwater discharge from the Ganges-Brahmaputra-Meghna river systems and the amount and pattern of annual rainfall. The amount of freshwater flow in the Sundarbans is not constant throughout the year due to its nature of fluctuation. Among the numerous rivers and streams, the Baleswar and Passur rivers and their distributaries have direct connection to the Ganges and their distributaries, which are the only source of freshwater supply at the eastern part of the Sundarbans. In the western part, the Sibsa and other rivers receive freshwater only from the localized catchment and hence are more susceptible to tidal saltwater intrusion during the dry season. The spatial and temporal variation of water salinity regulates soil salinity in these areas (Chaffey et al., 1985). Water salinity of the Sundarbans was 10 dS/m during the dry season of 1968, which raised to 25 dS/m during the dry season of 2003 (Islam and Gnauck, 2009). This steady increase in salinity is attributed to the lower discharge of transboundary freshwater from the Ganges River, siltation of the distributaries of the Ganges and other rivers, and construction of embankments “polder” system (Raha et al., 2012; Dasgupta et al., 2014). It is claimed that the regional hydrological balance has been altered after the construction of the Farakka Barrage (India) during 1975 through reducing the flow of fresh water at the downstream and resulted in increased soil salinity at the coastal areas of Bangladesh (Islam and Gnauck, 2011). However, the increasing trend of water salinity in the Sundarbans was noticed at the beginning of the 20^{th} century (Trafford, 1911; Curtis, 1933).

The trends of freshwater discharge at the Ganges at the Hardinge bridge point of Ganges and Gorai railway bridge point of Gorai River during the wet and dry season were analyzed by Water Resources Planning Organization, Bangladesh (WARPO) for the three distinct periods: pre-Farakka (1934-1974), post-Farakka (1975-1996) and post treaty of water sharing (1997-2014). The discharges of freshwater at the Hardinge bridge and Gorai railway bridge points were higher during the pre-Farakka period, while it decreased significantly during the post-Farakka period and then increased again during the post-treaty period (Table 6). However, siltation in the Gorai riverbed began before the construction of the Farakka barrage (Trafford, 1911; Curtis, 1933) and this situation was further aggravated after the completion of Farakka barrage. The Institute of Water Modeling (IWM), Bangladesh, forecasted that the high saline area of the Sundarbans will expand and push back the less saline zone considerably (IWM, 2010). This changing salinity regime will impact on the composition, distribution, abundance, and productivity of the biotic components of the Sundarbans ecosystem (Chaffey et al., 1985).

3.10. Extreme weather events

The funnel shaped Bay of Bengal is the breeding ground for tropical cyclones. Seventy five (75) tropical cyclones and tidal surges have hit the coastal areas of Bangladesh since records began in 1584 and up to the end of 2020 (Mahmood et al., 2020). During 2000-2021, five tropical cyclones (Sidr 2007, Rashmi 2008, Aila 2009, Bulbul 2019 and Amphan 2020) affected the Sundarbans. The number of Distant Cautionary Sig-

Table 6
Average minimum discharges during the wet and dry seasons at the Hardinge Bridge of the Ganges and Gorai-Railway Bridge of the Gorai River (Sources: Water Resources Planning Organization, Bangladesh).

Location	*Seasons*	*Discharge (m^3/s) Periods* Pre-Farakka (1934-1974)	*Post-Farakka(975-1996)*	*Post treaty (1997-2014)*
Hardinge Bridge of the Ganges	Wet	4381	3433	5016
	Dry	1997	865	1004
Gorai-Railway Bridge of the Gorai river	Wet	704	451	548
	Dry	166	49	66

