



Article

Fish Genetic Resources and Wetland Conservation in Bangladesh: Comparative Insights on Biodiversity, Sustainable Management, and Sustainable Development Goals

Atiqur Rahman Sunny ^{1,*} , Sharif Ahmed Sazzad ², Md Shishir Bhuyian ^{2,3}, Md. Nazmul Hasan ¹ ,
Md. Faruque Miah ¹, Md. Ashrafuzzaman ¹ and Shamsul Haque Prodhan ^{1,*}

¹ Department of Genetic Engineering and Biotechnology, Shahjalal University of Science and Technology, Sylhet 3114, Bangladesh; nayeemsust15@gmail.com (M.N.H.); faruque-btc@sust.edu (M.F.M.); azamanbt@gmail.com (M.A.)

² Pathfinder Research & Consultancy Center, Sylhet 3100, Bangladesh; sazzad@pathfinderconsultant.com (S.A.S.); shishir@pathfinderconsultant.com (M.S.B.)

³ Faculty of Biotechnology and Genetic Engineering, Sylhet Agricultural University, Sylhet 3100, Bangladesh

* Correspondence: atiksunny@yahoo.com (A.R.S.); shamsulhp@gmail.com (S.H.P.)

Abstract: Background: Bangladesh's wetlands support fish genetic resources, biodiversity, and food security but face obstacles like habitat degradation, overfishing, and climate change. This research looks at the diversity, abundance, IUCN conservation status, and stakeholder views for sustainable wetland management in three major wetlands: the Sundarbans mangrove (brackish water), the Sylhet floodplain (freshwater), and the Meghna River basin (estuary). Methods: To assess ecosystem health and vulnerability, we assess fish biodiversity and conservation status using Margalef's Species Richness Index and Shannon–Weaver Diversity Index. We also used structured questionnaires to interview and gain stakeholders' perceptions. Results: A total of 165 fish species were identified and categorized based on the IUCN Red List. The Sundarbans exhibited the highest species richness and diversity. The proportion of vulnerable species was highest in Sylhet (15%), followed by the Sundarbans (12%) and Meghna (9%), while 54% of fish species in Sylhet, 36% in the Sundarbans, and 26% in Meghna were not threatened. This study emphasizes integrated wetland management solutions that support SDGs 2 (Zero Hunger), 14 (Life Below Water), and 15 (Life on Land) as outlined by the Food and Agriculture Organization (FAO). Conclusion: Findings provide a foundation for policymakers, researchers, and conservationists to develop sustainable wetland management frameworks that safeguard fish genetic resources, livelihoods, and ecological balance.

Keywords: fish genetic resources; wetland biodiversity; sustainable fisheries; conservation strategies; SDGs; Bangladesh



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1. Introduction

Bangladesh, distinguished by its extensive network of rivers, marshes, and estuaries, contains one of the most diverse collections of fish genetic resources in South Asia [1,2]. These aquatic ecosystems support both commercial and subsistence fishing, which is essential for food security, economic development, and ecological balance [3,4]. The fishing industry significantly contributes to the national GDP and provides employment to millions, particularly in rural areas. Habitat degradation, overexploitation, pollution, and climate change jeopardize the viability of fish genetic resources [5–8]. These factors have led to a decline in fish species, disrupting the natural balance and threatening the livelihoods of local

fishing communities [6,7]. Fish genetic resources hold significance beyond their economic value; they are crucial for maintaining biodiversity and ecological processes [9–11]. Wetlands serve as breeding and nursery sites for many economically important fish species, promoting nutrient cycling, water filtering, and carbon sequestration [12,13]. Protecting and managing these resources in a way that does not harm the environment is important for keeping the environment stable over time and meeting national and international obligations to protect biodiversity, such as the Sustainable Development Goals (SDGs) set by the UNFAO [14–18].

Fish genetic resources (FGR) are the genetic material passed down from one generation to the next within and among populations of fish species. They are very important for protecting biodiversity, making ecosystems strong, and making sure that fisheries and aquaculture can continue to exist. The Food and Agriculture Organization (FAO, 2007) says that FGR is any genetic material that is important for food and farming now or in the future. This includes wild fish populations, domesticated species, and the genetic variants of these species. According to this study, fish species are good examples of fish genetic resources (FGR), especially when planning for conservation and long-term use in Bangladesh. Even though genetic variation within species is an important part of fish genetic resources, especially for breeding and adaptability, we only look at species-level genetic data because there is not much of it for all the taxa we looked at, and species identity is so important to modern ecosystem service frameworks. We also acknowledge and incorporate population-level genetic studies, such as those on *Tenualosa ilisha*, *Lates calcarifer*, and *Mugil cephalus*, when available, to strengthen the genetic foundation of our research. This broad view helps with larger projects that are in line with the Convention on Biological Diversity (CBD) and the Sustainable Development Goals (SDGs) [5,19]. It also promotes ecological and conservation goals. Notwithstanding the ecological and economic importance of FGR, investigations into its conservation and management within Bangladesh's wetlands are scarce. The Sundarbans Mangrove, the Sylhet Floodplain, and the Meghna River Basin are the three main wetland ecosystems that this study investigates. It looks at the condition, variety, and conservation priority of fish genetic resources in each of these areas. By looking at biodiversity, stakeholder opinions, and policy suggestions, this study aims to improve evidence-based conservation strategies that safeguard fish genetic resources (FGR) and support long-term ways of making a living. Utilizing molecular genetic techniques is essential for evaluating the population structure, genetic diversity, and adaptive capacity of significant fish species. Genetic variants must be accurately identified using techniques like DNA barcoding, microsatellite markers, and next-generation sequencing (NGS). These are important for managing fisheries and planning for their protection. For species like Hilsa (*Tenualosa ilisha*), Rohu (*Labeo rohita*), and Sankehead murrel (*Channa striata*) that are important for business and the environment, genetic tests are needed to assess population connectivity and identify signals of historical genetic bottlenecks, as well as potential risks arising from habitat loss or overexploitation [20]. Progress in genomic databases, conservation genomics, and cryopreservation of fish gametes is becoming essential for preserving fish genetic resources. The FAO's Global Plan of Action for Aquatic Genetic Resources (2019) emphasizes the imperative of incorporating molecular methodologies with conservation strategies to guarantee the enduring sustainability of aquatic genetic diversity [19]. This work seeks to integrate genetic findings to inform conservation strategies specific to the various wetland habitats of Bangladesh.

Even though fish genetic resources are important for both the environment and the economy, there is still not enough research on where they live, how they are protected, and how they are managed in different wetland areas of Bangladesh [19–21]. Contemporary research mostly focuses on species identification and biodiversity assessments, although

it lacks a comprehensive comparison of fish genetic resources across different ecosystems [22–25]. Little research has been conducted on the differences in species diversity between wetland habitats like freshwater floodplains, mangrove forests, and estuary rivers, as well as on their population numbers and the protection needs of these habitats [26–29]. Rectifying this deficiency is crucial for formulating successful conservation policies tailored to the unique challenges faced by each ecosystem [30,31].

The study is important because it compares and evaluates fish genetic resources in Bangladesh's three main wetland ecosystems: the Sylhet floodplain, the Sundarbans mangrove, and the Meghna River basin. These habitats represent distinct natural conditions and support varied fish populations, each facing specific conservation issues. The Sylhet floodplain, a dynamic freshwater ecosystem, has seasonal fluctuations that impact fish populations. The Sundarbans mangrove, a UNESCO World Heritage Site, supports a mix of freshwater and brackish water species but faces threats from salt intrusion and habitat degradation. The Meghna River basin, an estuarine environment, functions as a crucial fisheries hub but is increasingly affected by overfishing, pollution, and riverbank erosion. By comparing these habitats, we can learn more about the conservation priorities and management strategies that are needed to protect Bangladesh's fish genetic resources. This study examines and compares fish genetic resources in three different wetland areas by using biodiversity indices and IUCN Red List evaluations to observe species richness, abundance, and conservation status. This study seeks to emphasize the significance of fish genetics in wetland ecosystems. It links the necessity of safeguarding these species with objectives for food security, biodiversity conservation, and sustainable fisheries management. The results will make it easier to develop good conservation policies that deal with problems that are unique to each ecosystem and test the viability of a single national wetland management strategy.

2. Materials and Methods

In this study, we consider fish species as a fundamental component of fish genetic resources (FGR), aligning with the Food and Agriculture Organization of the United Nations (FAO) definition, which describes FGR as “genetic material of actual or potential value for food and agriculture, including wild populations, farmed species, and their genetic variations” (FAO, 2007). Given that species diversity plays a crucial role in maintaining genetic variability within populations, we used species occurrence and distribution as proxies for assessing the availability and status of FGR within the studied wetland ecosystems. This approach allowed us to evaluate biodiversity trends and conservation priorities without conducting new genetic assessments, instead drawing on available published genetic data where relevant.

2.1. Study Area and Data Collection

We conducted the study in three major wetland ecosystems in Bangladesh, which boast diverse aquatic habitats that sustain substantial fish genetic resources. To provide a comprehensive understanding, we selected diverse research locations within these ecosystems, including both brackish and freshwater environments.

