Exploring the Rich Diverse: Freshwater Fish Diversity and Bionomics in the Sundarbans

Abstract

The Sundarban is a mangrove area in the deltaformed by the confluence of the gangas brahmaputra and meghna river in the bay of Bengal. the hooghly river in india state of westbengal to the baleswar river in bangladesh.it comprises closed and open mangrove forests agriculturally used land, mudflats and barren lands. it is intersected by multiple tidal streams and channels. Four protected area in the Sundarbans are enlisted as UNESCO WORLD HERITAGE SITES, Sundarbans national park,sundarban west, east and south wildlife santuaries.the bengali name sundarban is beautiful forest.it may have benn derived from the word sundari,the local name of the mangrove sp *Heritiera fomes*. there many biodiversity like 453 faunal wildlife, including 290 birds,120 fish,42 mammal,35 reptiles and 8 amphibians.the goal of this review paper is discussing about freshwater fish diversity and its bionomics in sundarban delta.also about the a brief description of study area (Sundarban) encompassing definition of a mangrove ecosystem, importance of mangrove ecosystem, area and distribution of Sundarban; Indian Sundarban – area, location, fisheries related activities; importance of studying fish diversity.and try to generate a data base on some of the life history parameters and their conservation status and atlast study threats associated with fish diversity measures for sustainable fishery.

Keywords: Fish, Biodiversity, Piscine bionomics, Conservation, Sundarban, fish diversity, ecological phenomena, mangrove forest

1. Introduction

The Sundarbans mangrove forest, which spans an area of 140,000 hectares, is prominently situated on the delta formed by the Ganges, Brahmaputra, and Meghna rivers in the Bay of Bengal. This location is in close proximity to the northern boundary of India's Sundarbans World Heritage site, which was officially designated in 1987. The site exhibits a multifaceted system of tidal canals, mudflats, and small islands characterised by salt-tolerant mangrove forests, so serving as a noteworthy illustration of continuous ecological phenomena. This region is renowned for its diverse array of wildlife, encompassing 260 avian species, the Bengal tiger, and other endangered species like the estuary crocodile and the Indian python.

Mangroves are ecologically diversified and highly productive ecosystems (Hogarth, 2007) that play crucial roles in the functioning of the environment (Nagelkerken et al., 2008). Situated at the boundary between land and sea, these organisms play a crucial role in safeguarding coastal regions from various natural perils, including cyclones and tsunamis (Danielsen et al., 2005). They effectively retain sediment from land and facilitate the recycling of nutrients, thereby promoting the clarity of offshore waters. This, in turn, enhances the photosynthetic capabilities of phytoplankton, as well as the growth and resilience of coral reefs, seagrass beds, and reef fish communities (Mumby and Hastings, 2008). Additionally, they serve as significant habitats, nurseries, and refuges, providing sustenance for numerous organisms, including humans (Nagelkerken et al., 2008). These ecological systems also play a crucial role as carbon sinks, either by temporarily storing carbon in organic peat soils or as dissolved organic carbon in ocean sediments at deeper depths. This allows for the long-term offsetting of greenhouse gas emissions that are influenced by climate change (Kristensen et al., 2008). Mangroves possess significant economic value due to their provision of collective ecological services (Costanza et al., 2014; Salem and Mercer, 2012). Nevertheless, due to both human activities and climate conditions, mangroves worldwide are facing significant endangerment. If the current global yearly loss rates of 1%–2% persist, it is quite likely that no mangrove forests will remain by the end of the 21th century (Ellison et al., 2002).

Freshwater fish diversity in the Sundarbans mangrove forest of Bangladesh is a topic of significant ecological importance. Studies have highlighted the rich biodiversity present in this unique ecosystem, showcasing a diverse array of fish species that inhabit the rivers and water bodies within the Sundarbans. Research indicates that the Sundarbans host a substantial number of fish species, with a total of 322 species belonging to 217 genera, 96 families, and 22 orders recorded in the region (Habib et al., 2020). The fish bichemistry and biotechnology approaches to fish nutrition and the health status of fish (Lal et al., 2024ab). This diverse range of fish species includes vulnerable and endangered species, emphasizing the need for conservation efforts to protect the delicate balance of this ecosystem. The abundance and diversity of fish in the Sundarbans surpass adjacent freshwater and marine ecosystems in Bangladesh, making it a critical area for aquatic biodiversity (Uddin et al., 2021). Additionally, the Sundarbans serve as a natural world heritage site, underscoring the importance of preserving the freshwater fish diversity within this mangrove forest for future generations.

