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Review

Linking Wetland Ecosystem Services to Fish Genetic Resources with Special Reference to Hilsa Shad (*Tenualosa ilisha*): A Novel Study from Northeastern Bangladesh

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Abstract: The wetlands in northeastern Bangladesh are home to some of the most prolific and valuable ecosystems on the planet, offering a wide range of benefits to both the local and wider communities. A limited number of research on this topic have been carried out in various wetlands in coastal hilsa, but none have been located in the northeastern region of Bangladesh. Thus, the goal of this study was to better understand the most commercially relevant species (anadromous hilsa) in northeastern Bangladesh as well as to assess the wetland ecosystem services more thoroughly with the contribution of their fish genetic resources. In addition to laboratory studies, fieldwork was done in the fishing settlements along the Surma River, Hakaluki Haor, and Tanguar Haor. The study classified 77 fish species into 21 subcategories of ecosystem services, of which 56% were not threatened, 17% were vulnerable, and 10% were highly endangered. The species Hilsa was found to be the most economically significant, accounting for 1% of the GDP overall. The study determined if the hilsa stock of the examined wetlands maintains a single or several subpopulations in comparison to other parts of the country when they migrate from saline water to northeastern Bangladesh (freshwater). But when compared to other groups, the FST score was between 0.000 to 0.017, indicating that the populations are identical and that there is genetic material sharing between them. Additionally, these statistics imply that the Sylhet haor and adjacent river systems contain a single stock of Hilsa fish. Nevertheless, a number of stresses and risks, including overexploitation, illicit and destructive fishing, siltation, and natural disasters like flash floods, have been linked to changes in the supply of hilsa and other ecosystem services. This study also emphasizes the necessity of policy attention and research to address the concerns.

Keywords: wetland; ecosystem services; genetic diversity; hilsa; Bangladesh

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Introduction

Bangladesh boasts a significant wetland ecosystem that supports roughly 293 native freshwater species, 475 marine species, and 24 prawn species. These species are essential to the nation's ecological, cultural, and socioeconomic contexts (DoF, 2018; Hasan et al., 2023). Ecosystems offer humans a variety of products and services (MEA, 2005; Nelson et al., 2009, Hossain et al., 2023). Ecosystem services are the advantages that humans receive from the ecosystem. Wetlands are some of the most precious and productive ecosystems on the planet. They offer numerous benefits that fall under the category of wetland ecosystem services, including social, cultural, environmental, and economic (Barbier, 2008; Braat and de Groot, 2012; Islam et al., 2018). According to Alam et al. (2023; Bari et al., 2023) these functions include preserving the distinctive indigenous biota, protecting

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shorelines, controlling air gasses, storing carbon, and supplying cultural, recreational, and educational resources. The development of human societies in Bangladesh has been greatly influenced by the wetland ecosystems, yet these ecosystems are currently vulnerable to threats and their degradation may have an adverse effect on the ecosystem's ability to operate (Met Office, 2011; World Bank, 2013). Over 18 million people relied on the fish and fishery resources of these wetlands for their livelihoods, both directly and indirectly (Shamsuzzaman et al., 2017).

Furthermore, there is a discernible decline in the quantity and quality of the ecosystem services provided by wetland ecosystems as a result of numerous man-made and natural factors, including altered weather patterns, overexploitation, lower income, increased exposure to disasters, and an increase in disorders (Faruk et al., 2023; Ferdous et al., 2023; Mithun at al., 2023). However, little research has been done on the interactions between natural and man-made elements and how these affect aquatic biodiversity, wetland ecosystem services, and genetic diversity in Bangladesh's ecologically sensitive wetlands. To determine how the current management system can help to improve the problem, extensive investigation is therefore required. if it is helping to make things better or not. Bangladesh will now serve as a role model for its numerous accomplishments in the fishing resource sectors. Therefore, it is also necessary to determine whether the strategy takes into account how the communities see and accept these techniques in order to maintain this success.

Bangladesh has also attained a highly esteemed international standing as a result of its exceptional output in the third and fifth categories of inland open water catch and culture fisheries (Shamsuzzaman et al., 2017). In addition to providing a substantial amount of animal protein, the nation's present fish genetic resources account for roughly 3.50% of GDP and 25.72% of the agricultural GDP, both of which have contributed significantly to economic growth. 84.95% of Bangladesh's overall production comes from inland fisheries, whereas just 15.05 percent comes from marine fisheries (Islam et al., 2018, Tufael et al., 2023). The subsectors of inland capture and inland culture fisheries, which together occupy 3.89 and 0.83 million hectares and provide 28.19% and 56.76% of total fisheries production, respectively, make up the two further subsectors of inland fish production. Small-scale fisheries in mangrove, estuary, coastal, riverine, and lacustrine (haor) environments make up the majority of the industry's contributions, despite the presence of a few large-scale enterprises in marine areas. Thus, four unique representative ecosystems—mangrove, estuarine, riverine, and harbor habitats—will be taken into consideration for this study in light of its substantial contribution to the national economy.

In these wetland ecosystems, a variety of fish genetic resources are accessible; however, not all fish species—apart from the anadromous hilsa shad, Tenualosa ilisha—are found in the four habitats that have been chosen. Bangladesh is the world leader in the production of hilsa (Tenualosa ilisha), accounting for 65% of global production (DoF, 2018). The national fish, the hilsa (Tenualosa ilisha), has been granted the national Geographical Indication Registration Certificate and has contributed around 12.15% to the nation's total fish production, totaling 5.33 lakh MT. According to DoF (2018), Hilsa's contribution to Bangladesh's GDP is 1.15 percent. Hilsa is primarily an anadromous fish, though, moving from saltwater to freshwater in order to mate. It visits the nearby sea countries' river courses during the breeding season and returns to the sea after spawning. Following hatching, the young Hilsa spend many months developing in freshwater before returning to the ocean (Shamsuzzaman et al., 2017). To effectively manage hilsa, both in sanctuary places and in other potential hilsa non-sanctuary sites, it is crucial to evaluate the genetic makeup of the disease in the areas or regions that are now accessible. Therefore, it is necessary to determine whether the hilsa stock of different wetlands supports a single or many subpopulations.

This study aimed to evaluate the state of wetland ecosystem services in a more comprehensive manner, taking into account the several features of the ecosystem mentioned above, as well as the contribution and drivers of fish genetic resources. A limited number of studies have been undertaken on this topic, encompassing the various wetlands in Hilsa, but none have included the northeastern region of Bangladesh. To close this gap, the genetic makeup of anadromous hilsa fish in experimental settings is also evaluated in this study.

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Methodology

Study areas

Three northeastern wetlands in Sylhet and Sunamganj, where the study was conducted among fishing communities, are the Surma River, Hakaluki Haor, and Tanguar Haor.

Data collection and sampling

Fieldwork and laboratory activities were both included in this investigation. Household surveys, field observations, focus groups, oral histories, and interviews with key informants were some of the methods used to gather the empirical data (which included both qualitative and quantitative aspects).

Questionnaire interviews

Information on many elements of fish genetic resources, aquatic biodiversity, livelihood difficulties, and climate change were gathered through one-on-one interviews with resource users. Multiple-choice questions with quantitative or qualitative characteristics, as well as open-ended and predefined questions, were all part of the interviews. To guarantee the involvement of various stakeholder groups, focus group discussions, or FGDs, were also held. In order to accurately depict the current state of the wetland and dependent community, Participatory Rural Appraisal (PRA) methodologies were used.

