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Seasonal variation and fish assemblage at Hakaluki Haor, Moulvibazar, Bangladesh

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Abstract
Wetlands in Bangladesh have undergone rapid degradation, primarily attributable to a range of factors. These factors include a marked increase in population, extensive water diversion for irrigation purposes, depletion of swamp forests, as well as other natural and anthropogenic causes. Hakaluki Haor is a vast wetland area located at North East in Bangladesh provides habitat for a diverse range of fish species. Due to natural and anthropogenic causes, fish species are declining in the Hakaluki Hoar. Fish species are declining primarily due to the utilization of harmful gear, the drying of beels every year, and overexploitation. The aim of the research was to assess the occurrence of various fish species in different seasons, their distribution, and conservation status. The research was carried out over the course of three seasons (summer, autumn, and winter) spanning from September 2017 to August 2018. The study utilized a mixed methodology approach to investigate the fish assemblage, which included examining the fish catch on boats along with the fish available in the nearest assembling center (fish market). In addition, the Shannon-Weaver index was followed to recognize the species diversity (H), richness (D), and Evenness (e). The research documented the presence of 64 fish species that were classified into 25 different genera, and 24 families across 10 orders. The order Cypriniformes was the most prevalent, constituting 42% of the total number of species identified. Other orders such as Siluriformes (22%), Perciformes (16%), Channiformes (6%), and Clupeiformes (5%) also demonstrated a considerable variety of fish species, although Cypriniformes had the highest dominance with 42% of the total species documented. Additionally, the research determined that among the complete assemblage of fish species identified, a total of 14 (18.88%) were classified as species facing threats. Based on the analysis, 6.25% are vulnerable, 12.5% endangered, and 3.12% are critically endangered as per IUCN Redlist. The research observed the Shannon-Weaver diversity (H), richness (D), and evenness (e) values for the fish species, which were found to be 2.47, 6.28, and 0.65, respectively. Moreover, participants retorted that the present income from fishing had decreased as compared to five years ago. The research finds that anthropogenic pressure is one of the key reasons to fish decline at Hakaluki Haor. According to the findings of the current research, community-based wetland conservation and management have been proposed as a viable and sustainable strategy for augmenting the fish species abundance.

Keywords: Fish Species, Hakaluki Hoar, Fish Assessment, Fish biodiversity, Diversity Index

Introduction
Bangladesh has a large amount of open water within its borders, including rivers, canals, lakes created naturally or by humans, marshes, estuaries, impoundments with brackish water, and floodplains (Hossain M., 2015) [15]. Bangladesh is one of the leading countries in the world when it comes to fish production and is a major contributor to global fish production. According to the Department of Fisheries (DoF, 2018) in Bangladesh, the country produced 42.77 lakh metric tons (MT) of fish in the fiscal year 2017-18. In 2018, Bangladesh ranked as the third largest inland fish producer, the fifth largest aquaculture producer, and the eleventh largest marine fish producer (FAO, 2018) [14]. This Country is endowed with ample water resources, which are extensively spread throughout the country in diverse forms, including small bodies of water known as beels, natural low-lying areas, lakes, canals, haors, baors, small and large rivers, and estuaries. The total area covered by these water resources is approximately 4.7 million hectares (FRSS, 2016) [12]. In the freshwater habitats of Bangladesh, there exist 260 species of bony fishes, which are categorized into 145 genera and 55 families (Rahman AKA., 2005) [37-40].

Approximately half of the total land surface of Bangladesh is estimated to be covered by wetlands, which amounts to approximately 7-8 million hectares (Nishat, *et al.*, 1993) [36]. The provision of protein-rich food by capture fisheries and aquaculture is significant for both national food security and rural diets (Islam *et al*., 2020) [27]. The overall fish production in Bangladesh has increased from 2.1 million MT in 2003 to 4.2 million MT in 2019, which is largely attributed to the growth of aquaculture production (Fisheries Statistics of Bangladesh, 2018). The fisheries sector is the most significant use of wetlands in Bangladesh as it contributes to the provision of protein and generates sources of income and employment for millions of people (Rahman AKA, 2005; Ghosh *et al*., 2020) [37-40, 29].