The vast expense of Sundarban wetlands harbor several species of fishes that greatly contribute to the fisheries and the economy of the people in and around Sundarban. The diversity of fish fauna of this ecosystem is usually associated with tolerance to a wide range of salinity fluctuation and migration. Many low-salinity tolerant freshwater elements enter upper estuarine zone particularly ebb tide period, while marine elements are usually restricted to lower zone. Some species move freely in the entire salinity gradient during major part of the year, but very few species can be considered as 'residents. The well-established fact is that most species enter the brackish waters of mangroves and spend varying period of their life-span either for shelter and feeding or for spawning purpose (Mishra and Gopi, (2017).

2. Materials and methods

2.1 Study Area

The Sundarbans are located within the delta formed by the confluence of the Ganges, Brahmaputra, and Meghna rivers in the Bay of Bengal. The landform is comprised of a complex system of mudflats and islands formed by the accumulation of silt carried by rivers from their Himalayan origins. These sediment loads are divided by anastomotic channels and tidal waterways. The tidal amplitude seen in estuaries ranges from 3.5 to 4 metres, exhibiting seasonal fluctuations ranging from 1 to 6 metres. The Sundarbans, situated between the latitudes of 21°32′ to 22°40′N and the longitude of 88°05′ to 89°51′E, has an estimated expanse of 10,000 km2. Notably, 62% of this region is located within Bangladesh, while the remaining 38% is situated in India. This vast expanse represents the most extensive contiguous mangrove forest globally. The geographical area exhibits a tropical climate, featuring a dry season spanning from November to April, followed by a wet monsoonal period throughout the remaining months of the year. The yearly precipitation ranges from 1500 to 2000 mm. The region has frequent occurrences of tropical cyclones and lesser tidal events throughout the monsoon season, resulting in significant flooding and wind-related destruction. The average minimum and maximum temperatures during different seasons range from 12°C to 24°C and 25°C to 35°C, respectively.

2.2 Fish Sampling Methods

Fish specimens were obtained using various sorts of nets, including hand nets, cast nets,, gill nets and scoop nets from a diverse array of water bodies such as canals, "beels" (Bengali: huge ponds), abandoned waterways, ponds, and roadside ditches. The sampling took place in the

early morning hours, specifically between 06:00 and 08:00, and involved the local fishermen. Following collection, the fish were categorised based on their family. The newly collected specimens were captured by photography, and a small number of species that were representative from every family were stored in a 10% formalin solution for identification purposes. The other specimens were reintroduced into their natural habitat. The specimens that were gathered were subsequently classified according to established references on fish taxonomy (Talwar and Jhingran, 1991). According to Eschmeyer et al. (2016), the taxonomy and nomenclature were adhered to. According to Ghosh et al. (2003), fishes were classified into two categories: a) classified aquarium fish (CA), which can be kept in an aquarium throughout their entire life cycle (with a maximum length of 20cm for adult fish), and b) non-classified aquarium fish (NCA), which can only be kept in an aquarium during their juvenile stages (with a maximum length of 20cm for adult fish). According to the IUCN Red List of Threatened Species TM (2016), the conservation status of the fish species is determined. An investigation was conducted to document the decline in the diversity of native ornamental fish species in freshwater, as perceived by fishers. A survey utilising a cross-sectional questionnaire and a focused group discussion (FGD) were conducted in the Sundarban Biosphere Reserve, namely in the two major deltaic blocks, namely Sagar and Basanti. Conway *et al*. (1987) constructed threat ranks for fishes on a hypothetical scale ranging from 1 to 10.