A semi-structured questionnaire was used in an exploratory interview (total = 180) to gather the required data. An estimated sixty to seventy minutes were needed to complete each interview. Twenty focus group discussions (FGDs) with resource users were carried out in addition to the 180 interviews mentioned above. Each group consisted of 7-8 people. Ultimately, in order to gather and confirm the relevant data, twenty KII, or cross-check, interviews with local business owners and NGO staff were carried out. Interviews with locals and fishermen were place in pleasant locations like as paddy fields, fishermen's residences, fish markets, canal banks, beel and haor, and boats.

Sampling of fisheries taxa

Sampling and field survey was conducted among the local fishing communities, fishing boat operators, fish markets and landing centers situated in the adjacent area of the selected wetlands. To get real scenario about the species composition and diversity, sampling of the fisheries taxa was conducted quarterly basis during fishing operations, fish market and landing center situated in the closest area of the wetlands. Identification of the taxa was finalized by cross-checking with the Catalogue of Life 2017, annual checklist and IUCN Red List of threatened Species (Version 2017 -1) with the IUCN global status of available taxa (IUCN, 2000).

Hilsa sample compilation

Figure 1 illustrates the three different places from which T. ilisha samples were collected in Bangladesh's Sylhet division: Hakaluki haor, Tanguar haor, and Surma river. These environments range in salinity from 0.5 to 35 parts per thousand. Twenty fish each from the aforementioned sources contributed to the total of sixty fish that were gathered in 2022. These fish, whose average body weight was about 400 grams, were then taken to the lab to be examined. Using scissors, each fish sample's dorsal fins were carefully removed in the lab, preserved in 100% ethanol, and kept at -20°C for further processing.

Extraction of DNA

Muscle tissue amount was used to extract mitochondrial DNA (mtDNA). The GeneJET kit, which is sold commercially, was used for this extraction procedure. The method of operation comprised following the manufacturer's instructions for the kit. The DNA samples that were produced from this extraction procedure were then kept for further analysis at -20°C.

PCR Amplification

With the primers given in Table 1, the mtDNA Cytochrome b regions were successfully amplified by PCR. Each PCR reaction was carried out in a 50µl volume and included 5 µL of 1X buffer, 2.5 mM of each dNTP, 5 pmoles of each primer, 1.5 mM MgCl2, 3 units of Taq polymerase (Genei, India), and 25–50 ng of genomic DNA. A 50µl volume was used for each PCR reaction. In this investigation, the following PCR cycle conditions were used: (i) Five minutes of initial denaturation at 94°C; (ii) twenty-nine cycles of denaturation at 94°C, annealing at 55°C for one minute, and extension at 72°C for one minute and thirty seconds; and (iii) a final ten-minute extension step at 72°C, after which the sample is stored at 4°C. After PCR amplification, the extracted DNA's quality was evaluated by gel electrophoresis on a 0.8% agarose gel, which was then observed using a gel documentation system. The sequences that were acquired were then added to GenBank for future use.

Table 1. Primers used for amplification of mtDNA Cytob regions of *Tenualosa ilisha*.

mtDNA regions	Forward/Reverse	Primer sequence	Reference
Cytob	Forward	5′-GACTTGAAAAACCACCGTTG-3	Xiao et al. (2001)
	Reverse	5′-CTCGGATCTCCGGATTACAAGAC-3′	

Cytochrome b region Sequencing

The Cytochrome b region of Tenualosa ilisha's mtDNA was sequenced in five purified samples using an Applied Biosystems 3130 Genetic Analyzer. This was accomplished by utilizing a 20 µl reaction mixture that contained ultrapure water, 4.0 µl of the ready reaction premix, 2.0 µl of Big Dye terminator buffer, 0.32 µl of primer, and about 10 ng of the purified products as the template.

Data analysis

With the BioEdit sequence alignment editor, the sequences were first aligned and trimmed in accordance with observations from the chromatograph. They were then added to the GenBank database after that. BLAST (found at www.ncbi.nlm.nih.gov) was used to analyze the recorded data and look for similar sequences. DnaSP v 6.0 software was used to compute the genetic differences between the three populations and other populations of the T. ilisha Cytb gene (Rozas et al., 2017). The Neighbor-Joining Technique (Saitou and Nei, 1987) was applied to determine phylogenetic relationships between the nucleotide sequences of the cytochrome-b region of the samples under study and sequences from GenBank. The best-fit tree was then displayed. The proportion of times the related taxa clustered under the branches in the bootstrap test (1000 repetitions) (Felsenstein, 1985). The Kimura 2-parameter approach (Kimura, 1980) was utilized to compute the evolutionary distances, which were stated in terms of the number of base substitutions per site. MEGA11 was used for these evolutionary studies and pairwise genetic differentiation (FST) (Tamura et al., 2021).

Results and Discussion

Wetland Ecosystem services

Wetland ecosystem services can be classified into four categories: provisioning, regulatory, sustaining, and cultural. These categories were identified through qualitative and quantitative examination of the study's secondary and empirical data. Figure 1 depicts ten different service categories that either directly or indirectly helped the populations in northeastern Bangladesh; Figures 9 and 10 show three cultural services, four supporting, and four regulating services.

Provisioning services

The provisioning services including water, timber, firewood, fodder, medicine and food in the form of fishes. Other ecosystem services included such as navigation (80.85%), irrigation (70.65%), fodder (65.30%), firewood (60.40%), thatching materials (54.70%), and natural medicine (55.20%). The study identified a total of 77 species in the major wetlands of the northeastern Bangladesh. Among them 71 species were recorded in Tanguar haor and the Surma rivers. A total of 58 species were found in hakaluki *haor*. Identified species were distributed among 09 orders where 39 species were from cypriniformes, 12 were from siluriformes, 11 were recorded from perciformes, 5 species from clupiformes and channiformes, beloniformes represented 2 species and 1 species from Anguilliformes, Tetraodontifomes and Anguilliformes (Table 02).

Table 02. List of different fish genetic resources with their scientific, local and common name.

Sl. No.	Order	Scientific identity of the taxon with author	Vernacular or local Bengali name	Common English name	Availability of taxa			IUCN Status in BD[1]	IUCN global Status[2]
					TH	HH	SR		
1.	Anguilliformes	*Anguilla bengalensis* (Gray, 1831)	Bamos	Indian mottled eel	√	√	√	VU	NT
2.	Cypriniformes	*Salmostoma phulo* (Hamilton, 1822)	Fulchela	Flying barb	√	√	√	NT	LC
3.	Cypriniformes	*Esomus danrica* (Hamilton, 1822)	Darkina	Flying barb	√	√	√	EN	LC
4.	Cypriniformes	*Rasbora rasbora* (Hamilton, 1822)	Darkina	Flying barb	√	-	√	EN	LC
5.	Cypriniformes	*Chela labuca* (Hamilton, 1822)	Labuca	Hatchet fish	-	√	-	VU	NE
6.	Cypriniformes	*Psilorhynchus sucatio* (Hamilton, 1822)	Titari	River stone carp	√	√	√	NT	LC
7.	Cypriniformes	*Bengala elanga* (Hamilton, 1822)	Sephatia	Bengala barb	√	√	√	NT	NE
8.	Cypriniformes	*Barilius bendelisis* (Hamilton, 1807)	Joia	Hamilton's barila	√	-	√	EN	LC
9.	Cypriniformes	*Danio rerio* (Hamilton, 1822)	Anju	Zebra danio	-	√	-	NT	LC
10.	Cypriniformes	*Osteobrama cotio* (Hamilton, 1822)	Dhela	Cotio	√	√	√	EN	LC
11.	Cypriniformes	Systomus sarana (Hamilton, 1822)	Sarpunti	Olive barb	-	√	-	CR	LC
12.	Cypriniformes	*Puntius chola* (Hamilton, 1822)	Chalapunti	Chola barb	√	√	√	NT	LC
13.	Cypriniformes	*Pethia guganio* (Hamilton, 1822)	Molapunti	Glass-barb	√	√	√	NT	LC
14.	Cypriniformes	*Puntius conchonius* (Hamilton, 1822)	Kanchanpunti	Rosy barb	√	√	√	NT	LC
15.	Cypriniformes	*Puntius ticto* (Hamilton, 1822)	Tit punti	Ticto barb	√	√	√	VU	LC
16.	Cypriniformes	*Puntius sophore* (Hamilton, 1822)	Jatpunti	Pool barb	√	√	√	NT	LC
17.	Cypriniformes	*Puntius terio* (Hamilton, 1822)	Teri punti	One spot barb	-	√	-	NT	LC
18.	Cypriniformes	*Oreichthys cosuatis* (Hamilton, 1822)	Kosuati	Sortfinner barb	√	-	√	NT	LC
19.	Cypriniformes	*Garra* gotyla (Gray, 1830)	Gharpoia	Sucker head, Gotyla	√	√	√	NT	LC
20.	Cypriniformes	*Acanthocobitis zonalternans* (Blyth, 1860)	Bilturi	River loaches	√	-	√	NT	LC
21.	Cypriniformes	*Schistura corica* (Hamilton, 1822)	Koikra	Stone loach	√	√	√	NT	LC