Researchers looked into the Sundarbans Mangrove ecosystem (Figure 1A), which is known for its diverse species and complex estuarine system. They used the Kamarkhola and Koilashgonj research sites in Khulna, the Chila and Joymonigul sites in Bagerhat, and the Gabura and Burigoalini sites in Satkhira. These locations serve as a transitional zone between brackish and freshwater ecosystems. These locations are especially vulnerable to climate-induced changes, including increased salinity and cyclonic storm surges, which impact local fisheries and aquatic biodiversity. The Meghna River Basin (Figure 1B) is a

crucial estuary and freshwater environment supporting commercially vital fish species, including the study sites of Tarpor Chandi and Borostation in the Chandpur district. This area is characterized by significant fishing pressure, habitat deterioration, and pollution from industrial and agricultural discharges. The Sylhet Floodplain (Figure 1C), a dynamic freshwater wetland system, was represented by the research sites of Fenchuganj Bazar and Lamakazi Bazar in Sylhet district, alongside Uttor Sreepur in Sunamganj district. These three ecosystems are shown in their respective geographic context in Figure 1 (Panel D). These locations experience seasonal hydrological fluctuations and habitat fragmentation, impacting fish diversity and abundance.

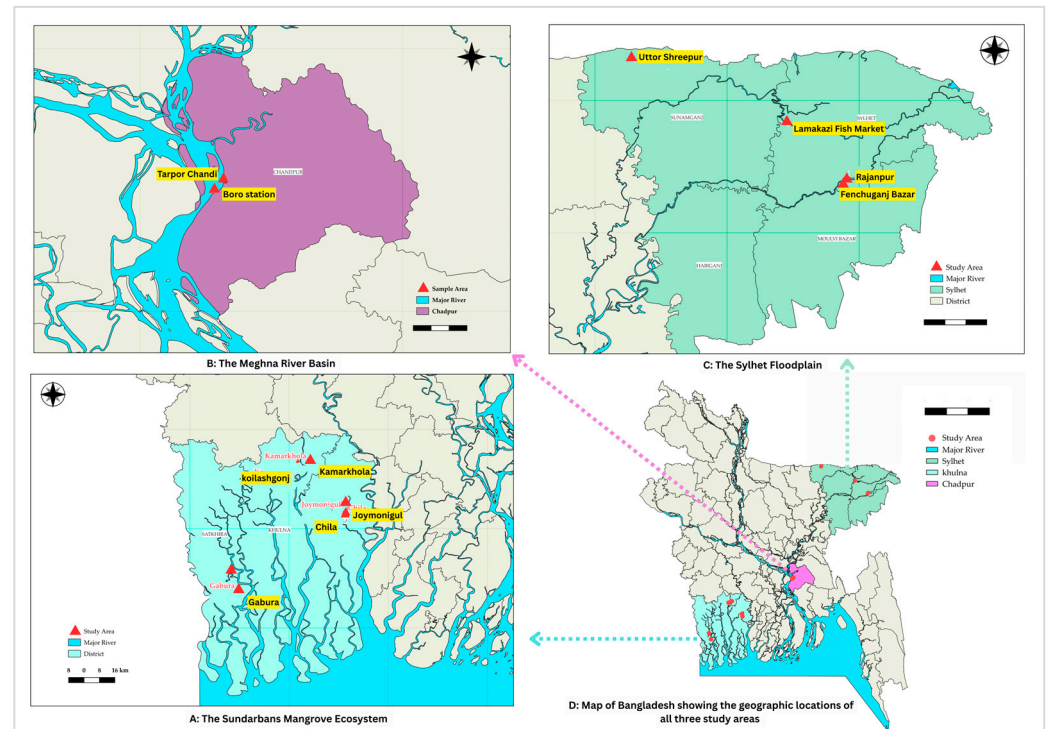


Figure 1. Locations of the study areas in Bangladesh: (A) Sundarbans Mangrove ecosystem (Khulna, Bagerhat, and Satkhira); (B) Meghna River Basin (Chandpur); (C) Sylhet Floodplain (Sylhet and Sunamganj); (D) Map of Bangladesh showing the geographic locations of all three study areas. The figure illustrates brackish, estuarine, and freshwater zones, with site-specific labels aligned with habitat type and ecosystem vulnerability discussed in the manuscript.

The data collection employed both quantitative and qualitative methodologies to deliver a thorough evaluation of fish genetic resources. Primary data were obtained through field surveys, interviews with key stakeholders, and structured questionnaires, while secondary data were derived from relevant literature, publications from the fisheries department, and the IUCN Red List. This comprehensive approach facilitated an in-depth analysis of fish diversity, conservation challenges, and the socio-economic factors influencing the sustainability of wetland fisheries.

2.2. Sampling and Fish Diversity Assessment

In accordance with the FAO paradigm, species-level data served as proxies to represent Fish Genetic Resources (FGR) within the examined ecosystems. Field surveys were conducted between January 2023 and June 2024, covering different seasons to account for variations in fish diversity. We collected fish species from relevant sites within the three wetlands using different fishing equipment, including cast nets (10–25 mm), gill nets (30–55 mm), seine nets (50 mm to 100 mm), and traps. Samples were gathered,

photographed, and identified utilizing standard identification guidelines, and they were subsequently verified by specialists to ensure accurate species identification. Additionally, secondary data sources, including records from the Bangladesh Department of Fisheries and the IUCN Red List of Threatened Species, were consulted to supplement species records and conservation status assessments.

2.3. Questionnaire and Interview Surveys

This study consolidates data from various stakeholders to offer a comprehensive understanding of the socio-ecological factors influencing the conservation of fish genetic resources in diverse wetland ecosystems. A systematic questionnaire was created to evaluate local stakeholders' views on fish biodiversity trends, conservation issues, and management approaches. We conducted formal interviews with 150 people and 30 FGDs (focus group discussions), each with 7–10 members. The participants' selection strategy included a purposeful sample method to guarantee the participation of essential stakeholders with varied viewpoints on wetland protection and fisheries management. The stakeholders involved local fishers (100), fish sellers (30), community leaders (10), and government fisheries officials (10) to obtain comprehensive insights into their experiences and knowledge. This process facilitated a thorough comprehension of the socio-ecological aspects affecting fish genetic resource management in the three wetland environments.

The questionnaires sought to evaluate respondents' perceptions of fish biodiversity trends over the past decade, the availability of different species, and the challenges faced in sustaining their fishing endeavors. We also inquired about the participants' awareness of conservation policies and traditional ecological knowledge pertinent to fishery resource management. Interviews were conducted at fishing locations, landing sites, and local markets to obtain direct insights into the changing patterns of fish diversity and abundance. Fishers were encouraged to reveal their experiences regarding declining fish populations, changes in fishing pressure, and the impacts of climate variability on their livelihoods. Attention was directed to documenting the coping strategies employed by fishermen in response to declining resources and habitat degradation.

In addition to individual interviews, focus group discussions (FGDs) were held with community leaders, fishery officers, and conservation practitioners. These discussions facilitated the verification of data gathered from individual fishermen and examined general perspectives on fish populations, traditional management practices, and the efficacy of current conservation initiatives. The FGDs served as a platform to identify potential strategies for improving the management of fish genetic resources in the studied wetlands. We interviewed key informants, including government fisheries officials, researchers, and local non-governmental organizations (NGOs) engaged in conservation efforts. The interviews provided additional insights into challenges in policy implementation, shortcomings in current management systems, and recommendations for sustainable fisheries management.

2.4. Data Analysis

Quantitative data from species sampling were analyzed using several biodiversity indicators and conservation assessment frameworks. We employed Margalef's Species Richness Index (d) to quantify the diversity of fish species within each environment. It accomplishes this by contrasting the quantity of species with the overall count of fish. To determine ecological stability and biodiversity health, we employed the Shannon–Weaver Diversity Index (H') to assess species diversity and evenness, which includes species abundance and distribution [18].

Margalef species richness (d):

$$d = (S - 1) / \log(N)$$

where S = Total species;

N = Total individuals.

Shannon–Weaver diversity index (H'):

$$H' = -\sum (P_i \times \ln P_i)$$

where H' = Shannon–Wiener index;

$P_i = n_i/N$;

n_i = No. of individuals of a species;

N = Total number of individuals.

We conducted an IUCN Conservation Status Analysis to determine the proportion of species categorized as threatened, endangered, or critically endangered. This method enabled the determination of conservation priorities by evaluating endangered species within each wetland environment. Qualitative analysis was used to organize the answers to qualitative data from interviews and focus groups into main topics, such as conservation issues, how people see changes in biodiversity, and suggested management strategies. This strategy enabled the triangulation of field data with stakeholder perspectives, ensuring a full and comprehensive analysis.

3. Results

3.1. Species Richness and Diversity Across Ecosystems

The study compared the number of species in the three wetland areas and showed that fish genetic resources were very different. We identified a total of 165 species and categorized them according to various conservation statuses (Table 1). According to the IUCN Red List, 80 species were designated as Least Concern, 51 as Not Threatened, 15 as Vulnerable, 12 as Endangered, and 8 as Critically Endangered. These findings highlight the varied degrees of conservation urgency among various fish species in the marshes of Bangladesh.