3. Results

The Sundarbans mangrove forest, situated in Bangladesh, harbours a wide array of fish species, as several studies have approximated the presence of approximately 172 fish species, 20 prawn species, and 44 crab species, which encompass two commercially valuable species. Chandra and Sagar (2003) reported the fish population in the Sundarbans region holds significant importance within the ecological system, as it serves as the primary habitat for almost 90% of the aquatic species found along the eastern coast of India. The loss of the fish population in the Sundarbans can be attributed to a multitude of factors. The removal of wetlands in the Sundarban estuary has caused a reduction in the diversity and intricacy of the estuarine environment, leading to significant decreases in the populations of certain frequently encountered fish species. Moreover, the infiltration of saltwater and abrupt rise in salinity resulting from climate change and human activities has presented a substantial peril to fish and other members of the aquatic

fauna in the Sundarbans region (Joshi and Ghose, 2014). According to a comprehensive 36-month investigation done by a team of scientists, the primary peril faced by fish and other aquatic organisms in the Sundarbans region is the encroachment of saltwater and the abrupt escalation of salinity levels. The survey additionally identified four observable factors contributing to the premature mortality of fish. These factors encompass alterations in tidal patterns and water movement, resulting in modifications to the tidal bed, avian consumption of fish during sudden declines in water levels, larger fish consuming smaller fish as water levels decrease, and human capture of fish that have migrated to breed as a consequence of tidal pattern changes (Haque *et al*., 2017). Unwise actions, such as human intrusion and heightened sediment deposition, have caused a swift expansion of the adjacent land area and a reduction in the internal aquatic environment, leading to a significant decline in aquatic biodiversity. The fish population in the Sundarbans has been adversely impacted by indiscriminate fishing techniques, which involve the simultaneous capture of indigenous fish species, juvenile prawn, crabs, and other molluscs (Donohue and Molinos, 2009). In order to mitigate the negative impact on the fish population in the Sundarbans, it is imperative to implement a shift in human behaviour. According to Habib *et al*. (2020), the state action plan for climate change is the most suitable platform for integrating recommended human activities into government policy. The implementation of suitable strategies aimed at preserving the fish population in the Sundarbans has the potential to uphold the ecological diversity and sustainability of the region.

Table: 1. Number of fish species reported by different authors.

Sl no.	Number of species reported	Reference
1	305	Pal et al. 2014
2	71	Hamilton, 1822
3	139	Mandal and Nandi, 1989
4	250	Chaudhuri and Chaudhury, 1994
5	83	Agrwal and Ghosh, 1995
6	176	Das, 1999
7	165	Sanyal, 1999
8	202	Khan, 2013
9	139	Mitra et al, 2005

Table: 2. A check list of freshwater fish diversity at Sundarbans mangrove delta.

Sl. No.	Name of the species	English common name	Local name	Feeding habit	Fishery importance	Exotic or Indigenous	Trophic Index	Maximum length reported (cm)	Length at maturity (cm)	Age at maturity (years)	Fecundity	IUCN Red list status
Order: Perciformes, Family: Osphronemidae												
1	***Trichogaster fasciata* (Bloch & Schneider.)**	Banded gourami	khalisa	Herbivore	minor commercial	exotic	3.1	12.5	5.7	1	500-600	Least concern
2	***Trichogaster lalius* (hamilton1822)**	Dwarf gourami	Lalkha-lisa	Herbivore	Aquarium highly commercial	exotic	3.1	9.5	3.9-4.3		150-2000	Least concern
3	***Trichogaster chuna* (hamilton 1822)**	Honey gourami	boicha	Planktivors	Aquarium commercial	indigenous	3	7	4			Least concern
Order: perciformes, family: channidae												
4	***Channa marulis* (hamilton,1822)**	Great snakehead	gajal	Carnivores	Aquaculture and game fish commercial	native	4.5	18.3	12	2-3	40000	Least concern
5	***Channa gachua* (hamilton 1822)**	Dwarf snakehead	gachua	Carnivores	Aquarium commercial	native	3.8	28.8	10.2	2-3	350-2200	Least concern
6	***Channa punctata* (bloch 1793)**	Spotted snakehead	lata	Carnivores	Aquaculture and as bait	indigenous	3.8	31	12	1	2000-290000	Least concern
7	***Channa striata* (bloch 1793)**	Strip ed snakehead		Carnivores	Aquaculture highly commercial	native	3.4	100	18	2	2300-26000	Least concern
Order: perciformes, family: badidae												