Haors refer to shallow depressions in the shape of saucers or bowls that occupy approximately 25% of the northeastern region of Bangladesh (Debnath, P., Hussain, M. and Nasren, S, 2020) [10]. One of the larger freshwater wetlands in Asia, Hakaluki Haor is among the 373 recognized haors in Bangladesh. Hakaluki Haor, which is one of the largest freshwater wetlands in Asia, consists of 80 interconnected seasonal beels. It covers the administrative regions of Fenchuganj and Golabganj Upazilas in Sylhet district, as well as Baralekha, Juri, and Kulaura Upazilas in Moulvibazar district (IUCN, 2004) [24] (CNRS, 2002) [8]. The Hakaluki Haor is a crucial sanctuary for both fish and birds and serves as a source of livelihood for around 190,000 people. It comprises of 6,000 small freshwater lakes called beels and covers an area of up to 18,000 hectares during the rainy season (Ahmed, S., 2006) [1]. Although the Juri, Kantinala, and Kuiachari rivers flow into the bells, there is only one river, the Kushiyara, that serves as an outlet (Ahmed, S., 2006) [1]. In April 1999, the government of Bangladesh acknowledged the vulnerable state of the Hakaluki Haor's ecosystem and designated it as an Ecologically Critical Area (ECA), as documented by Hossain (2019) [16].

The water levels within Hakaluki haor are regulated by the water levels in the Kushiyara River where the Juri River flows into it. In case the water levels of the Kushiyara River are below those of the haor, water will flow from the research sites to the river. In contrast, when the water level of the river exceeds the level of the research sites, there will be a reverse flow of water from the Kushiyara River into the wetland haor. The district offices of the Ministry of Land and Revenue lease the fishing rights for Hakaluki Haor to a successful bidder for the purpose of fishing. The local communities residing near Hakaluki Haor utilize it for various purposes such as fishing, collecting fuel-wood, and seasonal grazing. In Bangladesh, a strategy of community-based wetland management has been implemented to promote a balance between human demands and wetland conservation. However, relying solely on this approach may not be adequate to prevent the deterioration of wetlands (Byomkesh, T., Nakagoshi, N. and Md. Shahedur, R, 2008) [6]. According to previous research, 107 fish species were identified in Hakaluki Haor, out of which 32 were found to be on the endangered list. In addition, 66% of the mollusk population in the area has also decreased over time. (Masud Abdullah., 2005) [31]. The government has a responsibility to provide economic safety nets and implement effective management policies for the resources in the Haor region. Furthermore, the allocation of financial aid to various departments can have implications for small-scale enterprises, diversified agriculture, and off-farm activities that are dependent on the Haor ecosystem. There has been limited research conducted on species composition in the southeastern region of Bangladesh.

Many other socio-economic factors, such as low literacy, failing to comply with fisheries laws, and poor understanding and knowledge, were affecting the fish genetic resources of this crucial wetland. According to the vulnerability assessment of Hakaluki Haor, the ecosystem is facing current and potential impacts of climate change on its habitats, including beels, canals, rivers, agricultural lands, kanda (raised land), and waterfowl habitats. The susceptibility of ecosystems leads to the vulnerability of the people who depend on them (Department of Environment, 2005; Hossain, Rahman, and Islam, 2016) [11, 17]. To maintain a fish database, it is required to prepare a detailed fish inventory. Understanding the fish assemblage is necessary for preserving biodiversity in a given area. As a result, the purpose of this paper was to explain the fish assemblages in the Hakaluki Haor.

Methodology

Description of the study area

Hakaluki Haor is situated between 24°35´ to 24°44´ North latitude and 92°00´ to 92°08´ East longitude. It is situated in a region with a subtropical monsoonal climate that is marked by the distinct commencement and withdrawal of the monsoon season each year, which is a defining feature of the area (Islam, Md. *et al*., 2018) [23]. The selection of the site was based on the frequency of fish catches, as well as their sale and distribution to various regions within Bangladesh. The Department of Fisheries (DoF) in the Ministry of Fisheries and Livestock has established an Upazilla Fisheries Office responsible for managing fishing activities and implementing various initiatives to enhance fish stocks in each sub-district. One of the initiatives to improve fish stocks in each of the sub-districts is the development of community-based fisheries management strategies, which can be led by fishers, communities, or women. These strategies provide access to fish catch data from community-based management groups (Blake B, Barr J, Peris C, 2003) [5]. Figure 1 shows the overall study area along with the sampling points.