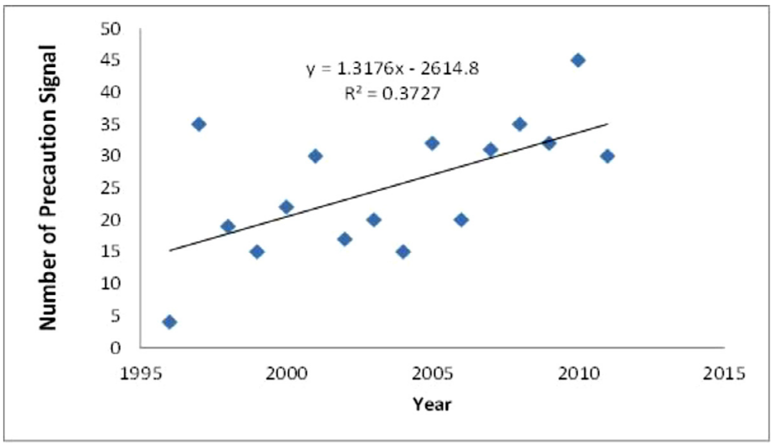

Fig. 5. Yearly number of Distant Cautionary Signal No. III (1995 to 2015) (Source: Khulna Weather Office)

nal No. III; issued increased steadily between 1995 and 2015 (Figure 5). The mangroves are highly resilient against such cyclones, but still suffer consequential effects on vegetation composition, sediment accretion, erosion pattern and hydrological system. It is estimated that almost 25 years are needed for vegetation structure to recover from each storm (Islam, 2008).The Sundarbans has had little time to recover with the frequency of cyclones. This dynamic nature of the mangrove ecosystem, as affected by cyclones and tidal surges, needs to be considered for the future management and conservation of the area. Planting mangrove species in large gaps of the forest can be an important management intervention (Harun-or-Rashid et al., 2009).

3.11. Embankment construction

Construction of embankments to the north of the Sundarbans was started about 200 years ago to protect human settlements and agriculture from tidal inundation and floods. The embankment system influences the tidal prism and tidal amplification and the extensive hydrological network at the regional scale (Pethick and Orford, 2013; Wilson et al., 2017). It is believed that embankments have altered the hydrodynamics network, sediment accretion and erosion pattern in the Sundarbans, which may alter the rate of sea level rise (Hale et al., 2019). In many cases, the creek beds (surrounding the Sundarbans) have risen higher than the low-lying areas behind the embankments. The frequent disruptions/breaches of the embankments due to tidal pressure, cyclonic events and tidal surges which result in prolonged inundation with saline water (Bhattacharya, 1998; Danda, 2007; Hale et al., 2019). Less fertile coarse soil particles are deposited at the periphery or adjacent to embankments, while more fertile finer sediment particles are carried to the interior of the Sundarbans (Hale et al., 2019).

3.12. Impact of tourism

The Sundarbans is gaining popularity as an important tourist destination for both domestic and international tourists. The Sundarbans has seven important tourist destinations: Koromjol, Koromjol, Kalagachia, Kotka, Kochikhali, Nilkomol (Hironpoint), Dublar Char. Every year, the famous three days long “Rash Mela” Hindu festival on Dubla Char of the Sundarbans, attended by thousands of visitors. Tourism is now an important source of revenue for the Sundarbans Forest Divisions. The number of tourists is highly variable and depends on several factors such as local facilities and the national and international economic and political situation (Uddin, 2011; Kumar, 2015). However, the tourist influx in the Sundarbans has increased considerably, from about 50,000 in 2001-2002 to about 180,000 in 2018-2019 (BFD, 2020c). Visits are mainly concentrated for the period from November to March (Figure 6).

There is no official assessment/ record of tourist carrying capacity for the above destinations. However, the huge number of tourists cause impacts: littering the forest floor and waterways (plastic bottles and other garbage); disturbing the wildlife by the use of loudspeakers, shouting, scaring and unusual body language; and often starting in the forest floor for fun (Hussain, 2014). The Forest Department issues tourist permits without any restriction. However, it has realized the negative influences of uncontrolled tourism in the Sundarbans and adopted a tourism guideline for the Sundarbans in 2014. Moreover, Rash Mela” (Hindu religion festival) in the Dubla Island of the Sundarbans has been restricted only for the Hindu pilgrims, which has able to reduce the tourist flux in a particular time. However, not all of the recommended guidelines are being followed properly due to shortage of staff and poor managerial capacity of the Forest Department. Other ways, solid waste (cans, plastic bags, water bottles, etc.) discarded by tourists and from boats/ships in the Sundarbans is an increasing concern, and is connected to the increasing number of tourists visiting the area. The waste may causing serious environmental implication of the Sundarbans mangrove ecosystem.