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22.	Cypriniformes	*Schistura scaturigina* (McClelland, 1839)	Dari	Stone loach	√	-	√	NT	LC
23.	Cypriniformes	*Schistura beavani* (Gunther, 1868)	Shavonkhokra	Greek loach	√	√	√	NT	LC
24.	Cypriniformes	*Somileptes gongota* (Hamilton, 1822)	Poia	Gongota loach	√	√	√	NT	LC
25.	Cypriniformes	*Botia dario* (Hamilton, 1822)	Rani	Stripped loach	√	-	√	EN	LC
26.	Cypriniformes	*Lepidocephalus guntea* (Hamilton, 1822)	Gutum	Guntea loach	-	√	-	NT	LC
27.	Cypriniformes	*Labeo rohita* (Hamilton, 1822)	Rui	Rohu	√	√	√	NT	LC
28.	Cypriniformes	*Catla catla* (Hamilton, 1822)	Catla	Catla	√	√	√	NT	LC
29.	Cypriniformes	*Cirrhinus cirrhosus* (Bloch, 1795)	Mrigal	Mrigal carp	√	√	√	NT	VU
30.	Cypriniformes	*Labeo calbasu* (Hamilton, 1822)	Kala Baush	Karnataka labeo	√	√	√	EN	LC
31.	Cypriniformes	*Labeo bata* (Hamilton, 1822)	Bata	Bata labeo	√	√	√	EN	LC
32.	Cypriniformes	*Chagunius chagunio* (Hamilton, 1822)	Jarua	Minor carp	√	√	√	NT	LC
33.	Cypriniformes	*Labeo angra* (Hamilton, 1822)	Angrot/kharas	Angra labeo	√	√	√	NT	LC
34.	Cypriniformes	*Labeo gonius* (Hamilton, 1822)	Ghainna	Kuria labeo	√	√	√	EN	LC
35.	Cypriniformes	*Labeo nandina* (Hamilton, 1822)	Nandina	Nandi labeo	√	√	√	CR	NT
36.	Cypriniformes	*Labeo pangusia* (Hamilton, 1822)	Ghoramach	Pangusia labeo	-	√	√	CR	NT
37.	Cypriniformes	*Cirrhinus reba* (Hamilton, 1822)	Bhagna	Reba carp	√	√	√	VU	LC
38.	Cypriniformes	*Amblypharyngodon mola* (Hamilton, 1822)	Mola	Mola carplet	√	√	√	NT	LC
39.	Cypriniformes	*Danio devario* (Hamilton, 1822)	Debari	Bengal danio	√	-	√	NT	NE
40.	Cypriniformes	Raiamas bola (Hamilton, 1822)	Bhol	Trout barb, Indian trout	√	√	√	EN	LC
41.	Siluriformes	*Eutropiichthys vacha* (Hamilton, 1822)	Bacha, Bhacha	Schilbi	√	√	√	CR	LC
42.	Siluriformes	*Clarias batrachus* (Linnaeus, 1758)	Magur	Walking catfish	√	√	√	NT	LC
43.	Siluriformes	*Wallago attu* (Bloch & Schneider, 1801)	Boal	Freshwater shark	√	√	√	NT	NT
44.	Siluriformes	*Heteropneustes fossilis* (Bloch, 1794)	Shing	Stinging catfish	√	√	√	NT	LC
45.	Siluriformes	*Pangasius pangasius* (Hamilton, 1822)	Pangus	Pangas catfish	√	√	√	CR	LC
46.	Siluriformes	*Ailia coila* (Hamilton, 1822)	Kajuli	Gangetic catfish	√	√	√	NT	NT
47.	Siluriformes	*Rita rita* (Hamilton, 1822)	Rita	Rita, Striped catfish	√	√	√	CR	LC
48.	Siluriformes	*Sperata aor* (Hamilton, 1822)	Ayre	Long-whiskered catfish	√	√	√	VU	LC
49.	Siluriformes	*Mystus cavasius* (Hamilton, 1822)	GolshaTengra	Gangetic mystus	√	√	√	VU	LC
50.	Siluriformes	*Mystus bleekeri* (Day, 1877)	Tengra	Catfish	√	√	√	NT	LC

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51.	Siluriformes	*Mystus tengara* (Hamilton, 1822)	BazariTengra	Stripped dwarf catfish	√	-	√	NT	NE
52.	Siluriformes	*Clupisoma garua* (Hamilton, 1822)	Garua	River catfish	√	√	√	CR	LC
53.	Tetraodontifomes	*Tetraodon cutcutia* (Hamilton, 1822)	Potka	Ocellated pufferfish	√	√	√	NT	LC
54.	Beloniformes	*Xenentodon cancila* (Hamilton, 1822)	Kakila	Freshwater garfish	√	√	√	NT	LC
55.	Beloniformes	*Hyporhamphus limbatus* (Valenciennes, 1847)	Ekthota	Congaturi Halfbeak	√	√	√	NT	LC
56.	Cyprinodontiformes	*Aplocheilus panchax* (Hamilton, 1822)	Kanpona	Blue Panchax	√	√	√	NT	LC
57.	Channiformes	*Channa striatus* (Bloch, 1793)	Shol	Snakehead murrel	√	√	√	NT	NE
58.	Channiformes	*Channa marulius* (Hamilton, 1822)	Gajar	Giant snakehead	√	√	√	EN	LC
59.	Channiformes	*Channa barca* (Hamilton, 1822)	Piplashol	Barca snakehead	√	√	√	CR	DD
60.	Channiformes	*Channa punctatus* (Bloch, 1793)	Taki	Spotted snakehead	√	√	√	EN	NE
61.	Channiformes	*Channa orientalis* (Bloch & Schneider, 1801)	Raga/Cheng	Walking snakehead	√	-	√	VU	NE
62.	Clupiformes	*Chitala chitala* (Hamilton, 1822)	Chital	Clown knifefish	√	√	√	EN	NT
63.	Clupiformes	*Notopterus notopterus* (Pallas, 1769)	Foli	Bronze featherback	√	√	√	VU	LC
64.	Clupiformes	*Corica soborna* (Hamilton, 1822)	Kachki	The Ganges River Sprat	√	-	√	NT	LC
65	Clupiformes	*Tenualosa ilisha* (Hamilton, 1822)	Ilish	Hilsa shad	√	√	√	NT	LC
66	Clupiformes	Gudusia chapra (Hamilton, 1822)	Chapila	Indian river shad	√	√	√	NT	LC
67.	Perciformes	*Macrognathus aculeatus* (Bloch, 1786)	Tara baim	Lesser spiny eel	√	√	√	VU	NE
68.	Perciformes	Mastacembelus armatus (Lacepede, 1800)	Baim	Spiny eel	√	-	√	EN	LC
69.	Perciformes	*Mastacembelus pancalus* (Hamilton, 1822)	Guchibaim	Spiny eel	-	√	√	VU	NE
70.	Perciformes	*Colisa fasciatu* (Bloch & Schneider, 1801)	Khalisha	Banded gourami	√	√	√	NT	NE
71.	Perciformes	*Colisa lalia* (Hamilton, 1822)	Lalkholisha	Dwarf gourami	√	-	√	NT	NE
72.	Perciformes	Anabas testudineus (Bloch, 1792)	Koi	Climbing perch	√	√	√	NT	DD
73.	Perciformes	Chanda nama Hamilton, 1822	NamaChanda	Elongate Glass Perchlet	√	-	√	VU	LC
74.	Perciformes	Parambassis lala (Hamilton, 1822)	LalChanda	Highfin Glassy Perchlet	√	√	√	VU	NT
75.	Perciformes	Parambassis ranga (Hamilton, 1822)	Rangachanda	Indian glassy fish	√	-	√	VU	LC
76.	Perciformes	*Chanda beculis* (Hamilton, 1822)	Chanda	Himalayan glassy perchlet	-	√	√	NT	NE
77.	Perciformes	Glossogobius giuris (Hamilton, 1822)	Bele	Freshwater goby	√	√	√	NT	LC