8	***Badis badis* (hamilton1822)**	Mud perch	Bot koi	Carnivores	Aquarium commercial	indigenous	3.3	7.1	2.7		100	Least concern
Order: perciformes, family: nandidae												
9	***Nandus nandus* (hamilton,1822)**	Gangetic leaf fish	bheda	Carnivores	Aquarium, commercial	indigenous	3.9	20	9-10	1	300	Least concern
Order perciformes; family: datnioididae												
10	***Datnioides polota* (hamilton,1822)**	Fresh water triple tails	Four barbed tiger fish	Carnivores	commercial	exotic	3.7	30	6.8-8.2			Least concern
Order: synbrsnchiformes, family: mastacembelidae												
11	***Macrognathus aral* (bloch & schneider 1801)**	One stripe spinyeel	aral	Carnivores	commercial	indigenous	3.1	63.5	10-18	1	250-5000	Least concern
12	***Macrognathus pancalus* (hamilton 1822)**	Barred spinyeel	guchi	Planktivores	Minor commercial	native	3.5	18	11-12	1	227-8310	Least concern
13	***Mastacembelus armatus* (lacepede,1800)**	Zig- zag eel	bami	Planktivores	Aquarium commercial	indigenous	2.8	90	25-48	1	2200-19500	Least concern
Order: Synbranchiformes, Family: Synbranchidae												
14	***Monopterus cuchia* (hamilton, 1822)**	Mud eel	cuchia	Carnivores	commercial	native	3.8	70	25	.5	225-5560	Least concern
15	***Ophisternon bengalense* (mcclelland, 1844)**	Bengal eel	bamosh	Planktivores	No interest	native	3.3	100	20		470	Least concern
Order: Cyprinidontiformes, Family: Aplocheilidae												
16	***Aplocheilus panchax* (hamilton, 1822)**	Blue panchax	bechi	Carnivores	aquarium	native	3.2	9	5	0.3-0.4	627-631	Least concern

Order: Cypriniformes, Family: Cyprinidae												
17	***Amblypharyngodon mola* (hamilton, 1822)**	Mola carplet	mourala	Herbivores	commercial	indigenous	3.2	20	6	.4	1000-13000	Least concern
18	***Puntius ticto* (hamilton, 1822)**	Ticto barb	Titu puti	Planktivore	commercial	native	2.2	12.5	5	0.6	6000-7000	Least concern
19	***Puntius terio* (hamilton, 1822)**	One spot barb	puti	plank	aquarium	native	2.6	10	4.2	.4	390	Least concern
20	***Puntius chola* (hamilton, 1822)**	Swamp barb	Chola puti	Planktivore	aquarium	indigenous	2.5	15	6.5	.2-.3	1500-6000	Least concern
21	***Pethia gelius* (hamilton, 1822)**	Golden dwarf barb	Gilli punti	Carnivores	aquarium	native	3.3	5.1	.5		70-100	Least concern
22	***Pethia conchonius* (hamilton, 1822)**	Rosy barb	Kanchan puti		Highly aquarium	native	2.9	14	6	.3-.4	523-1366	Least concern
23	***Pethia phutunio* (hamilton, 1822)**	Spotted sail barb	Phutani puti	Planktivores	aquarium	native	2.9	3.9	.5-.6	.3		Least concern
24	***Pethia ticto* (hamilton, 1822)**	ticto barb	Tet puti	Planktivores	aquarium	indigenos	2.2	12.5	4.3-4.8	.4	2230-8450	Least concern
25	***Danio rerio* (hamilton, 1822)**	Zebr a fish	anju	Carnivores	aquarium	native	3.1	3.8	2.5	.3-.4	400-500	Least concern
26	***Esomus danricus* (hamilton, 1822)**	Indian flying barb	danrika	Planktivores	aquarium	native	2.4	13	3.98	.6	292-3412	Least concern
27	***Laubuca laubuca* (hamilton, 1822)**	Indian glass barb	dorikana	Carnivores	Aquarium and bait	indigenous	3.2	10.5	4.7	.5	3980-7320	Least concern
28	***Rasbora daniconius* (Hamilton, 1822)**	Slen Derras bora	da nikono	Plank Ton feeder	aquarium	native	3.1	15	6.8-8.2	.5	200-350	Least concern
29	***Salmostoma bacaila***	Large razor	chela	Carnivores	No interest	indigenous	3.2	18	7.6-7.7	.8	9000-29000	Least concern