Research Tools

The study spanned a duration of one year, from September 2017 to August 2018, which was divided into four distinct seasons based on the classification used by the Bangladesh Meteorological Department (BMD): Winter season (Northeast monsoon) from November to February, Summer season (Pre-monsoon) from March to May, Rainy season (Southeast monsoon or monsoon) from June to August, and Autumn Season (Post monsoon) from October to November. Three sampling study sites were selected under two Upazilla encompassing the Barlekha, and Juri, Upazilla under the Moulvibazar district under the Sylhet division of Bangladesh. Specific fishing grounds as well as the fish markets were considered for this study. Semi-structured questionnaire interviews with the fishing community and stakeholders were conducted. The main research instruments used were questionnaires, focus group discussions, and interviews with key informants.

A preliminary visit along with monthly reconnaissance surveys was conducted to the selected sample sites. The targeted households were selected arbitrarily and interviewed based on the number of families within the village. The study area was sampled by selecting a total of 100 households,

distributed across three locations: West Balagaon (39 households), Halla (32 households), and Vukshimail (29 households). The data collection was made on relevant information covering the socio-economic characteristics of the respondent, Haor management system, stress on fish, land resources and its utilization, harvesting and economic gain.

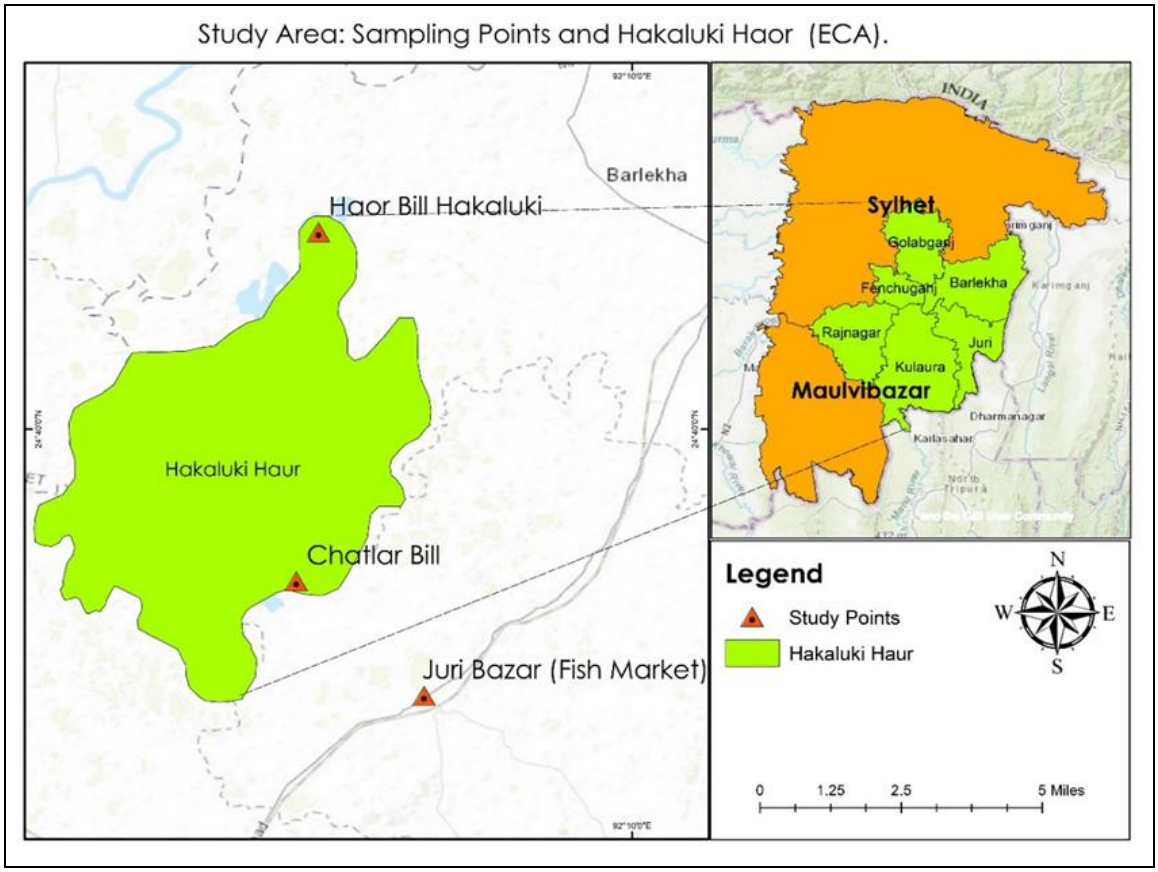

Fig 1: Location of the study area

Semi-structured questionnaire survey: A questionnaire survey was conducted by providing a semi-structured questionnaire to the participants selected randomly from the villages being studied. The respondents were inquired further questions based on their responses. Participatory Rural Appraisal (PRA) methods were applied to draw information. Data of the Production Year- 2017-2018 were collected and recorded in the questionnaires.

Focus Group Discussion (FGD): To avoid individual opinions and assess the collective perspective, Focus Group Discussions (FGD) were conducted in familiar places where people usually gather to rest, gossip and drink tea. A total of 10 FGDs were held in the three villages during the survey.

Key Important Interview (KII): Discussed with the local elite person, Mahajon (Fish dealer), head teacher of the local high school, political leader, and religious leader about collected data to do a qualitative evaluation. This evaluation helped us better to understand the socio-economic condition and fishing practices in the study area.

Statistical Analysis

Finally, data were analyzed employing Microsoft Excel 2013 and the SPSS statistical software. The results have all been presented using tables, pie charts, cylinder diagrams, and other visual elements.