The percentage of vulnerable species differed among environments, with 15% in Sylhet, 12% in the Sundarbans, and 9% in the Meghna River Basin, reflecting varying conservation priorities. Even with these worries, 54% of species in Sylhet, 36% in the Sundarbans, and 26% in the Meghna River Basin were listed as Not Threatened. The study also showed that there are differences in how resilient fish communities are in different ecosystems. Key informants mentioned that the Sundarbans is more resilient than other ecosystems because it has a lot of different species and a lot of different habitats that fish can use when the environment is bad. On the other hand, the Meghna River Basin and the Sylhet Floodplain were less resilient. This was shown by the fact that more threatened species lived there, and populations of commercially important taxa were going down. These ecosystems are more susceptible to external stresses, including habitat loss, overfishing, and pollution, which intensify species reductions and destabilize community structures.

A taxonomic study showed that 31% of the species belonged to the order Perciformes, 26% to order Cypriniformes, 21% to the order Siluriformes, 10% to the order Clupeiformes, 3% to order Channiformes, and 2% to the order Tetraodontiformes. The last 1% included species from a lot of different orders, such as Osteoglossiformes, Anguilliformes, Cyprinodontiformes, Carcharhiniformes, Myliobatiformes, Aulopiformes, Pleuronectiformes, and Synbranchiformes. This shows that the wetlands that were studied had much different taxonomic diversity.

Table 1. Species list and IUCN conservation status across study sites. This table represents the documented ichthyofauna across three wetland ecosystems. While fish species are considered proxies for fish genetic resources (FGR) in this study, the table itself is constructed from species occurrence and conservation data rather than direct genetic analyses. Column 2 lists the genus and species of each fish recorded, and Column 4 represents species diversities across ecosystems, where SYL = Sylhet Basin, MR = Meghna River Basin, and MN = Sundarbans Mangrove. The IUCN conservation status categories are as follows: LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered [23].

Order	Genus and Species	Vernacular or Local Bengali Name	Distribution			IUCN Status in BD	IUCN Global Status
			SYL	MR	MN		
Anguilliformes	<i>Anguilla bengalensis</i>	Bamos	✓		✓	VU	NT
	<i>Salmostoma phulo</i>	Fulchela	✓		✓	NT	LC
	<i>Salmostoma acinaces</i>	Chela		✓		LC	LC
	<i>Megarasbora elanga</i>	Along		✓		LC	EN
	<i>Devario devario</i>	Banspata		✓		LC	LC
	<i>Chela cachius</i>	Chep chela		✓		LC	VU
	<i>Puntius phutunio</i>	Phutani puti		✓		LC	LC
	<i>Esomus danrica</i>	Darkina	✓	✓	✓	EN	LC
	<i>Rasbora rasbora</i>	Darkina	✓		✓	EN	LC
	<i>Chela labuca</i>	Labuca	✓			VU	NE
	<i>Psilorhynchus sucatio</i>	Titari	✓		✓	NT	LC
	<i>Bengala elanga</i>	Sephatia	✓		✓	NT	NE
	<i>Barilius bendelisis</i>	Joia	✓	✓	✓	EN	LC
	<i>Danio rerio</i>	Anju	✓			NT	LC
Cypriniformes	<i>Osteobrama cotio</i>	Dhela	✓		✓	EN	LC
	<i>Systomus sarana</i>	Sarpunti	✓	✓		CR	LC
	<i>Puntius chola</i>	Chalapunti	✓		✓	NT	LC
	<i>Pethia guganio</i>	Molapunti	✓			NT	LC
	<i>Puntius conchoniuis</i>	Kanchanpunti	✓		✓	NT	LC
	<i>Puntius ticto</i>	Tit punti	✓	✓	✓	VU	LC
	<i>Puntius sophore</i>	Jatpunti	✓		✓	NT	LC
	<i>Puntius terio</i>	Teri punti	✓	✓		NT	LC

Table 1. Cont.

Order	Genus and Species	Vernacular or Local Bengali Name	Distribution			IUCN Status in BD	IUCN Global Status
			SYL	MR	MN		
Cypriniformes	<i>Oreochthys cosuatis</i>	Kosuati	✓		✓	NT	LC
	<i>Garra gotyla</i>	Gharpoia	✓		✓	NT	LC
	<i>Acanthocobitis zonalternans</i>	Bilturi	✓			NT	LC
	<i>Schistura corica</i>	Koikra	✓			NT	LC
	<i>Schistura scaturigina</i>	Dari	✓			NT	LC
	<i>Schistura beavani</i>	Shavonkhokra	✓			NT	LC
	<i>Somileptes gongota</i>	Poia	✓		✓	NT	LC
	<i>Botia dario</i>	Rani	✓			EN	LC
	<i>Lepidocephalus guntea</i>	Gutum	✓		✓	NT	LC
	<i>Labeo rohita</i>	Rui	✓	✓	✓	NT	LC
	<i>Catla catla</i>	Catla	✓	✓	✓	NT	LC
	<i>Cirrhinus cirrhosus</i>	Mrigal	✓	✓	✓	NT	VU
	<i>Labeo calbasu</i>	Kala Baush	✓	✓	✓	EN	LC
	<i>Labeo bata</i>	Bata	✓	✓	✓	EN	LC
	<i>Chagunius chagunio</i>	Jarua	✓		✓	NT	LC
	<i>Labeo angra</i>	Angrot/kharas	✓		✓	NT	LC
	<i>Labeo gonius</i>	Ghainna	✓	✓	✓	EN	LC
	<i>Labeo nandina</i>	Nandina	✓		✓	CR	NT
	<i>Labeo pangusia</i>	Ghoramach	✓			CR	NT
	<i>Cirrhinus reba</i>	Bhagna	✓	✓		VU	LC
	<i>Amblypharyngodon mola</i>	Mola	✓	✓	✓	NT	LC
	<i>Danio devario</i>	Debari	✓		✓	NT	NE
	<i>Raiamas bola</i>	Bhol	✓		✓	EN	LC
Siluriformes	<i>Eutropiichthys vacha</i>	Bacha, Bhacha	✓		✓	CR	LC
	<i>Ompok bimaculatus</i>	Kani Pabda		✓		NT	EN

Table 1. Cont.

Order	Genus and Species	Vernacular or Local Bengali Name	Distribution			IUCN Status in BD	IUCN Global Status
			SYL	MR	MN		
Siluriformes	<i>Ompok pabda</i>	Pabda	✓	✓	✓	NT	EN
	<i>Plotosus canius</i>	Gang magur			✓	LC	LC
	<i>Clarias batrachus</i>	Magur	✓	✓	✓	NT	LC
	<i>Bagarius bagarius</i>	Baghair	✓	✓	✓	NT	CE
	<i>Bagarius yarrelli</i>	Baghair		✓		NT	EN
	<i>Wallago attu</i>	Boal	✓	✓	✓	NT	NT
	<i>Heteropneustes fossilis</i>	Shing	✓	✓	✓	NT	LC
	<i>Pangasius pangasius</i>	Pangus	✓	✓	✓	CR	LC
	<i>Ailia coila</i>	Kajuli	✓	✓	✓	NT	NT
	<i>Rita rita</i>	Rita	✓	✓	✓	CR	LC
	<i>Sperata aor</i>	Ayre	✓	✓	✓	VU	LC
	<i>Sperata seenghala</i>	Guizza aor		✓		LC	VU
	<i>Mystus vittatus</i>	Tengra	✓	✓	✓	LC	LC
	<i>Mystus cavasius</i>	GolshaTengra	✓	✓	✓	VU	LC
	<i>Mystus bleekeri</i>	Tengra	✓	✓	✓	NT	LC
	<i>Mystus tengara</i>	BazariTengra	✓	✓	✓	NT	NE
	<i>Gogangra laevis</i>	Gang tengra		✓		LC	LC
	<i>Gogangra viridescens</i>	Gang tengra		✓		LC	LC
	<i>Gagata youssoufi</i>	Gang tengra		✓		NT	NE
	<i>Gagata cenia</i>	Gang tengra		✓		LC	LC
	<i>Nangra ornata</i>	Gang tengra		✓		LC	LC
	<i>Nangra nangra</i>	Gang tengra		✓		LC	LC
	<i>Clupisoma garua</i>	Garua	✓	✓	✓	CR	LC
	<i>Osteogeneiosus militaris</i>	Apuia		✓		LC	NE

Table 1. Cont.