	(hamilton, 1822)	belly minnow										
30	***Systomus sarana* (hamilton, 1822)**	Olive barb	Sar puti	Carnivores	Game fish	native	2.9	42	3.6-4	.4-.6	16000-29000	Least concern
Order: siluriformes, family: bagridae												
31	***Mystus gulio* (hamilton, 1822)**	Long whisker cat fish	Nuna tengra	Detrivores	commercial	native	4	46	8.3-8.5	1	11000-23000	Least concern
32	***Mystus tengara* (hamilton, 1822)**	Tengara cat fish	Choto tengra	Carnivores	Least commercial	indigenous	3.2	18	8.2-9.5	1	700-5000	Least concern
33	***Mystus cavasius* (hamilton, 1822)**	Gangetic mystus	gulia	Carnivores	commercial	indigenous	3.4	40	8.2-9.5	1	3000-63000	Least concern
34	***Sperata aor* (hamiloton, 1822)**	Long whisker cat fish	ayre	Carnivores	Game fish	native	3.6	180	57.3	4	45000-122000	Least concern
35	***Sperata seenghala* (sykes, 1839)**	Giant river cat fish	aor	Carnivore	Game fish	native	3.8	150	40-90	.4-.6	20000-46000	Least concern
Order: osteoglossiformes, family: notopteridae												
36	***Notopterus notopterus* (pallas, 1769)**	Bronze feather back	chital	Carnivores	aquarum	indigenous	3.5	60	15	1	1200-3000	Least concern
Order: siluriformes, family: schilbeidae												
37	***Ailia coila* (hamilton, 1822)**	Gangetic ailia	kajuli	Carnivores	commercial	native	3.6	30	15-	.8-1		Near threatened
38	***Silonia silondia* (hamilton, 1822)**	Silond cat fish	silon	Carnivores	Game fish	native	3.5	183	36	1	5000	Least concern
Order: cypriniformes, family: cobitidae												

39	***Lepidocephalichthys guntea* (hamilton, 1822)**	Guntea loach	botia	Carnivores	aquarium	indigenous	2.7	15	8-9	.6		Least concern
Order: siluriformes, family: horabagridae												
40	***Pachypterus atherinoies* (bloch, 1794)**	Indian potasi	batasi	Carnivores	Minor commercial	indigenous	3.3	15	7.2	4		Least concern
Order: siluriformes, family: siluridae												
41	***Ompok pabda* (hamilton, 1822)**	Pabdah cat fish	pabda	Carnivores	commercial	native	3.8	30	12.9	1	2500-41000	Near threatend
42	***Ompok bimaculatus* (bloch, 1794)**	Butter cat fish	pava	Carnivores	commercial	native	3.9	45	22.3	1	1700-68000	Near threatend
43	***Wallago attu* (bloch& schneider)**	Fresh water shark	boal	Carnivores	Game fish	native	3.7	240	40-52	2	66000-453000	Near threatend
Orde: siluriformes, family: pangasidae												
44	***Pangasius pangasius* (hamilton, 1822)**	Pangas cat fish	pangus	Carnivores	commercial	native	3.4	300	63	3-3.5	80000	Least concern
Order: siluriformes, family: sisoridae												
45	***Bagarius bagarius* (hamilton, 1822)**	goonch	Bag mach	Carnivores	Game fish	indigenous	3.7	200	20	1	57000	Near threatend
Order: siluriformes, famly: clariidae												
46	***Clarius Magur* (Hamilton,1822)**	Walking cat fish	magur	Omnivores	commercial	indigenous	3.4	47	23	1	1477-	End angered
Order: siluriformes, family: heteropneustidae												
47	***Heteropneustes***	Stinging	singhi	Omnivores	commercial	native	3.6	31	12	1	4000-	Lea t

	***fossilis* (bloch, 1794)**	cat fish									46000	concern
Order: beloniformes, family: adrianichthyidae												
48	***Oryzias dancena* (hamilton, 1822)**	Indian medeka	Munda kanni	Planktivores	Minor commercial	native	3.3	3.1	.36-.4	.4		Least concern
Order: Anabantiformes, family: Anabantidae												
49	***Anabas testudineus* (Bloch, 1792*)***	Climbing perch	Climbing perch	Macro phytic	Economic food fish	Indigenous	3.0±0.4	25.0cm	9.5		86,108	Data deficient (DD)
50	***Anabas cobojius* (hamilton, 1822)**	Gangetic koi	Vernacula	Planktivores	commercial	Indigenous	3.5±0.4	30.0 cm	10		89,991	Data deficient