Species identification

The identification of fish species in the study areas was carried out by examining their morphometric and meristic characteristics as specified by (Rahman, A.K.A., 2005) [37-38-39-40] and (Van Der Laan, R., Eschmeyer, W.N., And Fricke, R., 2014) [42]. Once the fish species from the study areas were identified, they were classified systematically using Nelson's classification system (Nelson, J.S., 2006) [35].

Diversity Index

The assessment of fish species diversity in Hakaluki Haor was conducted by evaluating the richness (total number of distinct fish species) and evenness (uniformity in the distribution of individuals across species) of fish populations based on data on the abundance and distribution of fish species in the area. The Shannon-Wiener index (H) was selected as a comprehensive index to evaluate the fish species diversity of Hakaluki Haor in terms of richness. The Shannon-Wiener index was calculated using the formula below.

$$\text{Shannon's diversity index } H(s) = -\sum (pi * \ln pi) \quad \text{(i)}$$

Where H(s) represents the Shannon-Wiener information function, pi represents the proportion of individuals belonging to the i-th species, and ln represents the natural logarithm. The maximum possible value for H(s) is H(max.), which is achieved when all species in the sample have equal abundance.

$$\text{Simson's diversity index}(\lambda)\ \lambda = \Sigma(ni/N)^2 \quad \text{(ii)}$$

This formula is used to calculate the evenness index of a sample, where NI represents the number of individuals in each species, N represents the total number of individuals, and S represents the total number of species in the sample.
And, Pielou's evenness index (J') is a measure of the distribution of individuals among species in a community. It ranges from 0 to 1, with 0 indicating complete inequality (one species dominates the community) and 1 indicating complete evenness (all species are equally represented in the community).

It is calculated as J' = H/H(max) (iii)

The Shannon-Wiener index (H) is calculated by taking the negative sum of the proportional abundance of each species multiplied by its natural logarithm. H(max) is the natural logarithm of the total number of species.
Also, the study used a formula to estimate the number of small fish species that were difficult to count. The formula is given by:

Wt/Ns = Ws/n (iv)

The formula for estimating the total weight of small fish found involves multiplying the weight of a subsample (Ws) by the number of individual small fish in each subsample (Ns), and then dividing the result by the total number of subsamples (n). The total weight of small fish found (Wt) is then equal to the product of the average weight of each individual small fish and the total number of small fish found. This method was used in a study conducted by Iqbal (2015) [21].