Order	Genus and Species	Vernacular or Local Bengali Name	Distribution			IUCN Status in BD	IUCN Global Status
			SYL	MR	MN		
Siluriformes	<i>Batrachocephalus mino</i>	Katabukha		✓		LC	NE
	<i>Arius arius</i>	Kata mach			✓	LC	LC
	<i>Arius gagora</i>	Gagla		✓		LC	NE
	<i>Silonia silondia</i>	Shilong		✓		LC	LC
	<i>Gagata gagata</i>	Ghora kata		✓		LC	LC
	<i>Neotropius atherinoides</i>	Batasi		✓		LC	LC
	<i>Eutropiichthys murius</i>	Muribacha		✓		LC	LC
	<i>Hemibagrus menoda</i>	Ghagla		✓		LC	NT
	<i>Hara jerdoni</i>	Kutakanti		✓		LC	LC
Tetraodontiformes	<i>Tetraodon cutcutia</i>	Potka	✓			NT	LC
	<i>Lagocephalus lunaris</i>	Potka			✓	LC	LC
	<i>Arothron immaculatus</i>	Pufferfish		✓		LC	LC
Beloniformes	<i>Xenentodon cancila</i>	Kakila	✓		✓	NT	LC
	<i>Hyporhamphus limbatus</i>	Ekthota	✓		✓	NT	LC
Cyprinodontiformes	<i>Aplocheilus panchax</i>	Kanpona	✓	✓	✓	NT	LC
Channiformes	<i>Channa striatus</i>	Shol	✓	✓	✓	NT	NE
	<i>Channa marulius</i>	Gajar	✓	✓	✓	EN	LC
	<i>Channa barca</i>	Piplashol	✓		✓	CR	DD
	<i>Channa punctatus</i>	Taki	✓	✓	✓	EN	NE
	<i>Channa orientalis</i>	Raga/Cheng	✓	✓	✓	VU	NE
Osteoglossiformes	<i>Chitala chitala</i>	Chital	✓	✓	✓	EN	NT
	<i>Notopterus notopterus</i>	Foli	✓	✓	✓	VU	LC
Clupiformes	<i>Corica soborna</i>	Kachki	✓	✓	✓	NT	LC
	<i>Tenuulosa ilisha</i>	Ilish	✓	✓	✓	NT	LC

Table 1. Cont.

Order	Genus and Species	Vernacular or Local Bengali Name	Distribution			IUCN Status in BD	IUCN Global Status
			SYL	MR	MN		
Clupiformes	<i>Hilsa kelee</i>	Gurta ilish			✓	LC	LC
	<i>Tenualosa toli</i>	Chandana ilish			✓	LC	LC
	<i>Gudusia chapra</i>	Chapila	✓	✓	✓	NT	LC
	<i>Anodontostoma chacunda</i>	Chakunda			✓	LC	LC
	<i>Stolephorus tri</i>	Kata phasa			✓	LC	LC
	<i>Thryssa purava</i>	Pati faisya			✓	LC	LC
	<i>Thryssa hamiltoni</i>	Ram fesha			✓	LC	LC
	<i>Chirocentrus dorab</i>	Korati chela			✓	LC	LC
	<i>Opisthopterus tardoore</i>	Faisya			✓	LC	LC
	<i>Goniolosa manmina</i>	Gonichapila		✓		LC	LC
	<i>Coilia dussumieri</i>	Olua		✓		LC	LC
	<i>Coilia ramcarati</i>	Meghaolua		✓		LC	LC
	<i>Setipinna phasa</i>	Phasa		✓		LC	LC
	<i>Setipinna taty</i>	Teliphasa		✓	✓	LC	LC
Perciformes	<i>Macrognaathus aculeatus</i>	Tara baim	✓		✓	VU	NE
	<i>Mastacembelus armatus</i>	Baim	✓			EN	LC
	<i>Mastacembelus pancalus</i>	Guchibaim	✓		✓	VU	NE
	<i>Colisa fasciata</i>	Khalisha	✓	✓	✓	NT	NE
	<i>Colisa lalia</i>	Lal kholisha	✓		✓	NT	NE
	<i>Anabas testudineus</i>	Koi	✓	✓	✓	NT	DD
	<i>Chanda nama</i>	Nama Chanda	✓	✓	✓	VU	LC
	<i>Parambassis lala</i>	Lal Chanda	✓		✓	VU	NT
	<i>Parambassis ranga</i>	Ranga chanda	✓	✓	✓	VU	LC
	<i>Chanda beculis</i>	Chanda	✓	✓	✓	NT	NE

Table 1. Cont.

Order	Genus and Species	Vernacular or Local Bengali Name	Distribution			IUCN Status in BD	IUCN Global Status
			SYL	MR	MN		
Perciformes	<i>Glossogobius giuris</i>	Bele	✓	✓	✓	NT	LC
	<i>Polynemous paradiseus</i>	Tapasi		✓	✓	LC	LC
	<i>Eleutheronema tetradactylum</i>	Tailla		✓		LC	NE
	<i>Pseudapocryptes elongatus</i>	Chewa		✓		LC	LC
	<i>Apocryptes bato</i>	Chering		✓		LC	LC
	<i>Parapocryptes batoides</i>	Dali chewa		✓		LC	LC
	<i>Periophthalmus koelreuteri</i>	Dahuk		✓		LC	LC
	<i>Eugnathogobius oligactis</i>	Tiger goby		✓		LC	VU
	<i>Awaous guamensis</i>	Baila		✓		LC	LC
	<i>Awaous grammepomus</i>	Nuna Baila		✓		LC	LC
	<i>Brachygobius nunus</i>	Belia		✓		LC	VU
	<i>Gobiopterus chuno</i>	Chuna Bele		✓		LC	LC
	<i>Trypauchen vagina</i>	Shada chewa		✓	✓	LC	LC
	<i>Odontamblyopus rubicundus</i>	Lal chewa		✓	✓	LC	LC
	<i>Badis badis</i>	Napit koi		✓		LC	LC
	<i>Nandus nandus</i>	Meni	✓	✓		LC	NT
	<i>Otolithoides pama</i>	Poa		✓		LC	LC
	<i>Macrospinoso cuja</i>	Kuizza poa		✓		LC	NT
	<i>Johnius coitor</i>	Koitor poa		✓		LC	LC
	<i>Johnius plagiostoma</i>	Kala Poa			✓	LC	LC
	<i>Secutor ruconius</i>	Tek chanda		✓		LC	NE
	<i>Sillaginopsis panijus</i>	Tular dandi		✓		LC	LC
	<i>Terapon jarbua</i>	Barguni			✓	LC	LC
	<i>Scomberoides commersonnianus</i>	Shurma			✓	LC	LC

Table 1. Cont.

Order	Genus and Species	Vernacular or Local Bengali Name	Distribution			IUCN Status in BD	IUCN Global Status
			SYL	MR	MN		
Perciformes	<i>Datnioides polota</i>	Reka			✓	LC	NE
	<i>Leptomelanosoma indicum</i>	Lakkha			✓	LC	LC
	<i>Chelon parsia</i>	Faiysha bata			✓	LC	LC
	<i>Liza parsia</i>	Parsia			✓	LC	LC
	<i>Valamugil cunnesius</i>	Jati bata			✓	LC	LC
	<i>Pampus argenteus</i>	Fali chanda			✓	LC	LC
	<i>Pampus chinensis</i>	Rup chanda			✓	LC	LC
	<i>Lates calcarifer</i>	Koral			✓	LC	LC
	<i>Mugil cephalus</i>	Pata bata			✓	LC	LC
	<i>Planiliza subviridis</i>	Sobuj bata			✓	LC	LC
	<i>Rhinomugil corsula</i>	Khorsola			✓	LC	LC
	<i>Sicamugil cascasia</i>	Kachki bata			✓	LC	LC
	<i>Scatophagus argus</i>	Bistara			✓	LC	LC
	<i>Eupleurogrammus muticus</i>	Boro churi			✓	LC	LC
	<i>Lepturacanthus savala</i>	Choto churi			✓	LC	LC
	<i>Euthynnus affinis</i>	Maitta			✓	LC	LC
	<i>Scomberomorus commerson</i>	Champa maitta			✓	LC	LC
Carcharhiniiformes	<i>Scoliodon laticaudus</i>	Thutti Hangor			✓	NT	NT
Myliobatiformes	<i>Himantura uarnak</i>	shapla pata			✓	VU	VU
	<i>Telatrygon zugei</i>	Tuni shapla pata			✓	VU	VU
Aulopiformes	<i>Harpadon nehereus</i>	Loitta			✓	LC	LC
Pleuronectiforme	<i>Cynoglossus macrostomus</i>	Kukur jeeb		✓		LC	LC
Synbranchiiformes	<i>Monopterusuchia</i>	Kuchia		✓		LC	LC

Species distribution exhibited considerable variation among ecosystems. The Sundarbans Mangrove reported the highest species with 104 species, followed by the Meghna River with 95 species and the Sylhet Floodplain with 81 species. The predominant fish order differed among different locations, indicating their distinct ecological conditions. In the Sylhet Floodplain, 48% of fish species were classified as Perciformes, signifying the preeminence of this order in freshwater ecosystems. In the estuary environment of the Meghna River, 36% of the species were Siluriformes. In the Sundarbans Mangrove ecosystem, on the other hand, 32% of the species were Perciformes, showing a mixed dominance. This difference in the most common orders shows that salinity gradients, hydrodynamics, and plant cover, among other habitat-specific environmental factors, have a big effect on the structure of fish communities.

Biodiversity indexes also corroborated these findings (Table 2). The Margalef's Species Richness Index (d) was greatest in the Sundarbans Mangrove (5.1), succeeded by the Sylhet Floodplain (4.2) and the Meghna River Basin (3.8). The Shannon–Weaver Diversity Index (H') was highest in the Sundarbans (3.4), signifying a generally equitable species distribution, but it was lower in the Sylhet Floodplain (2.8) and the Meghna River (2.6) (Table 2). The data support the view that the Sundarbans have a more complex and perhaps more stable fish community and reflect the condition that the Meghna River and the Sylhet Floodplain experience greater environmental fluctuations, fishing pressure, and habitat degradation, consequently impacting the species diversity of fishes.