4. Discussion

The Sundarbans, a vital ecosystem shared by India and Bangladesh, is home to a diverse range of freshwater fish species. These fish not only support livelihoods but also contribute significantly to the nutritional security of the local population, particularly in South and Southeast Asia (Roy et al., 2023). However, the Sundarbans face challenges such as over-exploitation, extreme climatic events, and salinity intrusion due to climate change, leading to a decline in freshwater fish diversity. The reduction in fish stocks has direct implications on the livelihoods of the people dependent on these resources (Habib et al., 2020). To address these issues and ensure the conservation of freshwater fish diversity in the Sundarbans, sustainable solutions like proper freshwater management, alternative livelihood options, and community awareness are crucial. Researchers emphasize the importance of focusing on the conservation and utilization of small indigenous fish species to maintain the delicate balance of this unique ecosystem (Parvin et al., 2023; Sultana et al., 2022; Lal et al., 2022; Mogalekar et al., 2023, Sahil et al., 2022).

Freshwater fish diversity in the Sundarbans is an essential aspect of the region's rich biodiversity and has significant implications for the livelihood and nutritional security of local communities. Research on this topic highlights the importance of understanding the diversity and conservation of freshwater indigenous fish resources in the Indian Sundarban Biosphere Reserve (Sen and Mandal, 2019). However, studies on the diversity of fish fauna in the Sundarbans mangrove forest of Bangladesh are sparse and patchy, indicating a need for further research in this area (Habib et al., 2020). The thrust of existing research has focused on the brackish water fish spectrum of the Indian Sundarbans, including both Osteichthyes and Chondricthyes. While this research provides valuable insights into the region's fish diversity, it is essential to expand the scope of research to include freshwater fish species, which play a crucial role in supporting the rural population's food security (Saha et al., 2021). The conservation of freshwater fish species in the Sundarbans is a critical challenge, with over-exploitation, extreme climatic events, and habitat degradation leading to a decline in fish stocks, particularly affecting small indigenous fish (SIF) populations (Mandal et al., 2013) and periphyton (Lowanshi *et al*., 2023). Therefore, efforts towards the conservation of these freshwater fish species are essential to ensure the sustainability of both the ecosystem and the communities dependent on them. Further research is

necessary to expand our understanding of the region's freshwater fish species and their conservation needs.

The conservation of freshwater fish diversity in the Sundarbans is a critical topic for research papers. The Sundarbans, a UNESCO World Heritage Site, is a vital ecosystem in Bangladesh and India, home to a rich biodiversity including over 300 plant species, 400 fish species, and 270 bird species. However, the region faces challenges such as salinity increase due to climate change, impacting flora, fauna, and local livelihoods. Over-exploitation and extreme climatic events have led to a decline in small indigenous fish (SIF) stocks, affecting the livelihoods of people in the region. Research highlights the importance of freshwater fish not only for livelihoods but also for nutritional security in South and Southeast Asia (Habib et al., 2020; Roy et al., 2023). Conservation efforts need to focus on understanding the interrelationships between consumers and resources, considering the impact of human activities and natural processes on biodiversity. The Sundarbans plays a crucial role in preserving coastal aquaculture against climate change impacts, making it essential to explore sustainable solutions to protect this unique ecosystem. Researchers should analyze the effects of salinity, climate change, and anthropogenic factors on fish diversity in the Sundarbans to develop effective conservation strategies that ensure the long-term sustainability of this valuable ecosystem (Saha et al., 2021; Parvin et al., 2023).