3.13. Navigation route and increased movement of sea-going vessels

Mongla sea port was established in 1950 to enable national trade and import/export of goods. It is situated 131 km upstream from the Fairway Buoy (at the approach to the Passur River) in the Bay of Bengal. This river is the navigation route from the sea to the port and runs through the Sundarbans forest. It divides the Sundarbans into two main parts as

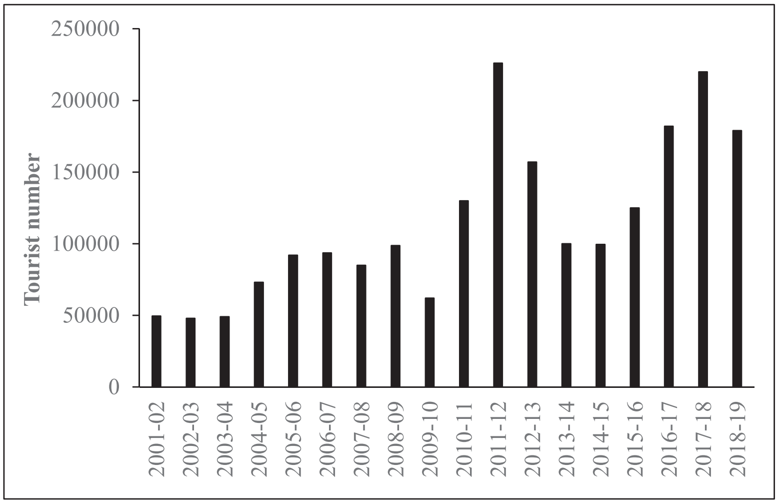

Fig. 6. Annual tourist visitors to the Sundarbans: 2001-2002 to 2018-2019 (Sources: BFD 2020c).

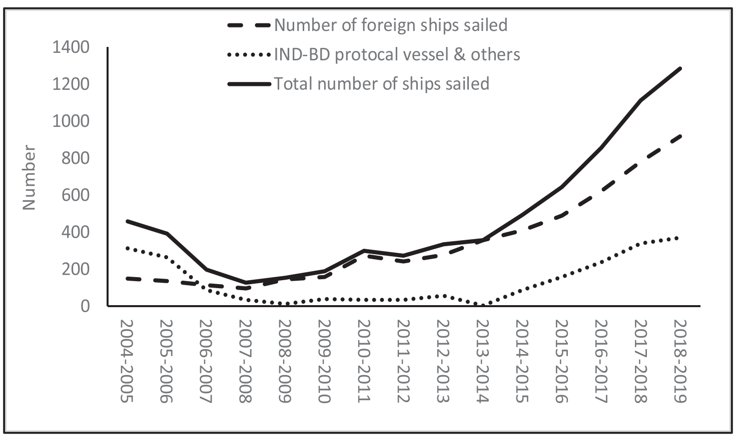

Fig. 7. Number of ship sailed from the Mongla port from 2004-2005 to 2018-2019 (Source: Mongla Port Authority 2019).

well as connectes the other large rivers in the Sundarbans, e.g. Baleswar, Bhola, Marjata, Arpangasia, Shibsa, and Jamuna.