Results

Current status of Fish Species

The study conducted at Hakaluki Haor documented 64 types of fish that belong to 25 genera, 24 families, and 10 orders. In the present study conducted at Hakaluki Haor, Cypriniformes, which includes carps and minnows, was the dominant order, comprising 42% of the total fish species caught. Other diverse orders were Siluriformes (22%), Perciformes (16%), Channiformes (6%), Clupeiformes (5%), Osteoglossiformes (2%), Tetraodontiformes (1%), Synbranchiformes (1%), Beloniformes (1%), and Cyprinodontiformes (2%). The Order based graphical comparison of fish species were shown in Figure 2. The freshwater bodies of Bangladesh are primarily dominated by certain groups of fish, including Cypriniformes, Siluriformes, and Perciformes (Rahman A.K.A., 2005) [37-38-39-40].

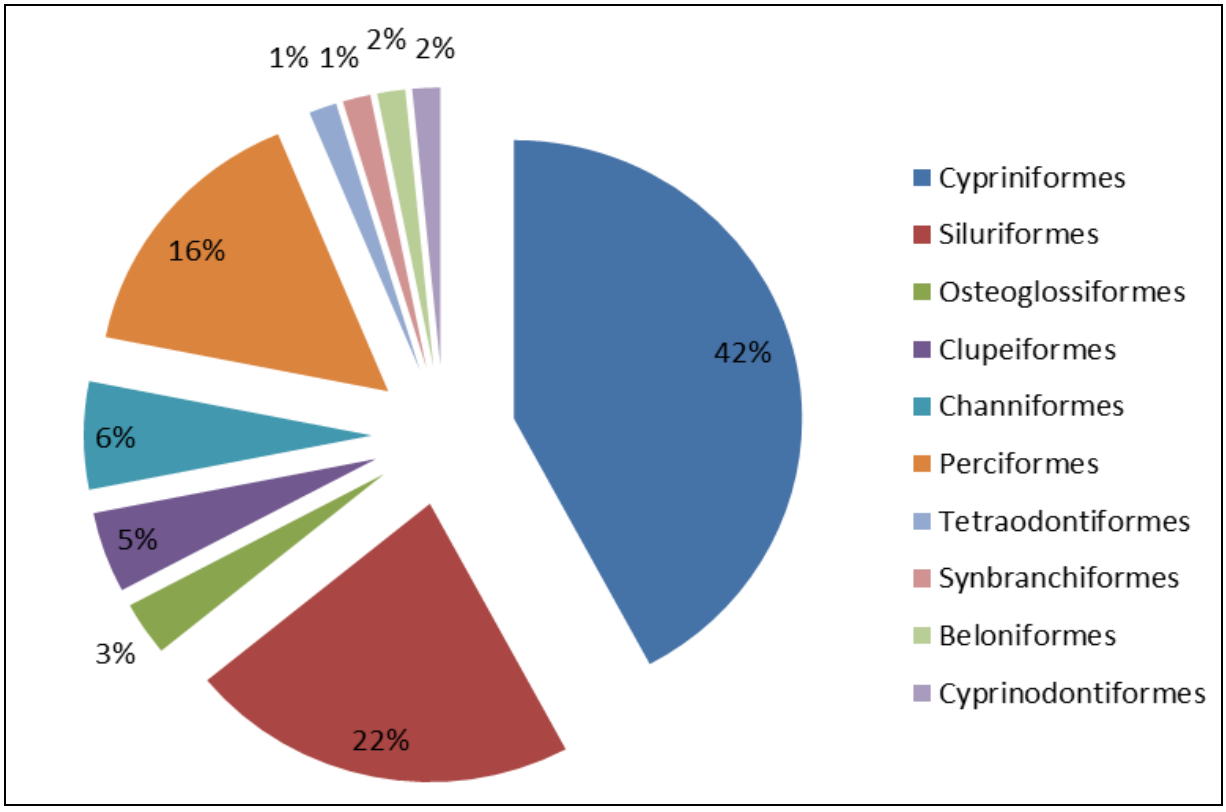

Fig 2: Order-wise composition of fish from the study area

The family Cyprinidae was found the most dominant family, with 25 species, accounting for 37.5% of all the fish species recorded in the study. Other dominant families were Bagridae (6.25% of species), Channidae (6.25% of species), Schilbeidae (4.68% of species), Clupeidae (4.68% of species), Mastacembalidae (4.68% of species), Balitoridae (3.125% of species), Clariidae (3.125% of species), Notopteridae (3.12% of species), Cobitidae (1.56% of species), Heteropneustidae (1.56% of species), Pangasiidae (1.56% of species), Belontiidae (1.56% of species), Anabantidae (1.56% of species), Gobiidae (1.56% of species), Nandidae (1.56% of species), Cichlidae (1.56% of species), Ambassidae (1.56% of species), Sisoridae (1.56% of species), Tetraodontidae (1.56% of species), Synbranchidae (1.56% of species), Belonidae (1.56% of species), and Cyprinodontidae (1.56% of species) respectively.
The family Cyprinidae has been found to contribute significantly to the numerical composition of fish species in various open water bodies, as it has a large number of species by (Ahsan *et.al.*, 2014) [2] and (Rao, J. C. S., Raju, C. S. and

Simhachalam, G., 2014) [41], corroborates with the findings of the present study.

Seasonal variation of fish species