4.1 Various threat of sundarban mangrove

4.1.1 Human activity

The Sundarbans, similar to mangroves elsewhere, continue to face significant challenges primarily due to human pressure. Despite the assertion that Sundarbans is in a pristine condition, a significant portion exceeding 50% of the north-western regions and intertidal areas inside the Sundarbans delta have undergone continual deforestation to accommodate human habitation, settlement, agricultural activities, and brackish water fisheries. The primary threats to the forest include land use change, pollution resulting from industrialization and economic activities such as the proximity of shipping ports to the forest, extensive aquaculture, and excessive resource exploitation (Sardar and Samadder, 2021). The Sundarabans is situated inside the Khulna administrative zone, which serves as a significant industrial centre for the nation. This location is strategically advantageous for the establishment of shipping yards, paper mills, and ports. The

degradation of the Sundarbans' ecosystems has been exacerbated by uncontrolled pollution from these sources, increased economic activities, and changes in land use in recent years. This is despite the fact that the Sundarbans serves as a well-established natural coastal barrier that protects the forest and inland areas. The importance of natural protection increases exponentially as cyclones become more common due to global warming (Khan et al., 2021).

4.1.2 Barrage construction

The establishment of the Farakka barrage on the distributries of the Ganges river since 1975 has resulted in a decrease in the dry season freshwater flow into the mangrove-dominated western Sundarbans. The principal macrofauna (arboreal monkeys, gavial, large cats) of the system were threatened by freshwater famine, which can be caused by both natural and human activities. Furthermore, it distorts the inherent salinity of the forest system, hence enabling the infiltration of salt (Rahman and Rahaman, 2018). Heriteris fomes is the primary mangrove species found in the Sundarbans, which thrives in environments with lower salt levels. The introduction of salinity into the western Sundarbans region in India has resulted in the eradication of a species with low tolerance to salinity from the area. It can be inferred that the species in Bangladesh is likely to face a comparable outcome, since the flow of freshwater is progressively constrained by the construction of the barrier (Islam and Gnauck, 2009).

4.1.3 Pollution

Pollution poses a significant hazard to the biodiversity of the Sundarbans. The frequent occurrence of noise and light pollution caused by cargo ships traversing the Sundarbans rivers has a detrimental impact on the daily rhythms of animals, leading them to seek shelter. Oil spills and the dumping of bilge water pollute the water that marine organisms depend on for their survival. The prawn business in the Sundarbans promotes monoculture, leading to a significant quantity of by-catch that is captured and subsequently abandoned (Hossain et al., 2024). Honey collectors that venture into forested areas employ fire as a means to expel bees from their hives, so causing damage to the bees' habitats and potentially causing combustion of vegetation. In order to meet the growing demand for Sundarbans products, such as prawns and honey, islanders are compelled to engage in resource extraction to a greater extent than in previous times (Hossain et al., 2024). The release of waste from trawlers, fishing boats, and cargoes, as well as

the unregulated disposal of sludge from industrial activities, contribute to the existing contamination of water in the rivers of the Sundarbans delta. In 2014, a significant oil spill occurred in the Shela river in the Sundarbans, resulting from a wrecked cargo. This incident garnered considerable public attention (Islam et al., 2017). It is imperative to mitigate the effects of climate change, deforestation, salinification, extreme weather events, natural disasters, noise pollution, light pollution, oil spills, bilge water discharge, and resource exploitation in order to preserve freshwater fish variety in the Sundarbans. Furthermore, the implementation of consistent monitoring and adaptation strategies can contribute to the preservation of biodiversity in the Sundarbans region (Rahman et al., 2009).

4.1.4 Nutrient enrichment

The Sundarbans estuarine ecosystem can experience notable impacts on the mangroves and phytoplankton communities as a result of nutrient loading. Eutrophication, a phenomenon characterised by the enrichment of nutrients, has the potential to elevate the mortality rate of mangroves by the promotion of shoot growth in proportion to root development, so negatively impacting the water relationships of plants. The mangrove vegetation in the Sundarbans can be negatively impacted by this (Manna et al., 2010). The phytoplankton community in the Sundarbans estuary exhibits a notable abundance of species variety and species richness, suggesting the presence of a robust and thriving phytoplankton population inside the estuary. During the post-monsoon period (November 2008 - February 2009), there was a consistent increase in species diversity. This led to a corresponding rise in phytoplankton biomass (chlorophyll-a > 10 ¼g L -1) at all the sites, indicating that the estuary was in a eutrophic state. During the premonsoon period (March-May, 2009), there was a decrease in both the species diversity index and the biomass of phytoplankton. Hence, the variety of phytoplankton is influenced by other factors outside the availability of nutrients, including fish predation and water pollution levels (Manna et al., 2010; Earp et al., 2018). The Sundarban estuarine environment is primarily influenced by sedimentation from the three major rivers, namely Ganga, Bramhaputra, and Meghna. The salinity in this region has been shown to be affected by both geographical and temporal factors. Nevertheless, the mangrove forest in the Sundarbans region is not in its original state and lacks any human involvement. It is currently facing significant threats,

which have the potential to impact the ecological dynamics of the world heritage site Sundarban and contribute to the occurrence of bioinvasion (Rahaman et al., 2013).