This Passur river is rich in aquatic diversity and is famous for hilsa fish (Tenualosa ilisha) and other species of fish and shrimp, Gangetic dolphin (*Platanista* gangetica), Irrawaddy dolphin (*Orcaella brevirostris*), and crocodiles. However, the diversity and abundance of the aquatic resources of this river likely to be affected by the increased movement of sea-going vessels. The annual number of ships sailing from Mongla port has increased from 454 to 1283 during the last 15 years (2004-2005 to 2018-2019) (Figure 7). The number is expected to increase further in the future with the modernization of the port, operation of the new Rampal coal-fired power plant and development of industrial estates in the Mongla Export Processing Zine (EPZ) and Khulna.

The increased movement of vessels can affect wildlife and aquatic animal in different ways. Sound pollution may affect the feeding, grazing, breeding, and movement of important wildlife like tiger and deer. Searchlight operated at night by vessels may impact on nocturnal flying insects, e.g. attracting them, desynchronise ecological interactions, prolonging foraging, causing desensitisation and spatial disorientation, disrupting recognition amongst species, etc. Ballast and bilge water discharge from foreign ships can potentially introduce alien invasive species. Increased river bank erosion can be expected with increased movement of sea-going vessels. The Passur River is subject to a high rate of siltation and frequent dredging may be required to permit uninterrupted passage for ships. Such dredging may modify the route for fish migration and disrupts or displaces the benthic community.

3.14. *Pollution*

The Sundarbans ecosystem is now under pollution threat due to the pressure of anthropogenic activities inside and around the Sundarbans, e.g. industrialization, pollution (e.g. heavy metals), urbanization, intensive farming using agrochemicals, tourism, navigation, and capsizing of water vessels carrying goods (oil, coal, cement, fertilizer, etc.) (Rahman et al., 2009). All of these activities may affect the soil, water and air quality of the Sundarbans, which can ultimately affect the health and quality of the aquatic and terrestrial ecosystems of this forest.

3.14.1. *Industrial pollution*

There has been a steady increase in the number of industrial activities in the southweastern Bangladesh, stimulated by the construction of Padma Bridge, Rampal coal-fired power plant, the modernization Mongla port and different government investment plans. Industries are mainly located in Kustia, Khulna, Jessore, Bagerhat, Mongla Export Processing Zone, and Mongla port area. They include medium to heavy industries, small and cottage industries, agriculture-based industries and natural resource-based industries (BEZA, 2015). As of April 2018, 190 industrial projects had been approved around Mongla port in the Environmentally Critical Area (ECA) (65 km away from the World Heritage site). UNESCO (2019) reports that 154 medium to heavy industries, small and cottage industries, agriculture-based industries, and natural resource-based industries are operating in the ECA bordering the Sundarbans. The distance from the outer boundary of the Sundarbans forest to the industries is between 5 and 10 km. All these industries were established in the 1990s and 2000s. Among them, 130 are categorized as 'orange' (mostly non-polluting) and 24 as 'red' (having a significant pollution threat to the surrounding environment) (MEFCC, 2019).

3.14.2. Agrochemical and heavy metal pollution

Agrochemicals are becoming the important sources of pollutants to the Sundarbans ecosystem which may cause detrimental influences on the biogeochemistry of this forest (Rahman et al. 2009). A range of fertilizers, insecticides, fungicides, herbicides, rodenticides and other chemicals are used to improve crop production and aquaculture at the upstream part of the Sundarbans and are identified in mangrove sediments (Chowdhury and Maiti, 2016; Kumar et al., 2016). These pollutants get incorporated into the food chain and accumulate in higher tropic levels, disrupting ecosystem biochemical cycles (Rahman et al., 2009). Overall, agrochemical pollution leads to loss of biodiversity, increased mortality of fish and shellfish, human health risk through contamination of the food chain (Islam et al. 2006; Shamsad et al. 2009). This can cause algal blooms, changes in the structure of aquatic communities, decreased biological diversity, fish death, and oxygen depletion events (Twilley, 1998; Ramesh, 2000).