Table 2. Species richness and diversity across wetlands.

Wetland Ecosystem	Margalef's Index (d)	Shannon–Weaver Index (H')
Sylhet Floodplain	4.2	2.8
Sundarbans Mangrove	5.1	3.4
Meghna River Basin	3.8	2.6

The existence of endangered and critically endangered species underscores the pressing necessity for conservation strategies specific to each habitat. The Sundarbans, while having the most biodiversity of the three ecosystems, are under serious conservation concerns due to habitat degradation and overexploitation. Key informants in Khulna mentioned that the presence of a large percentage of vulnerable species reflects the increasing pressure from deforestation, climate-induced salt intrusion, and heavy fishing operations. Participants mentioned in FGDs (focus group discussions) that the destruction of mangrove forests, which serve as key breeding and nursery sites for many fish species, has led to population decreases in commercially and ecologically valuable species. Urgent conservation measures, including sustainable fishing laws, mangrove afforestation, and management of protected areas, are essential to minimize these risks and preserve the biodiversity of the Sundarbans.

The Meghna River, a key fishery hub, faces severe challenges due to overfishing, industrial pollution, and habitat fragmentation, leading to a persistent loss of vital fish species. District Fisheries Officer of Chadpur mentioned that unsustainable fishing methods like indiscriminate netting and harvesting juvenile fish have become more common, which has caused the populations of many commercially important species to drop. Moreover, industrial effluent and agricultural runoff have polluted riverine ecosystems, further intensifying the fall of fish populations. Implementing fisheries co-management strategies, stringent pollution control measures and seasonal fishing prohibitions is essential for the restoration of fish populations in the Meghna River.

The Sylhet Floodplain sustains a variety of fish species and demonstrates considerable richness among species. This ecosystem is being jeopardized by seasonal water variability,

agricultural growth, and encroachment on wetland regions. The conventional seasonal flooding patterns that facilitate breeding and spawning cycles for numerous fish species are being disrupted by hydrological alterations and changes in land use. Fishers mention in FGDs (focus group discussions) that agricultural development has resulted in increased pesticide and fertilizer runoff, impacting aquatic biodiversity. Key informants mentioned that the conservation methods for the Sylhet Floodplain must prioritize integrated wetland management, the creation of community-led fish sanctuaries, and sustainable land-use practices to preserve the ecological integrity of the ecosystem.

3.2. Establishing Fish Genetic Resources as a Key to Wetland Ecosystem Services

The critical function of fish genetic resources in preserving wetland ecosystems is increasingly recognized as vital for biodiversity conservation and ecological stability. Insights from stakeholders at the three research locations underscore the substantial impact of environmental changes on fish genetic diversity. In the Sylhet Floodplain, more than 75% of individuals, including fishermen, traders, and community leaders, articulated significant apprehensions over habitat degradation and its detrimental impact on local fish species. It is said that species like spotted snakehead (*Channa punctata*) and tengara catfish (*Mystus tengara*) have become less common because wetlands are being turned into farms, and people are fishing without following the rules.

In the Sundarbans, almost 60% of respondents recognized saline intrusion as a significant factor influencing alterations in species composition. Interviews with fisheries officials showed that species that can survive in salt water, like Asian seabass (*Lates calcarifer*) and grey mullet (*Mugil cephalus*), are becoming more common, while fish that need fresh water are becoming less common. These changes signify an urgent need for adaptive conservation strategies to mitigate the impacts of environmental stressors on fish species.

People from the Meghna River Basin, particularly commercial fishermen, identified industrial pollution and unsustainable fishing techniques as the primary threats to fish species. Seventy percent of fish dealers in this region indicated a substantial decline in the catch volumes of hilsa (*Tenualosa ilisha*), a species of economic significance, attributing this reduction to overfishing and inadequate enforcement of fisheries regulations.

These findings indicate the necessity of including fish genetic conservation in national wetland management plans. The preservation of genetic diversity in fish populations is crucial for maintaining ecological functioning, ensuring food security, and bolstering local economies. A comprehensive conservation strategy that includes ecological, socio-economic, and policy-driven initiatives is essential for preserving long-term ecosystem resilience and sustainable fisheries and assuring species viability, adaptability, and survival amid environmental changes.

3.2.1. Genetic Insights from Population Studies of Key Bangladeshi Fishes

The study mostly looked at fish genetic resources (FGR) at the species level, but it is important to put the results in the context of Bangladesh's ichthyofauna's overall genetic diversity. More and more population genetic research is showing us important things about the structure, connectivity, and vulnerability of native fish populations. This shows how important it is to include genetic factors in conservation plans.

Tenualosa ilisha (Hilsa shad), the most emblematic migratory species of Bangladesh, exhibits considerable genetic heterogeneity among populations from various river systems, as indicated by a microsatellite marker study. The results show that genes do not move around freely and show how important it is to have separate management units that use conservation methods that are right for each location [27].

Lates calcarifer (Barramundi) has shown high levels of intra-population genetic diversity in both brackish and freshwater environments in Bangladesh. This genetic variability reflects its adaptability to diverse habitats and underscores its potential for aquaculture development and conservation planning in regions increasingly affected by salinity shifts due to climate change [32].

Channa striata (Striped snakehead), a freshwater predator, has demonstrated significant genetic divergence across geographically isolated populations in Bangladesh. RAPD marker analysis reveals that habitat fragmentation has played a major role in reducing gene flow, reinforcing the need for site-specific conservation strategies to prevent further genetic erosion [16].

Pangasius pangasius, a commercially important riverine catfish, has been the subject of allozyme-based studies that point to genetic impoverishment in certain river systems. The findings suggest that some populations may be caught in an extinction vortex, wherein genetic, demographic, and environmental pressures reinforce each other, thereby elevating extinction risk [7].

Mugil cephalus (Flathead grey mullet) populations display limited gene flow but also reveal localized genetic vulnerabilities, such as reduced heterozygosity. These features may compromise their long-term adaptability and survival if conservation interventions are not implemented in time [17].

These molecular results show how important it is for Bangladesh's national fisheries genetic resources policy to include population genetics. Molecular methods like microsatellites, RAPD, and allozyme markers give us important information for finding evolutionarily significant units (ESUs), figuring out genetic bottlenecks, and planning for stock enhancement and conservation areas. This paper stresses that protecting fish genetic resources in Bangladesh should include both species-level assessments of biodiversity and genetic evidence, looking at both large-scale ecological patterns and small-scale genetic changes.

3.2.2. Role in Achieving SDGs

The findings of this research emphasize the intricate and vital relationship between fish genetic resources and sustainable development, directly influencing many Sustainable Development Goals (SDGs) in Bangladesh. The nation's extensive wetlands and riverine ecosystems provide essential homes for several fish species, many of which are crucial to ecological stability and food security. Fish serves as the primary source of animal protein for over 60% of the country's population, making its conservation and sustainable management vital for addressing malnutrition and enhancing food security [5]. The preservation and rehabilitation of fish genetic resources directly contribute to SDG 2 (Zero Hunger) by ensuring the sustained availability and stability of fish populations, particularly benefiting vulnerable and marginalized communities that rely heavily on inland and coastal fisheries for sustenance and economic support.

Interviews with stakeholders and field studies have shown substantial concerns over the deterioration of fish populations and associated ecosystems. A significant majority (85%) of fish dealers and fishermen from the Sundarbans and Meghna River Basin expressed apprehensions about the declining fish resources and their detrimental effects on economic stability and local lives. Overexploitation, habitat degradation, and climate-related stresses continue to threaten the sustainability of fisheries, adversely impacting small-scale fishermen and associated companies. These findings underscore the paramount importance of SDG 14 (Life Below Water), which emphasizes the protection and sustainable utilization of marine and freshwater resources. To rapidly halt the decline of fish populations and save animals in wetland regions, it is imperative to effectively manage fisheries, conserve ecosystems, and implement evidence-based policies.

The escalating issues with fish genetics underscore the pressing necessity for robust conservation initiatives to safeguard them, as delineated in SDG 15 (Life on Land) [27]. Field research and biodiversity assessments reveal the alarming destruction of habitats in floodplains, mangrove estuaries, and river wetlands. Human activities like deforestation, land appropriation, and agricultural expansion exacerbate this loss [22]. These harmful actions hurt biodiversity and species viability and change important ecosystem services like the cycling of nitrogen, the availability of breeding grounds, and the natural resilience of fish populations. The gradual deterioration of wetland integrity further undermines the reproductive success of vital fish species, ultimately diminishing total genetic diversity and threatening ecological stability.

An extensive, ecosystem-oriented conservation strategy is essential to adequately address these challenges. Important steps should include restoring natural habitats on a large scale, making it easier to change how land is used in wetlands, and creating scientifically designated protected areas to protect important breeding and nursery habitats. To protect fish genetic resources and the ongoing benefits they bring to biodiversity and human well-being, it is important to make community-driven conservation efforts better through participatory management frameworks and strict policy enforcement. To make sure that conservation efforts are in line with larger national and international sustainability goals, we need a national framework for wetland conservation that includes strategies for sustainable fisheries management and socio-economic development [27]. Collaboration among governmental bodies, local communities, conservation groups, and research institutions is crucial for advancing a holistic approach to wetland protection. By aligning these programs with Sustainable Development Goals (SDG), Bangladesh may enhance its initiatives to safeguard aquatic ecosystems, promote sustainable fishing practices, and bolster the economic resilience of people reliant on fish resources. This holistic and cohesive strategy will ensure the enduring preservation of Bangladesh's wetland ecosystems, fostering a balance between conservation objectives and economic advancement.