4.2 Measurements of conservation of Sundarban delta

The property consists of three animal sanctuaries and has a track record of successful national legislative safeguarding for its land, forest, and aquatic ecosystem from the early 19th century. The establishment of these three wildlife sanctuaries occurred in 1977 with the enactment of the Bangladesh Wildlife (Preservation) (Amendment) Act, 1974. Prior to this, these sanctuaries were initially designated as forest reserves in 1878. The Bangladesh Wildlife (Preservation) (Amendment) Act 1974, in addition to the Forest Act, 1927, regulates many activities related to the entry, movement, fishing, hunting, and exploitation of forest products. Multiple field stations have been created in the Sundarbans West region to facilitate the provision of facilities for management personnel. The restricted forest does not possess any officially acknowledged local rights, and the entry and collection of forest products are contingent upon the issuance of licences by the Forest Department (Siddique et al., 2023).

Sundarbans West has implemented several field stations to facilitate the provision of facilities for management personnel. Local rights inside the restricted forest are not acknowledged, and access to the collection of forest products are contingent upon permissions given by the Forest Department (Siddique et al., 2023; Iftekhar, 2010). A substantial body of study has been undertaken pertaining to the animals and ecology of the Sundarbans. WWF, the National Zoological Park, the Smithsonian Institution, and other organisations have provided international advice and help in developing operational plans for the property, with a specific focus on wildlife conservation and management (Gopal and Chauhan, 2006). The Sundarbans facilitates sustainable lifestyles for millions of individuals in the surrounding area and serves as a protective barrier against hurricanes, cyclones, tidal surges, sea water seepage, and encroachment. According to Jamal et al. (2022), the region offers employment opportunities during specific periods for a significant population residing in nearby small villages. These individuals engage in diverse occupations like as wood-cutting, fishing, honey gathering, and leaf and grass gathering. The tourism figures continue to exhibit a very modest level as a result of challenges associated with accessibility, transportation arrangements, and inadequate amenities, such as suitable lodging options. The influences of mass tourism are improbable to have an impact on the

property's prices. The property's legal protection effectively prohibits many activities, such as unlawful hunting, timber extraction, and agricultural encroachment, which have the potential to negatively impact the property's values. Climate change may lead to an increased frequency of storms, cyclones, and tidal surges, which can reach heights of up to 7.5 m. Additionally, the characteristics of the places themselves may potentially constitute a potential threat (Camilleri and Camilleri, 2018).

5. Conclusion

Mangroves are a wide range of beneficial ecological communities that thrive at the boundary between land and sea. The mangrove forests found in the Sundarban region are recognised as the largest globally. They offer a diverse array of crucial ecological services, encompassing the provision of sustenance and water for millions of their residents, safeguarding against the most severe consequences of natural calamities like cyclones and tsunamis, functioning as a substantial and enduring carbon sink, retaining terrestrial sediments, and serving as a habitat for numerous species, including the endangered and protected Royal Bengal tiger. The significance of the Sundarbans encompasses both local and global contexts, as various stakeholders with diverse agendas strive to determine its future trajectory. Over the past 25 years, the Sundarban mangrove ecosystem has experienced the influence of human activities, gradual climatic shifts, and occurrences of severe weather phenomena. The influence of human activities in the populated region of the Indian Sundarbans on mangrove forests, salinity increase, relative mean sea level rise, and land loss is expected to be more significant than previously believed. The protection of mangrove forests is a very intricate and multifaceted task due to the interplay of climatic hazards, development patterns that depend on certain paths, and environmental governance. The enforcement of legal protection is closely intertwined with power dynamics and therefore not be regarded as a universally applicable virtue. The extraction of goods and expansion of arable land exert direct human strain on these highly protected woods.

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