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Conservation status of fishery species

The findings of the study showed that the wetlands have a highly rich biodiversity. However, as per the IUCN classification of fish species, 43 of them were classified as not threatened, 13 species were found in both group as vulnerable and endangered, and 08 species as critically endangered (Figure 02). The IUCN (2000) listed 77 species, of which 56% were not threatened, vulnerable and endangered both represented 17% and 10% were critically endangered. The study also indicated that the majority of the species were classified as Least Concern (LC) globally, with global trends either unknown or declining. This designation necessitates additional research to determine the appropriate conservation measures for the fishing species in the research areas.

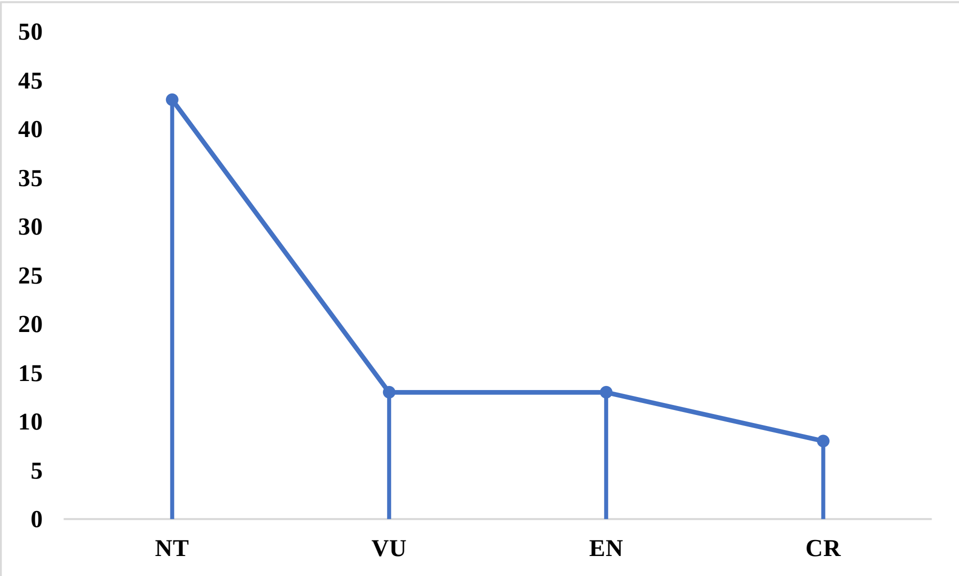

Figure 02. Conservation status of fish genetic resources of northeastern Bangladesh.

Most economically significant species

The species that has the most economic significance is Hilsa. Figure 03 shows a 92% increase in hilsa production during the preceding fifteen years. A contribution of 1% to the GDP, the average hilsa production was over 5.71 lakh tonnes, valued at over US$ 700 million. The production of hilsa is also rising daily (Figure: 04). Hilsa used to be accessible in more than 100 rivers in Bangladesh. Although it was accessible to all socioeconomic strata, hilsa began to progressively fall over a few decades, reaching a minimum in 1991–1992 and continuing until 2002–2003 at 0.19 million tonnes. Given the declining trend in hilsa production, the government decided to regulate the amount of jatka and brood hilsa caught during the 2003–2004 mating season in an effort to boost production. Hilsa accounted for over 11% of the nation's total fish production in 2005–06, and its share is still rising today. But in mangrove, estuary, and haor basin environments, hilsa has once again become a common species. In order to determine if the chosen hilsa stock maintained a single or multiple subpopulation, we gathered hilsa samples from several parts in uncharted haor dominate areas for this study. This project will support the implementation of an efficient hilsa management plan for sanctuary areas in the other hilsa prospective non-sanctuary areas as well.

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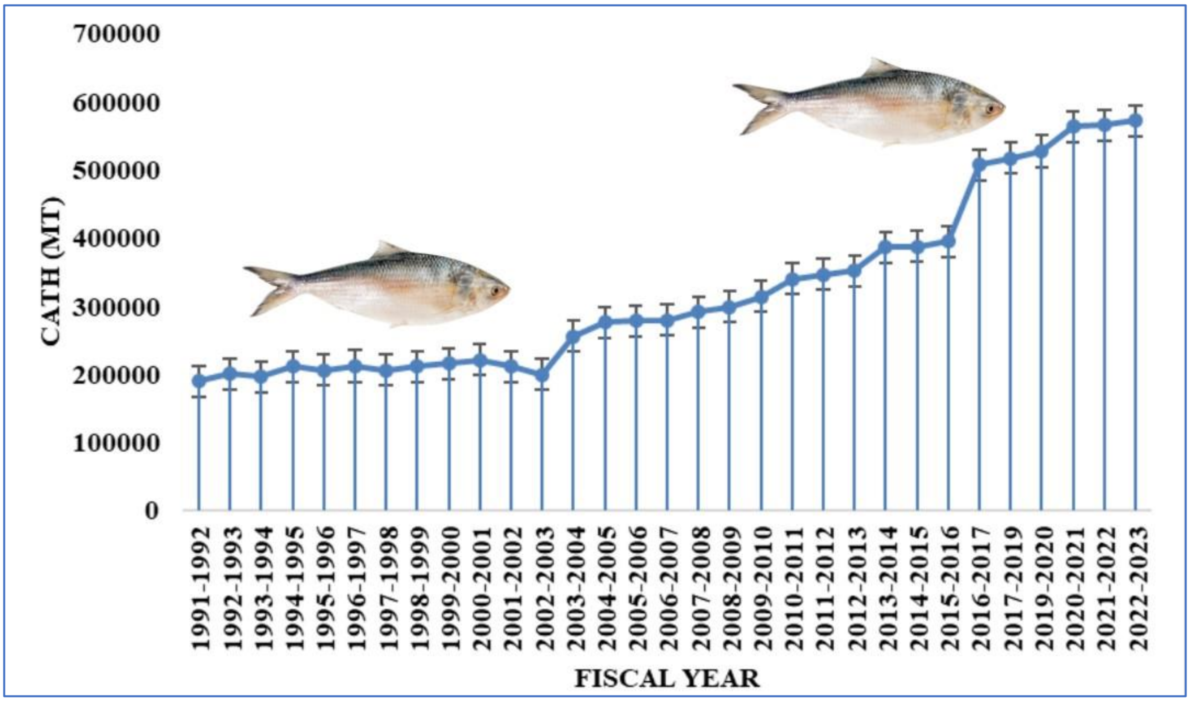

Figure 03. Total hilsa catch in Bangladesh from1991-2023.