3.2.3. Management Strategies: Site-Specific vs. Comprehensive Approach

There is no single way to manage the Sylhet Floodplain, the Sundarbans Mangrove, and the Meghna River Basin, even though they all have their own unique natural features, conservation concerns, and economic importance. To protect fish genetic resources and ensure long-term ecological sustainability, we need a conservation strategy that combines site-specific actions with a national framework for managing wetland areas.

The results derived from stakeholder interviews highlight the need for tailored management methods that address the primary concerns affecting each wetland ecosystem (Table 3). The growth of agriculture and the degradation of wetlands in Sylhet are significant factors contributing to the decline of many plant and animal species. This necessitates community-driven restoration initiatives and stringent regulations around land utilization. The Sundarbans confront issues of increasing salinity in the water and environmental alterations attributable to climate change. This scenario necessitates adaptable aquaculture methods, initiatives for mangrove restoration, and surveillance of salinity levels. The Meghna River Basin faces challenges such as industrial pollution, overfishing, and unregulated resource exploitation. To resolve these concerns, it is imperative to establish regulations for industrial waste, devise sustainable fishing practices, and enhance monitoring systems.

Table 3. Conservation challenges and perceived solutions based on interviews.

Challenge	Sylhet Floodplain (Fishers’ Perspective)	Sundarbans Mangrove (Community Leaders)	Meghna River Basin (Traders and Regulators)
Habitat Destruction	80% told wetland loss due to agriculture	70% reported salinity intrusion altering habitats	65% noted increasing industrial pollution
Overfishing	55% reported about overharvesting	75% mentioned declining juvenile fish due to unregulated fishing	80% observed commercial exploitation as a major threat
Climate Change	40% concerned flooding shifts affecting breeding patterns	85% cited sea-level rise impacts on mangroves	60% found extreme weather to disrupted fish migration
Policy Implementation	30% thought regulations were weak or unenforced	50% agreed with the implementation of fishing bans	45% claimed stricter enforcement of fishing laws

Such findings emphasize that conservation measures must align with the unique biological and socio-economic characteristics of each region. Localized activities, such as community-led wetland restoration, sustainable fishing regulations, and climate adaptation methods, are essential for improving conservation outcomes. Strengthening the resilience of wetland ecosystems will need the enhancement of scientific research, biodiversity monitoring, and stakeholder engagement.

3.2.4. Is a Unified Wetland Management Plan Possible?

Bangladesh’s many wetland environments, such as the Sundarbans, Meghna River Basin, and Sylhet Floodplain, each display distinct ecological traits and conservation issues. The viability of a cohesive wetland management strategy necessitates a comprehensive approach that addresses both localized conservation requirements and broader national policies. Stakeholder interviews disclosed diverse viewpoints on wetland governance that are tailored to each region and address the unique problems each wetland ecosystem faces (Table 4), with 65% of fisheries managers and policymakers endorsing a nationalized framework for wetland conservation, whereas 35% of local fishers and community leaders expressed apprehensions regarding centralized regulations inadequately addressing site-specific ecological dynamics. The Sundarbans, designated a UNESCO World Heritage Site, have organized administration, while the Meghna River Basin and Sylhet Floodplain are susceptible to disjointed governance. Notwithstanding these disparities, expert analyses indicate that essential elements of a cohesive wetland policy can be standardized, including enhanced environmental monitoring to evaluate ecosystem health; community-oriented conservation initiatives adapted to local socio-economic contexts; and legal frameworks to govern habitat degradation, overfishing, and pollution. Conservation efforts in all three ecosystems can be improved by using a hybrid governance strategy that balances the needs of each ecosystem with the needs of the whole country.

Table 4. Conservation challenges across wetlands.

Challenge	Sylhet Floodplain	Sundarbans Mangrove	Meghna River Basin
Habitat Destruction	High (Agricultural expansion)	Medium (Salinity intrusion)	Medium (Erosion, pollution)
Overfishing	Medium	High	High
Climate Change	Low	High (Sea-level rise)	Medium (Flooding)
Policy Implementation	Weak	Moderate	Weak

Furthermore, stakeholder interviews revealed an urgent requirement for sustainable aquaculture laws and competent fisheries management across all three habitats. The respondents said that awareness campaigns, capacity-building initiatives, and incentives for ecologically friendly behaviors would greatly enhance compliance with conservation measures. Integrating these activities into a multi-stakeholder governance framework would bolster the ecological and socio-economic resilience of Bangladesh's wetlands.

The study stresses how important it is to have a unified framework for managing wetlands that makes sure that local conservation efforts are in line with national policy oversight. This mixed conservation model, which combines local solutions with national policy implementation, will fully address the complicated problems of biodiversity loss and wetland degradation. During a key informant interview, two professors from Sylhet Agricultural University suggested that Bangladesh can effectively protect its wetland ecosystems and preserve its fish genetic resources for future generations by fostering collaborative governance, strengthening regulatory frameworks, and supporting community-led conservation initiatives. Through the implementation of adaptable management strategies and evidence-based policies, the nation can safeguard its biodiversity, preserve ecological equilibrium, and bolster its economy amidst escalating environmental concerns.

4. Discussion

This study provides an overview of the different kinds of fish that live in three ecologically different wetland areas in Bangladesh. These fish are important parts of the country's fish genetic resources (FGR). We demonstrate a complete picture of the threats to wetland biodiversity and how they might affect future conservation efforts by combining data on where species occur with socio-ecological views from stakeholders. The results underscore that species-level diversity indicates fundamental ecological stresses and management deficiencies and provide a foundation for broadening FGR evaluations to include population-level genetic monitoring. These insights illustrate existing biodiversity trends and highlight the pressing necessity for adaptive conservation policies that address biological vulnerabilities, habitat degradation, and socio-economic factors influencing resource utilization.

4.1. Contribution to Sustainable Development Goals (SDGs)

The findings of this study emphasize the essential role that fish genetic resources play in achieving key Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 14 (Life Below Water), and SDG 15 (Life on Land) [33–37]. Fish constitutes the principal source of animal protein for more than 60% of the Bangladeshi populace, hence directly associating its protection with food security [27,38–41]. Safeguarding fish biodiversity guarantees the integrity of this food chain, particularly for rural and at-risk communities. Stakeholders from the Sundarbans and Meghna regions voiced apprehension regarding the diminishing fish populations and the economic ramifications of biodiversity decline [42]. Overfishing, habitat degradation, and climate-related stressors jeopardize the viability of fisheries and the resilience of local populations. Tackling these difficulties directly corresponds with the objectives of SDG 14, highlighting the sustainable utilization and preservation of aquatic habitats [43,44]. Likewise, problems such as deforestation, land use conversion, and pollution undermine the ecological integrity of wetland ecosystems, which are essential to SDG 15 [44]. These pressures compromise breeding habitats and diminish genetic diversity, undermining ecosystem services and the long-term sustainability of species. Attaining these objectives necessitates synchronized conservation initiatives, community involvement, and robust governance. This study advocates a multi-stakeholder approach that incorporates ecological knowledge, local stewardship, and adaptive man-

agement to guarantee the long-term viability of wetland ecosystems and their genetic resources [22].

4.2. Conservation Challenges and the Need for Adaptive Strategies

Wetland conservation in Bangladesh necessitates adaptive frameworks capable of addressing ecological variability and socio-economic conditions in all river basins. Stakeholder interviews indicated a demand for real-time ecological data, participatory governance, and tailored conservation measures [40,44]. Nationwide implementation of tools such as biodiversity monitoring, ecosystem modeling, and climate-resilient aquaculture methods is essential. In places where fish populations are being overused and habitats are damaged, working together on flexible management solutions can help use fish genetic resources (FGR) in a sustainable way [45]. Integrated approaches, as evidenced in various global river systems, bolster long-term ecological resilience and safeguard biodiversity.

4.2.1. Sylhet Floodplain: Agricultural Encroachment and Hydrological Fluctuations

Field studies and interviews with stakeholders showed that the Sylhet Floodplain is a habitat that is very likely to get worse because of changes in water management and the growth of agriculture [40–42]. The conversion of wetlands for rice cultivation and infrastructural development has resulted in significant ecological alterations, affecting aquatic biodiversity [43–45]. Seasonal hydrological fluctuations exacerbate the stresses imposed upon fish populations, impacting reproductive cycles and sustainability [46]. Local fishers emphasized the significance of community-oriented conservation initiatives [47]. These encompass the establishment of fish sanctuaries, the restoration of wetlands, and the use of sustainable fishing techniques to mitigate the adverse impacts of environmental changes [31–33]. Implementing seasonal fishing prohibitions in breeding zones and enhancing water resource management helps safeguard ecosystems and maintain the long-term health of fish populations. Community-driven fishing initiatives in the Mekong Delta have effectively rehabilitated degraded wetlands. This implies that such strategies may also be effective in Sylhet [48].