Cadmium, chromium, copper, nickel, lead, mercury and arsenic are the most common heavy metals identified in the mangrove ecosystem. They occur naturally and also released to the environment through the anthropogenic processes. Mangroves act as pollutant sink. Heavy metals can combine with soil organic matter to form a complex and become unavailable to the mangrove biota (Adrino, 1986; Lacerda et al., 1991; Mahmood et al., 2001). Heavy metal affects both plants and aquatic resources of mangroves. When present at toxic concentrations, Heavy metal disrupts a variety of physiological processes and functions and cellular structure of mangrove plant species at toxic concentration (Lacerda et al., 1991; Mahmood et al., 2001; Huang et al., 2020). In other ways, the sediment the Passur River contained comparatively higher concentration of heavy metal (Co, Cr, Cu, Fe, Ni, Pb, Fe, and Zn) than the Indian part of the Sundarbans (Ranjan et al., 2018).

3.14.3. Oil pollution

Oil pollution is becoming a serious threat to the biodiversity of the Sundarbans. The source of oil pollution is the sea going large shipping vessels passing through the Sundarbans for the Mongla sea port (ESCAP, 1988; Scott, 1989). Mechanized boats, fishing trawlers, goods carrying vessels and passenger/tourist's vessels regularly discharge bilge and ballast water, and are also responsible for oil spill oil in the river (Iftekher, 2004). Moreover, a large portion of oil accidentally leaks from the oil carrying vessels. Several notable oil spills have occurred in the waterways of the Sundarbans. The most prominent oil spill events were reported during 1990 near the Jongra forest camp, 1994 at the Dhangmari Forest Station, 2014 in the Shela River of the Sundarbans (Karim, 1994; Bdnews24, 2014).

Oil spills threaten mangrove trees, seedlings, plankton, soil micro, and macro organisms, birds, fish and aquatic animals, pollute water and affect soil quality in the mangrove ecosystem (Duke, 2016). The light fraction of the oil is the most toxic, which fortunately evaporates or degrades rapidly. The heavier fraction causes most of the chronic impacts on mangroves: damage to aerial roots, reduction in litter fall, and reduced survival and deformation of seedling (Iftekhar, 2004). The oil amalgamated on the leaf surface may create blockage on stomata and affect the essential physiological process of mangrove plant species such as- photosynthesis, respiration and also the water metabolism of mangrove plants (Peng, 2000). Fish can also absorb oil directly when feeding, tainting their tissues. Aromatic hydrocarbons in crude oil are persistent and carcinogenic, having a tendency to be biologically accumulated in fish tissue and further accumulated at higher tropic levels of the food chain (Rahman et al., 2009; Shigenaka, 2002).

4. Conclusion

Human settlement around the Sundarbans increased greatly and it was converted for human habitation and agricultural land to full the demand of the increasing population of that areas. This conversion significantly reduced the area coverage of the Sundarbans from 19,508 km^2 to 10,217 km^2 at present time during 1770 and 2019 respectively. The local people highly dependent on the resources of this forest for their livelihood and daily consumptions. At the same time, this forest was extracted officially to earn revenue starting from the British colonial government to the end of the last century. These situations exert immense pressure on the resource bases of the Sundarbans and resulted in the depletion of the forest resources. Different management interventions were taken to maximize the gain without potential negative impact on the forest ecosystem. Nevertheless, this aspiration was not achieved before the implementation of the integrated resources management plan for the Sundarbans. A synthesis demonstrated that the Sundarbans has gone through a series on management interventions for the production of timber, raw material supply to the wood based industries, and integrated management and co-management initiatives. These management initiatives can be divided into different paradigm shift in the management of the Sundarbans like conversion for agriculture, timber production for revenue collection, inventory based management and integrated management and co-management. In another way, from the recent past to the present, different natural and anthropogenic events were identified as major or minor issues and challenges for the management of the Sundarbans ecosystem as a whole. Therefore, the identified issues and challenges need to address during the preparation of a management plan or taking any management intervention for the Sundarbans.

Conflict of interest

No conflict of interest.

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