Analysis of genetic diversity of commercially important species Hilsa

Genetic diversity

A total of 744 nucleotide sequences were utilized to examine the genetic structure of the hilsa population. Three distinct haplotypes were identified among the three populations. Within the *T. ilisha* samples, 271 segregating (polymorphic) sites were observed. The average nucleotide frequencies across all populations were as follows: A = 28%, T = 24%, C = 30%, and G = 18%. Furthermore, the average %G~C content within the populations was determined to be 47.73%. Nucleotide diversity (PiJC) and haplotype diversity (Hd) were calculated as 2.50198 and 1.000, respectively, among the populations.

Pairwise differences among populations of Hakaluki haor, Tanguar haor and Surma river were 0.000-0.011 measured by F_{ST} (Table 03). However, compared to other groups the F_{ST} value ranged from 0.000-0.017 and thus presenting the sharing of genetic material between the populations and indicating these populations are identical. These data also suggest that, there is a single stock of Hilsa fish in Sylhet haor and river system, as they share a similar geographical distribution and are part of the same drainage system. Furthermore, the data also points to a lower genetic diversity within the Hilsa population in the Sylhet haor and river system, as well as in neighboring areas.

Table 03. The Pairwise population distinctions of the genetic structure of different populations of *Tenualosa ilisha* through fixation index (F_{ST}) by MEGA 11 software.

Sl. No.	*Tenualosa ilisha*	1	2	3	4	5	6	7
01	Hakaluki haor, BD							
02	MN101849.1, India	0.005						
03	MN748955.1, BD	0.015	0.015					
04	MN748960.1, BD	0.003	0.003	0.010				

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05	MN748965.1, BD	0.013	0.013	0.000	0.010			
06	Surma river, BD	0.003	0.010	0.012	0.000	0.009		
07	MN748971.1, BD	**0.017**	**0.017**	0.000	0.010	0.000	0.013	
08	Tangur haor, BD	0.011	0.014	0.015	0.003	0.013	0.011	**0.017**

Single nucleotide polymorphism and deletion

Two single nucleotide polymorphisms (SNPs), namely A4G and A13T, were detected within a 744-base pair segment of the Hakaluki haor partial sequence after conducting a blast analysis on NCBI (https://blast.ncbi.nlm.nih.gov/Blast.cgi). In contrast, the partial sequence of Tanguar haor revealed seven SNPs, specifically A6G, C10G, A24G, C29A, A104T, C165A, and T738G. Notably, in the sequence of the Surma river, two nucleotides (T) were found to be absent at positions 611 and 736. These SNP findings indicate that the Tanguar haor population is likely experiencing higher genetic pressure compared to the Hakaluki haor and the Surma river among the three populations.

Conserved sequences

Nucleotides that are not conserved are indicated using a green color. The alignment was produced using ClustalW (Thompson et al., 1994) and displayed in a CLC sequence viewer (Figure 1) (https://www.qiagenbioinformatics.com/).

Phyologenetic analysis

The sequences initially aligned using the ClustalW algorithm, were then analyzed using the K2P-distance model to construct a phylogenetic tree aimed at tracing the species' origin and understanding their evolutionary relationships (Figure 05). According to the neighbor-joining tree, it is evident that *T. ilisha* from different locations formed a distinct cluster, indicating that all subpopulations exhibited identical observed and expected heterozygosity, as strongly supported by a 1000% bootstrap value. The phylogenetic analysis reveals that *Gudusia chapra*, *Tenualosa macrura*, and *Tenualosa toil* share a closer genetic relationship with *Tenualosa ilisha*, while *Ilisha melastoma*, followed by *Ilisha elongate*, and *Hilsa kelee* appear to be more distantly related species. Consequently, the phylogenetic tree suggests that these species likely share similarities in their appearance and overall structure, potentially contributing to the confusion in their morphological identification. However, the phylogenetic tree clearly indicated that the fish collected from Hakaluki haor, Tanguar haor, and Surma river were identified as belonging to the *T. ilisha* species.

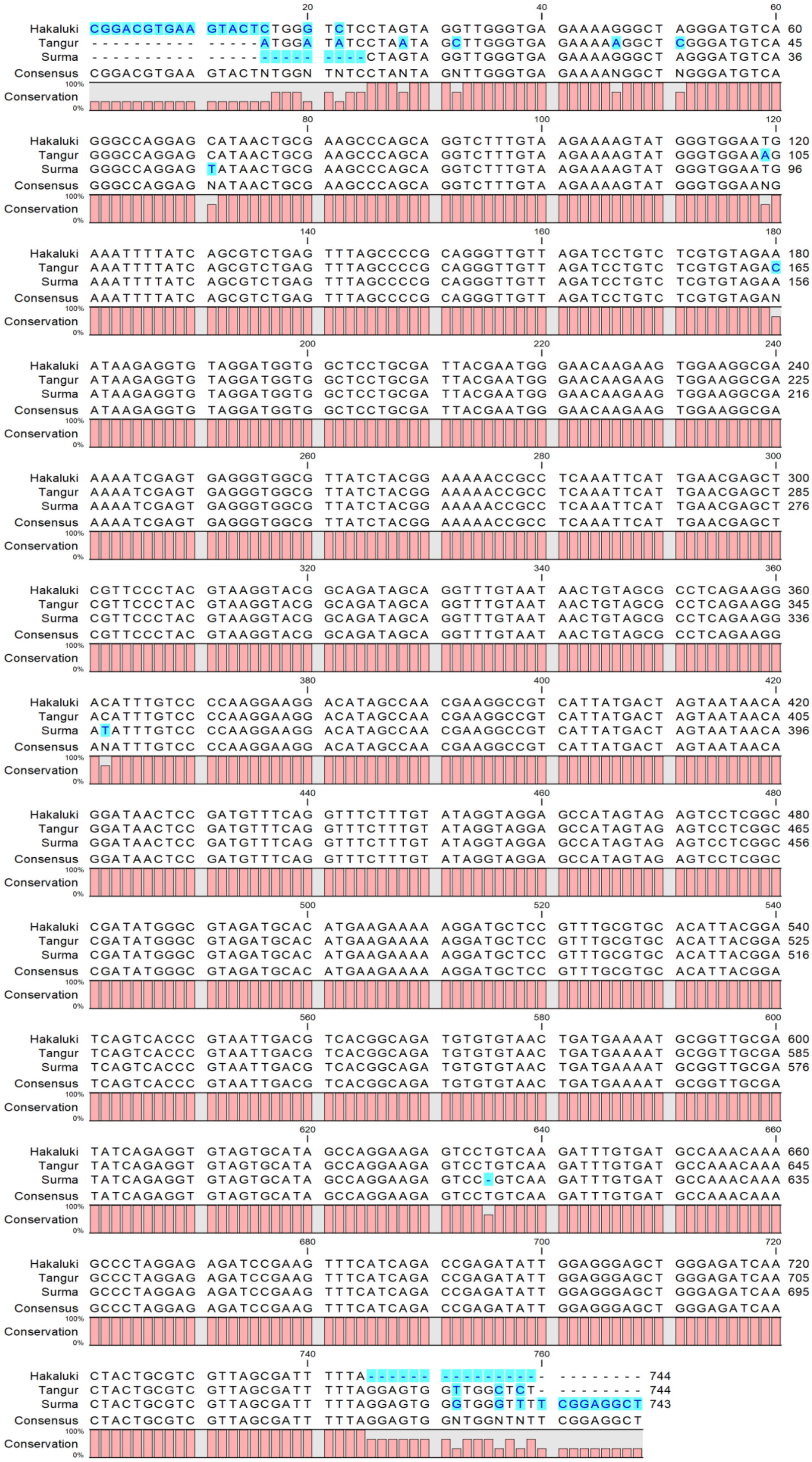

Figure 05. Alignment of nucleotide sequences of *Tenualosa ilisha* collected from Hakaluki haor, Tanguar haor, and Surma river to identify conserved sequences.