4.2.2. Sundarbans Mangrove: Salinity Intrusion and Climate Change Pressures

The Sundarbans, a UNESCO-designated mangrove environment, faces increasing challenges from saltwater intrusion, habitat fragmentation, and exploitation. More than 70% of respondents, comprising fishermen and conservation officers, emphasized the necessity for stricter fishing regulations and improved strategies to address increasing sea levels and shifts in fish species [20,22]. The transition from freshwater fish to saltwater species, such as *Lates calcarifer* and *Mugil cephalus*, illustrates the environmental alterations induced by climate change [20]. To help with these problems, conservation efforts should focus on planting more trees, making aquaculture more resistant to salt water, and improving monitoring systems for long-term fisheries management. Furthermore, including local expertise in conservation planning may improve resilience strategies and foster community engagement in wetland preservation efforts. Restoring mangroves in the Amazon Basin has shown that planting trees strategically and getting local people involved can make fish habitats much better and increase biodiversity [49]. We may adopt similar tactics for the Sundarbans to alleviate habitat degradation and enhance fisheries resilience.

4.2.3. Meghna River Basin: Industrial Pollution and Overfishing

The Meghna River Basin, a crucial hub for commercial fishing, is undergoing a rapid reduction in biodiversity due to industrial pollution, improper fishing practices, and inadequate implementation of fisheries management standards. Interviews with stakeholders revealed that more than 80% of dealers and fishers had observed a decline in significant

fish species, particularly Hilsa [27]. This reduction is attributable to unchecked overfishing and habitat degradation. Furthermore, industrial effluent and agricultural runoff have intensified the deterioration of water quality, thereby jeopardizing fish genetic diversity.

To address these problems, policymakers need to make sure that environmental laws are strictly followed, that sustainable fishing gear is used, and that community-based fisheries governance frameworks are built. Enhancing pollution regulation, promoting alternative employment for fishers, and adopting sustainable aquaculture practices might mitigate human environmental effects [24]. These discoveries highlight the necessity for adaptive conservation frameworks customized to ecological and socio-economic contexts.

4.3. Integrating Local Knowledge and Community-Based Co-Management in Conservation

Stakeholder-derived traditional ecological knowledge (TEK) is essential for developing effective conservation strategies. Throughout all three wetlands, local fishers and community members offered comprehensive insights regarding fish migration, breeding seasons, and habitat-specific behaviors [18,28]. These findings, grounded in millennia of practice, are essential for adaptive, ecosystem-specific management. Notwithstanding its significance, TEK frequently remains inadequately employed within formal policy frameworks. Integrating traditional ecological knowledge into conservation governance can enhance ecological resilience and foster community ownership [22]. In the Sundarbans, fishers modify harvesting schedules according to moon cycles and water salinity—traditions transmitted through generations [24]. Likewise, Sylhet communities impose restrictions on fishing during peak breeding periods and informally oversee juvenile fish habitats [18]. Community-based co-management frameworks offer a systematic approach to amalgamating traditional ecological knowledge with contemporary scientific management [44,50]. Research from successful co-management frameworks around the world, including some areas in Bangladesh, shows that when local communities are involved in planning and enforcement, there is better adherence to regulations, improved biodiversity, and more sustainable use of resources. Financial and institutional assistance, including Payment for Ecosystem Services (PES), training in sustainable aquaculture, and livelihood diversification initiatives, can enhance community capacity to preserve wetland habitats [25]. Policymakers must institutionalize participatory platforms, promote collaborative decision-making, and integrate traditional ecological knowledge with scientific research for optimal results [27]. Integrating traditional knowledge with community-based governance is crucial for the sustained conservation of wetlands in Bangladesh. It promotes inclusion, improves compliance, and aids in the preservation of Fish Genetic Resources (FGR) across ecological and socio-economic aspects [27].

4.4. Policy Recommendations for Sustainable Wetland Management

Based on the study's results and the feedback from important stakeholders, a set of comprehensive policy suggestions are made to ensure the long-term protection of fish genetic resources in Bangladesh's wetland areas. These recommendations emphasize targeted strategies to save ecosystems, enhance management practices, engage local communities, and develop integrated conservation programs. All of these factors are crucial for maintaining ecological balance and supporting those who depend on wetlands for their livelihoods.

4.4.1. Site-Specific Management Strategies

Given the natural diversity of Bangladesh's wetland habitats, conservation initiatives must be tailored to the distinct environmental circumstances, obstacles, and socio-economic dependencies of each region. A generalized strategy may prove ineffective, as various wetlands encounter distinct hazards that necessitate specific conservation strategies [27].

On the Sylhet Floodplain, conservation initiatives must prioritize the restoration of seasonal wetlands and the creation of fishing sanctuaries to safeguard breeding populations. Habitat damage from changing water levels and agricultural development needs strong restoration efforts. For example, natural river channels need to be dug up again, and fishing needs to be limited in fish sanctuaries during breeding seasons. Moreover, we must strengthen land-use laws to prevent further habitat damage [21,22].

The Sundarbans Mangrove, a UNESCO World Heritage Site, needs climate-adaptive conservation techniques, especially to alleviate saltwater intrusion and combat sea-level rise. High salinity levels have changed the make-up of fish species in a big way, helping species that can handle salt and hurting populations that depend on freshwater [19]. Enhancing sustainable fisheries management regulations by limiting overfishing and habitat degradation is crucial for long-term resilience. Moreover, extensive mangrove restoration initiatives can alleviate coastal erosion and establish nursery habitats for commercially important fish species. Moreover, investing in saline-resistant aquaculture research can offer alternative livelihoods for fishing populations experiencing diminishing freshwater fish stocks [20,24].

The Meghna River Basin confronts significant challenges due to industrial pollution, overfishing, and habitat destruction. Conservation strategies must prioritize the enhancement of pollution control measures, the implementation of fisheries quotas, and the development of riverbank stabilization projects. It is important to have strict rules so that industrial waste, agricultural runoff, and untreated sewage do not pollute important fish habitats [44]. It is important to use sustainable fishing methods, like limiting the number of Hilsa (*Tenualosa ilisha*) that can be caught so that populations do not drop too much because of overfishing. Furthermore, riverbank stabilization measures, including vegetation planting and sediment retention methods, can avert erosion-induced habitat degradation and hence maintain the basin's biological integrity [27].

4.4.2. Strengthening Fisheries Governance and Law Enforcement

Effective fisheries governance requires not only robust regulatory frameworks but also adaptive enforcement strategies responsive to evolving ecological and socio-economic challenges. In Bangladesh, the absence of strong enforcement mechanisms contributes to habitat degradation, illegal fishing, and unsustainable extraction of fish genetic resources. Strengthening institutional capacity for environmental monitoring, surveillance, and policy enforcement is therefore imperative [18–20].

Targeted investments should be made in modern enforcement tools such as satellite tracking, geographic information systems (GIS), and drones to monitor fishing activities and detect violations. For transboundary species like *Tenualosa ilisha*, collaborative enforcement across districts and regions is essential for consistent management [16,22].

Importantly, fisheries governance must also involve local stakeholders in the design and enforcement of rules. Joint decision-making, participatory enforcement patrols, and community-supported reporting mechanisms have proven effective in enhancing compliance and trust. As highlighted earlier in Section 5.2, integrating local knowledge with enforcement structures not only improves legitimacy but also supports culturally grounded conservation practices. By embedding these participatory models into the governance framework, Bangladesh can better align conservation outcomes with the realities of wetland-dependent communities [11,20].

4.4.3. Enhancing Public Awareness and Stakeholder Engagement

The efficacy of wetland conservation initiatives is closely linked to public awareness and the involvement of key stakeholders, including residents, lawmakers, researchers,

and conservation groups. To get people to change their behaviour in ways that help conservation goals, we need to better understand the ecological and economic importance of fish genetic resources [40–42]. Educational programs should be executed at both local and national levels to inform fishermen and merchants about the lasting consequences of overfishing, habitat destruction, and pollution. Incorporating environmental education into school curricula may instill conservation ideals in younger generations, ensuring long-term sustainability [44].

Furthermore, mass media platforms, including television, radio, and social media, should be utilized to disseminate information on conservation initiatives and effective strategies for sustainable fisheries management [16]. Stakeholder engagement must be stressed in the formulation and execution of policies. Collaborative workshops, roundtable talks, and multi-stakeholder forums facilitate the exchange of information among government agencies, scientific researchers, and community leaders. Promoting open dialogues that honor both traditional knowledge and scientific facts can result in improved and more successful conservation measures [44].

4.4.4. Developing a National Wetland Conservation Framework

The intricate nature of wetlands is so complicated that a piecemeal policy approach is not enough to stop the threats to fish stocks that are getting worse. A comprehensive national wetland management strategy is crucial to integrate scientific research, traditional ecological knowledge, and participatory governance into a unified framework. Formulating a national strategy to safeguard wetlands necessitates collaboration across several disciplines, including environmental science, fisheries management, policy development, and socio-economic research [41]. Establishing a single regulatory authority to oversee wetland conservation initiatives helps enhance coordination and eradicate redundancy in efforts. This framework must guarantee that conservation strategies adhere to international environmental accords, including the Convention on Biological Diversity (CBD) and the Sustainable Development Goals (SDGs), particularly SDG 14 (Life Below Water) and SDG 15 (Life on Land) [44].