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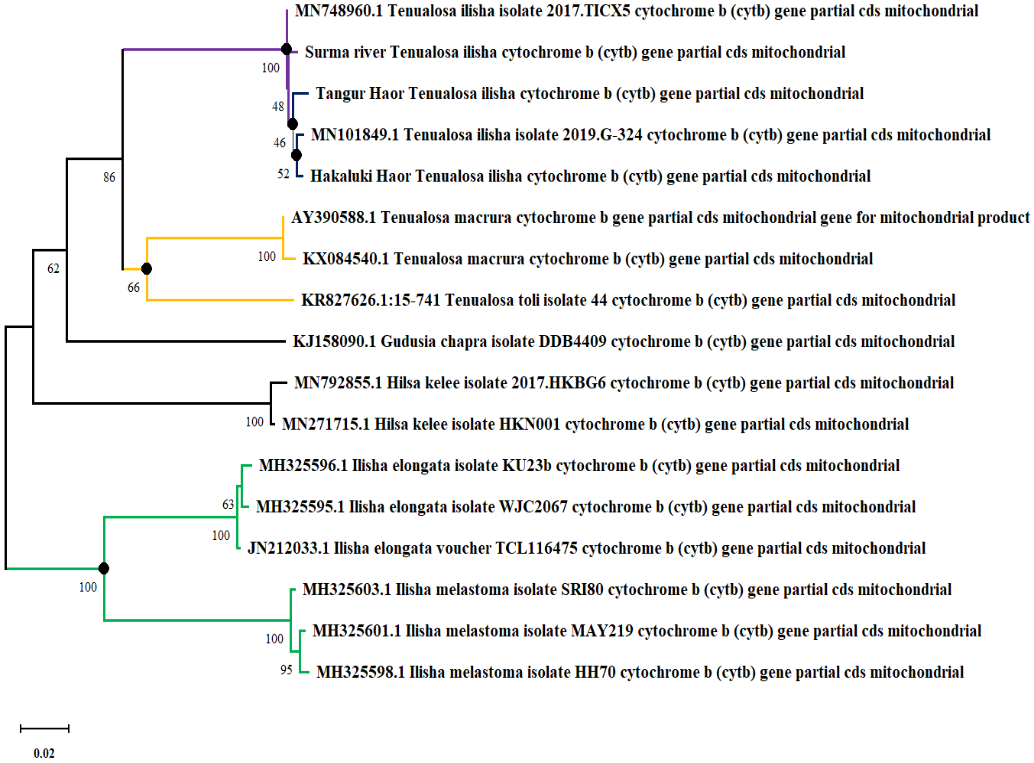

Figure 06. The evolutionary history deduced using the Neighbor-Joining technique and the best-fit tree depicted. The percentage of times the associated taxa grouped in the bootstrap test (with 1000 replicates) indicated beneath the branches. The evolutionary distances were calculated using the Kimura 2-parameter method, expressed in terms of the number of base substitutions per site.

Cultural services

In the areas under investigation, almost 70% of the wetlands were utilized for cultural purposes. Each wetland is owned by religious people in these communities, who also reference wetlands as suitable grounds for spiritual, educational, and research purposes (Figure 07). Additionally, these services will have a major impact on economic development and were crucial to ecotourism and recreation.

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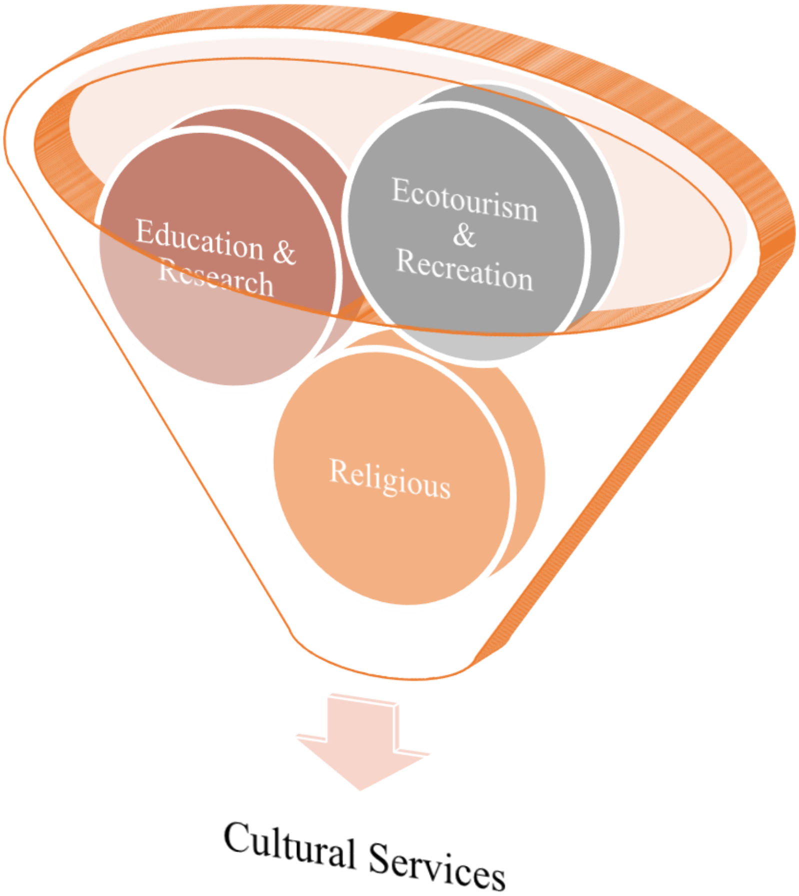

Figure 07. Cultural Services of Wetland Ecosystem.

Supporting services

Supporting services including the biodiversity conservation, soil formation, nutrient cycling and primary production played a crucial role in the ecosystem services of the northeastern wetlands (Figure 08). It was found during the field observation there was 70% of households value biodiversity conservation.

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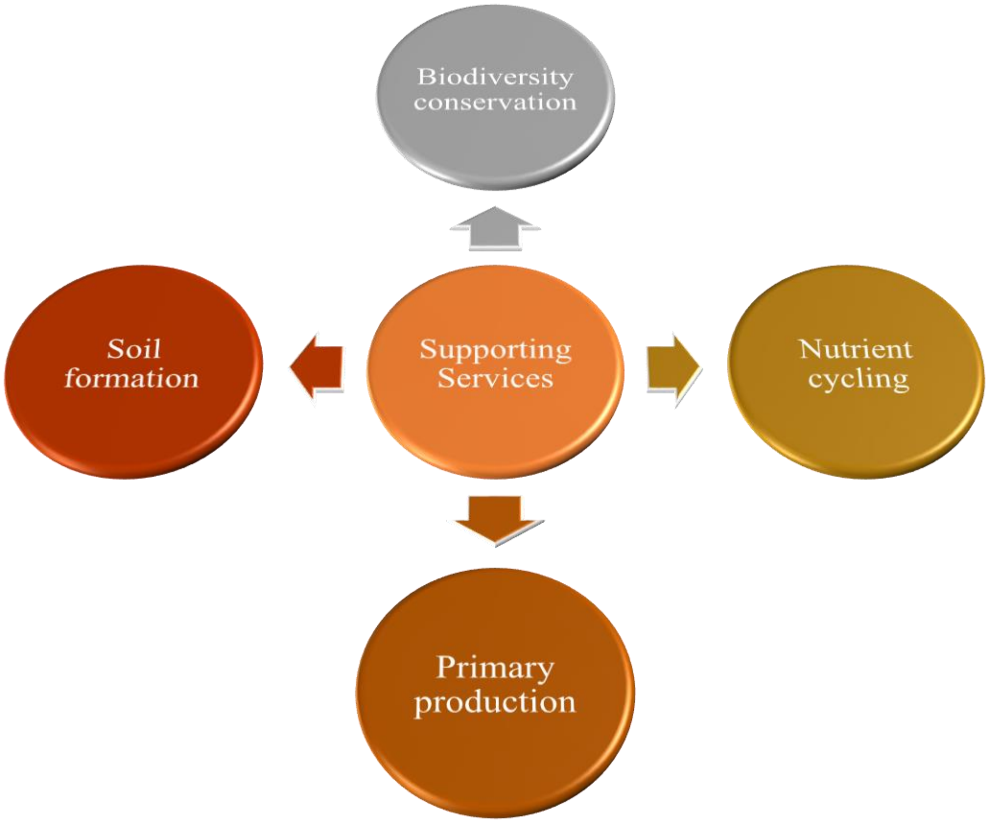

Figure 08. Wetland Ecosystem Supporting Services.

Regulating services

Majority of the households stated that practically all wetlands played a vital role in water purification, flood regulation, and sediment retention. According to the lower perceptions of erosion protection (15.35%) and higher views of flood control (55.25%) can be explained by the fact that the majority of the analyzed economically significant wetlands are situated in studied areas (Figure 09). Furthermore, professional judgments and field observations demonstrated that urban influenced wetlands give the best pollution management and regulation services. Though urban influenced wetlands are severely limited in their function due to urban trash, they nonetheless play an important part in pollutant chemical regulation when compared to other types.

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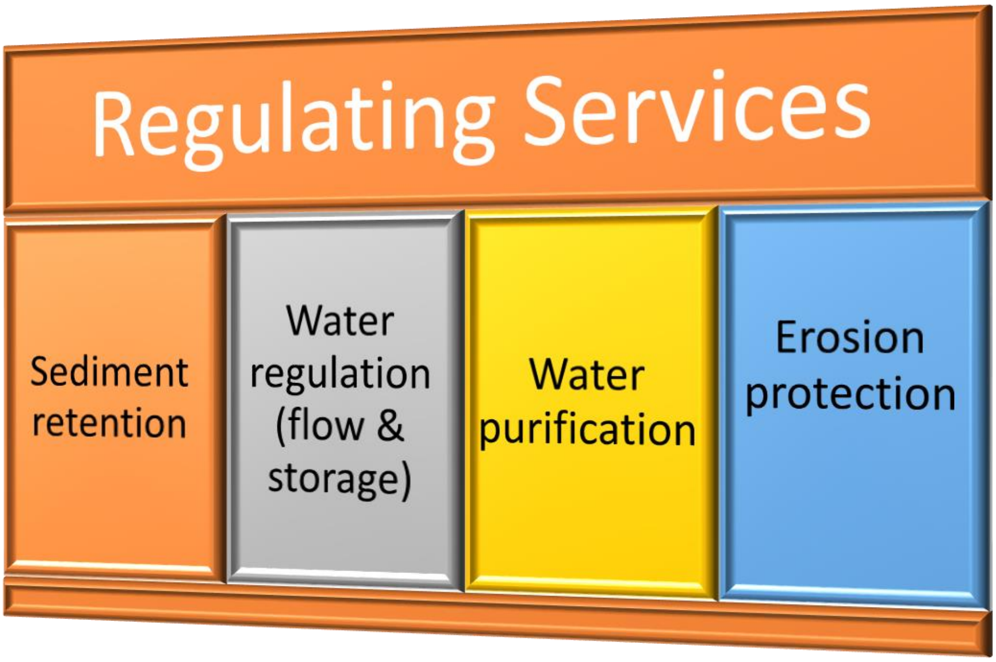

Figure 09. Wetland Ecosystem for Regulating Services.

Drivers of wetland ecosystem services focusing fish genetic resources:

The northeastern region of Bangladesh has been facing significant threats in recent times, including flash floods, natural disasters, and changes in temperature and precipitation. The majority of disasters, droughts, severe cyclone dangers, and other events impact wetland communities. During that time, the locals shared their unimaginable miseries and eventually lost all power and dependence on relief.

The majority of the wetland-dependent resource community is living below the marginal poverty line and is dependent on debt collection from the local moneylenders, known as *Dadan* or *Dadonder*. From this money, they fulfill their consumption needs and other activities and are sometimes bound to sell their fish to them at a very cheap rate compared to the market. Besides, some respondents indicated that this factor pushes them to catch fish during the ban period, which is identified as illegal fishing according to the government. Besides, overexploitation by using illegal fishing gear and equipment has adversely affected the wetland ecosystem services. The land use pattern of fresh water has changed significantly, and many more economic activities and urbanization have been found in the study areas. Local fish species become critically endangered due to the unaware dredging and riverbank establishment of roads, bridges, culverts, and other unplanned urbanization development. Some key informants revealed that the unplanned dredging and land occupied adversely affected the fish habitat and gradually reduced fish availability.

Globally, pollution has gained controversy in recent years, and Bangladesh's northeastern wetland is severely contaminated. Human waste, motor oil spills, plastic waste, poisoning fish to catch them, and a host of other factors eventually contaminate freshwater ecosystems, including water and soil. “The haor was innumerable with exuberant varieties of fish, but we no longer find sufficient fish in the haor due to some people coming from townships using poison for catching fish and left; gradually, fishers are also declining,” explained a local fisherman during the interview. On the other hand, tourist and recreational boats travel frequently and use high-bit sound systems for different recreation purposes, which affects the environment extremely.