Development in wetland conservation must be emphasized to guarantee long-term sustainability. We can use government funding, international grants, and private sector investments to improve conservation programs, capacity-building efforts, and infrastructure development for sustainable fisheries management. Additionally, the framework must include rigorous ecological evaluations and biodiversity monitoring to assess conservation initiatives and modify policies as needed [22].

4.5. Future Research Directions

This study gives a full scenario of the genetic resources of fish in Bangladesh's three main wetland areas. However, there remain significant research gaps that require filling. Addressing these concerns is crucial for enhancing conservation initiatives, refining regulations, and maintaining the long-term health of wetland ecosystems. To help make conservation policies and fisheries management based on facts, future research should focus on important areas like long-term ecological monitoring, socio-economic assessments, and climate resilience studies.

4.5.1. Molecular Genetic Analysis of Key Fish Species

A major study focuses on employing molecular genetic techniques to assess the population structure, genetic diversity, and adaptive potential of key fish species. It is important to know about the genetic diversity of species that are economically and ecologically important, like the Hilsa and the Barramundi [20]. This is because it helps manage fisheries and protect wildlife. Molecular methods, like DNA barcoding, microsatellite markers, and

next-generation sequencing (NGS), can help figure out how populations are connected and how much they breed with each other. Genetic methods are particularly effective in detecting historical population bottlenecks, providing insights into past demographic declines that may inform present conservation planning. Furthermore, genetic studies may clarify certain population units that require targeted conservation initiatives. So, to make sure that conservation efforts are based on biological, ecological, and genetic differences rather than political boundaries, genetic research is needed to divide populations into manageable units in fisheries. Understanding the genetic structure and gene flow dynamics in fish populations helps policymakers come up with good conservation plans that protect genetic diversity and lessen the risks of overfishing [51,52]. Southeast Asian research has shown that genetically based fisheries management is needed because each site needs its own set of conservation measures because each population changes in its own way. Hilsa populations in the Bay of Bengal exhibit considerable genetic heterogeneity within river systems, indicating the necessity for river-specific conservation measures instead of a generalized management approach [27]. Pangasius catfish populations in the Mekong River have genetic structures that necessitate specific fishing management [51]. Genetic studies help set management units by telling the differences between populations that have adapted to their environment and stocks that have bred with other species. This is important for setting sustainable fishing limits and protecting areas [53]. Furthermore, evaluating gene flow and connectivity in fish populations determines the suitability of transboundary management vs. localized conservation strategies [54]. Overexploitation and habitat degradation frequently cause genetic bottlenecks, resulting in diminished adaptation and increased extinction risks [55]. Monitoring genetic diversity is important for species that are facing climate change and changes in their habitats because it helps us figure out how they are adapting and ensures the long-term survival of the population [56]. Bangladesh's fisheries depend a lot on wild stocks. Using genetic studies in fisheries management can help species become more resilient by finding and protecting locally adapted genetic variants [27]. It can also help plan for sustainable harvesting based on population genetics and help protect habitats by keeping genetic corridors open to stop inbreeding and population declines [51,52]. Utilizing genetic concepts in fishery management helps ensure the enduring viability of fish genetic resources, thereby bolstering food security, ecosystem stability, and economic livelihoods.

4.5.2. Long-Term Ecological Monitoring and Conservation Impact Assessment

Longitudinal research investigating biodiversity, environmental factors, and fish species diversity can track variations in fish populations across time. Current conservation initiatives, like seasonal fishing bans, fish sanctuaries, and wetland restoration efforts, require a thorough assessment to determine their ecological and socio-economic effects [25]. Longitudinal studies examining biodiversity, environmental conditions, and fish species variety can monitor fluctuations in fish populations over time. This knowledge is crucial for enhancing fish management strategies. Monitoring processes must encompass the assessment of water quality parameters such as dissolved oxygen, pH, salinity, and contaminant concentrations. It also helps to comprehend the impact of environmental changes on fish genetic resources [24]. The integration of remote sensing and geographic information systems (GIS) significantly improves wetland monitoring. It facilitates the analysis of alterations in ecosystems, hydrology, and land utilization across time. Data-driven approaches will empower conservationists and policymakers to develop more adaptable and region-specific conservation frameworks that account for long-term ecological trends [27].

4.5.3. Socio-Economic Assessments of Conservation Policies on Local Livelihoods

To obtain a full scenario of the socio-economic situation in wetland communities, socio-economic assessments should use a variety of methods, such as household surveys, participatory rural appraisals (PRAs), such as seasonal calendars, resource mapping, and ranking exercises, were conducted to gather local perceptions of conservation impacts and livelihood vulnerabilities and ethnographic research. Furthermore, gender-specific research is vital to assess the effects of conservation policies on many social groups, particularly women who hold significant yet often neglected roles in fisheries and aquaculture. Figuring out the costs and benefits of conservation efforts can help make fair compensation systems, other ways to make a living, and programs that build people's skills so that the community supports the long-term management of fisheries. Furthermore, investigations into community-based fisheries management may yield valuable insights into the efficacy of local regulations in safeguarding resources. Instances of effective co-management can generate policy concepts and foster collaboration, enhancing conservation initiatives and promoting economic stability [5,9,16,24].

4.5.4. Climate Resilience Studies and Adaptive Fisheries Management

Climate change drastically jeopardizes Bangladesh's wetland ecosystems by altering hydrological regimes, exacerbating salt intrusion, and intensifying severe weather events. Future research should concentrate on examining the impact of climate change on fish genetics and identifying strategies to enhance the resilience of fisheries [24]. When looking at the effects of climate change, it is important to look at how fish distribution patterns, reproductive cycles, and the viability of habitats change in different climate scenarios. Modeling studies can predict the effects of increasing temperatures, altering monsoon patterns, and changing river flows on vital fish species [31]. Species reliant on seasonal flood pulses for reproduction may have reproductive challenges if erratic rainfall disrupts established breeding environments. Comprehending these biological reactions can enhance fisheries management. This includes modifying fishing schedules, rehabilitating habitats, and establishing water management regulations to maintain stable fish populations. Exploring climate-friendly aquaculture techniques is essential for safeguarding food security and alleviating strain on wild fish populations. Developing salt-tolerant fish strains through selective breeding or aquaculture innovation is essential for ensuring sustainable livelihoods in regions facing increased salinity due to climate change and habitat alteration, improving the farming of rice fish (fish species that inhabit rice fields), and looking into sustainable feed options can all help fisheries adapt to changes in the environment and lessen the damage to wetland habitats. Institutions must enhance their capacity to incorporate climate risk assessments into fisheries decision-making [44]. This will safeguard fish genetic resources and sustain the livelihoods of those reliant on wetlands during climate change.

5. Conclusions

This study emphasizes the crucial role of fish genetic resources in conserving wetland ecosystem services, augmenting biodiversity, and fostering sustainable fishing in Bangladesh. Wetlands, including the Sylhet Floodplain, Sundarbans Mangrove, and Meghna River Basin, serve as crucial breeding grounds for fish. Nonetheless, these regions are becoming imperiled owing to habitat degradation, climate change, industrial pollution, and detrimental fishing methods. A comprehensive conservation strategy is insufficient due to the Sylhet Floodplain's susceptibility to fluctuations in water levels and agricultural activities. This necessitates the establishment of restoration initiatives and fish conservation zones. The Sundarbans mangrove is experiencing increased salinity and difficulties related to climate change. This requires the establishment of new fishing control legislation and activities to promote

the growth of more mangroves. The Meghna River Basin, a vital commercial fishing hub, is witnessing a marked reduction in biodiversity owing to industrial pollution and overfishing, highlighting the need for stricter pollution regulations and enhanced fisheries management. Studies show that protecting different kinds of fish and wetlands needs conservation efforts that focus on specific ecosystems, use strong evidence, and include input from people who live there. Improving fisheries management requires strengthening policy enforcement and fostering greater community involvement. Insufficient restrictions, inadequate supervision, and enforcement shortcomings lead to the overexploitation of fish resources. Including local fishermen, conservation experts, and community groups in collaborative management frameworks could help people follow conservation laws and get resource users more involved in protecting the biodiversity of wetland areas. Collaboration across all disciplines and industries is vital to guarantee the robustness of fish genetic resources. This requires environmental conservation and the advancement of economic growth. Investments in alternative livelihoods, sustainable aquaculture, and wetland restoration programs can alleviate fishing demand while improving economic stability for vulnerable fishing communities. Public awareness campaigns and environmental education initiatives can foster a stronger conservation ethic among stakeholders, enhancing societal dedication to biodiversity preservation. Future conservation programs must prioritize the amalgamation of ecological, genetic, and socio-economic studies to inform policy choices and improve wetlands management. Improving cooperation among government agencies, educational institutions, and local communities will be crucial for achieving sustained conservation results. By proactively addressing the challenges identified in this study, Bangladesh can safeguard its vital fish genetic resources for future generations while advancing its broader conservation and sustainability goals.

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