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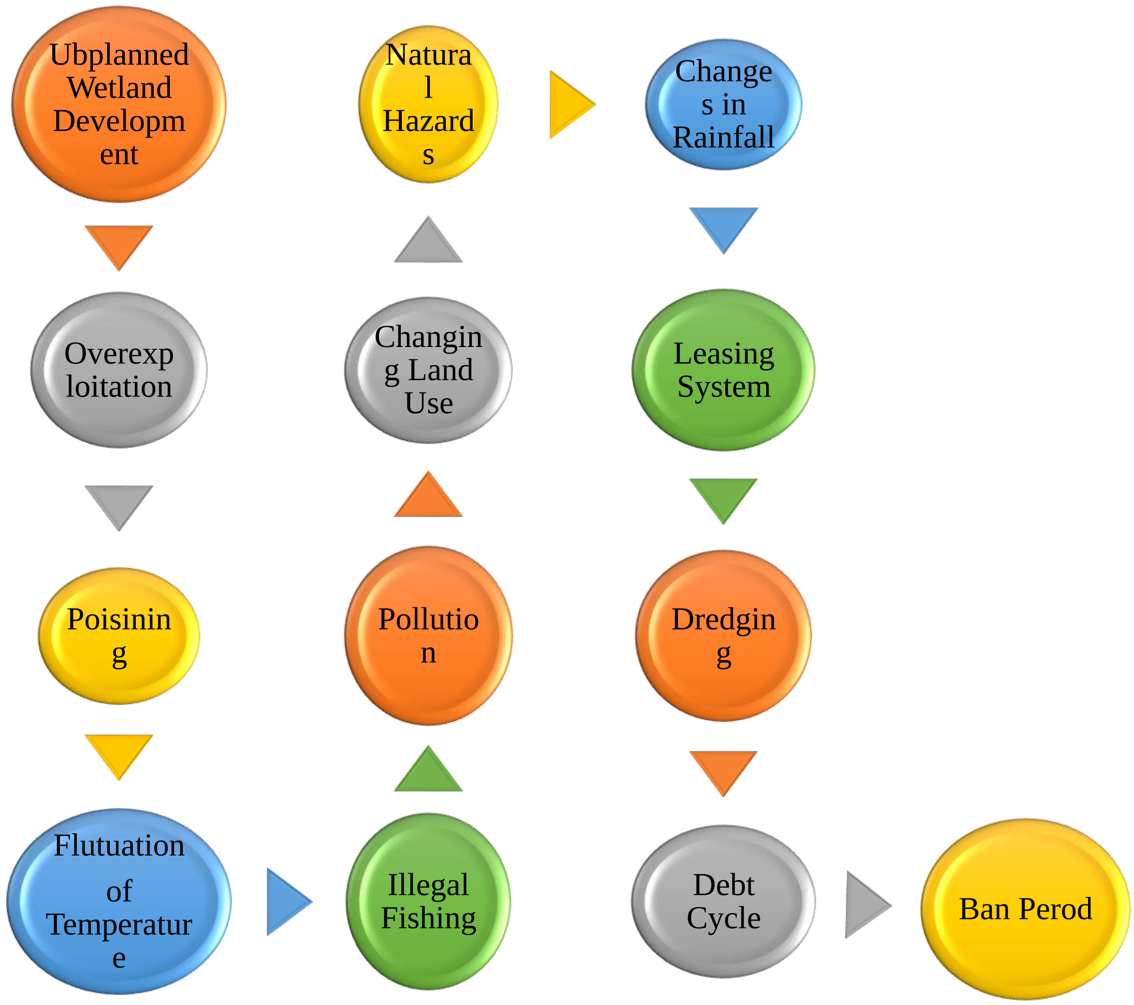

Figure 10. Drivers of Wetland Ecosystem Services.

Discussions

It has been attempted by humans to rely on nature to supply them with goods and services (Mahbub et al., 2023; Mithun et al., 2023). Ecosystem services (ES) are features of ecosystems that are useful to humans directly or indirectly (Islam et al., 2018). The Millennium Ecosystem Assessment identified basic services like food, timber, and fiber that make up the ES, as well as cultural services like recreation and aesthetic beauty and regulatory services like flood control and climate regulation. One of the primary immediate benefits that we obtain from the wetland is fish (Sunny et al., 2018). In Bangladesh and throughout the division, fish is a staple diet for many people. Because of the abundance of various rivers, including as the Beel, Baor, and Hor, the northeastern part of Sylhet has a lot of potential for freshwater capture fisheries. There are 289 common species of fish in freshwater bodies; the most important species for commerce is the hilsa. Hilsa migrates to freshwater from saltwater to breed. Before going back to the ocean, the young Hilsa spend several months growing in freshwater after hatching (Shamsuzzaman et al., 2017). Thus, assessing the genetic makeup of hilsa in the sites or regions that are accessible is essential to ascertaining if the hilsa stock of various wetlands supports one or multiple subpopulations.

In order to effectively manage species, population genetic structure must be studied, and genetic variety is essential to population maintenance and preservation (Luhariya et al., 2012; Asaduzzaman et al., 2020). The migratory lifestyle of species and the dynamic environmental factors they encounter, like shifting salinities, turbidities, suspended sediments, food availability, and other ecological factors, can cause genetic diversity in fingerlings, juveniles, and adults to differ (Nwafili and Gao, 2026; Hossain et al., 2026; Tamario et al., 2019; Asaduzzaman et al., 2029). The current investigation has revealed a reduced degree of genetic variation in the cytochrome b area of T. ilisha fish, in contrast to earlier discoveries from the examination of the fish's mitochondrial regulatory region (Sultana et al., 2022). Numerous variables affect genetic diversity, which gives populations the resilience and flexibility they need to survive in the face of shifting environmental conditions. Moreover, F statistics (Fst) and phylogenetic analysis show that every community under study has a comparable genetic structure, demonstrating the genetic material shared by the populations and suggesting their homology. Given their similar geographic range and shared drainage system, these findings also imply the existence of a single stock of Hilsa fish in the Sylhet river and haor system. Additionally, the data indicates a reduced level of genetic diversity among the Hilsa population in the Sylhet river system and haor, as well as in nearby regions. A 1000% bootstrap value strongly suggests that all subpopulations of T. ilisha showed identical observed and anticipated heterozygosity, as demonstrated by the neighbor-joining tree, which clearly shows that the species constituted a separate cluster. Therefore, the evolutionary tree implies that these species probably have similar overall morphology and appearance, which may have contributed to the confusion around their morphological identification. The fish gathered from Hakaluki haor, Tanguar haor, and Surma river, on the other hand, were unambiguously identified as belonging to the T. ilisha species, forming a distinct cluster, according to the phylogenetic tree. Riverine, estuarine, and marine hilsa fish populations are likely two or possibly three different species found within Bangladeshi borders, according to Mazumder and Alam (2009).

We found that there was very little population differentiation in the Surma river populations and Hakaluki haor populations in the current study, while there was a little and inconsequential differentiation in the Tanguar haor populations. One possible explanation for this divergence is that the physical attributes of the ecosystem influence the genetic makeup of these people. Because the water bodies are physically adjacent to one another and may share a shared gene pool, our current findings also suggest that there is continuing gene flow among these populations. All of this data points to the conclusion that these groups are neither experiencing a population decline nor a bottleneck at present time. Additionally, the modest range in FST values among the three populations points to a restricted or nonexistent rise in the rate of mutation, which is encouraging for the conservation of large commercial species like hilsa. The size of the population affects how much genetic drift occurs. In terms of gene frequencies, a population will eventually attain equilibrium if it has a constant size and mutation rate. The FST results suggest that there is low variety among various freshwater populations, which is explained by our examination of the genetic structure of hilsa.

Further research is necessary to determine the degree of population differentiation, including the collecting of samples from hilsa occurrence zones in other nations or territories, given that hilsa populations migrate over international borders. Finding out if there are any anthropogenic or natural factors influencing the growth, availability, or any other aspect of hilsa is also necessary. The likelihood that hilsa may suffer as a result, however, has increased in recent decades because to concerns about the rapid degradation and loss of world ecosystems and their services. A major barrier to achieving sustainable development is the potential impact that the loss of ecosystem services may have on wetland productivity, economies, and human civilizations. Fish genetic resources, wetland resource users, and sustainable development all depend on wetland protection and sustainable management being given high priority.

Conclusion

The socioeconomic growth and means of subsistence for the country's climate-vulnerable population in northeastern Bangladesh depend heavily on the wetland environment. The services provided by the ecosystem include a wide variety of plant species, fish, native and migratory birds, and other critters. The study categorized the current services according to how the people living in the Surma river's Sunamganj area, Hakaluki haor, and Tanguar haor in Sylhet saw them. The study revealed that the climate communities had been getting cultural services, maintenance and regulation services, provisioning services, support, and provisioning services for a number of decades before. Hilsa was found to be the most significant species in terms of legacy, science, education, and trade, aside from its aesthetic value. But it turns out that the residents' irresponsible use of resources has

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caused these ES to undergo substantial changes. To solve the issues facing the wetland, research and policy attention are thus critically needed. This entails switching from the present management regimes to an ecosystem-based approach, with a focus on co-management of fisheries. Having said that, the findings of the study will assist researchers in better integrating genetic studies with the benefits that wetland ecosystems offer. They will also assist policymakers in developing more sensible strategies to increase productivity and safeguard future supply.

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