During the winter season, this study confirmed 55 species of fish which is the maximum in number. Throughout the study period, the minimum water depth facilitated more efficient use of fishing gear by fishermen. As a result, the number of recorded fish species was higher during this time. However, in June and July, heavy rainfall caused the water level to reach its highest level, making fishing difficult, and the least number of species were recorded during this period. Table 1 provides information about fish orders, families, and scientific names of species, English names, habitat, and their conservation status in Bangladesh.

Table 1: Fish diversity and conservation status of fish fauna recorded at Hakaluki Haor of Bangladesh from September 2017 to August 2018.

Serial No.	Family	Scientific Name of Species	English Name	Habitat	Conservation status*	
					IUCN Local status	IUCN Global status
Order: Cypriniformes						
1	Cyprinidae	*Labeo rohita*	Ruhu	Rivers and wetlands (Beels, Haors and Baors)	LC	LC
2		*Labeo calbasu*	Orangefi Labeo, Black Rohu	Rivers and wetlands (Beels, Haors and Baors)	LC	LC
3		*Labeo gonius*	Kuria Labeo	Rivers and wetlands (Beels, Haors and Baors)	NT	LC
4		*Labeo bata*	Bata Labeo	Rivers and wetlands (Beels, Haors and Baors)	LC	LC
5		*Cirrhinus cirrhinus*	Mrigal Carp, Mrigal	Rivers and wetlands (Beels, Haors and Baors)	NT	VU
6		*Systomus sarana*	Olive barb, Peninsular Olive Barb	Rivers, canals, beels, ponds	CR	LC
7		*Catla catla*	Catla	Rivers, canals, beels, ponds	LC	LC
8		*Ctenopharyngodon idella*	Grass Carp	Rivers, canals, beels, ponds	NL	LC
9		*Cyprinus carpio communis*	Mirror Carp	Rivers, canals, beels, ponds; (Exotic).	NL	NL
10		*Cyprinus carpio*	Mirror Carp	Rivers, canals, beels, ponds; (Exotic).	NL	VU
11		*Cyprinus carpio specularis*	Mirror Carp	Rivers, canals, beels, ponds; (Exotic).	NL	NL
12		*Securicula gora*	Ghora chela	Rivers, beels and canals	NT	LC
13		*Salmostoma phulo*	Finescale Razorbelly Minnow	Rivers, beels and canals	NT	LC
14		*Esomus danricus*	Flying Barb	Rivers, beels and canals	LC	LC
15		*Rasbora daniconius*	Blackline Rasbora, Common Rasbora,	Rivers, beels and canals	DD	LC
16		*Hypophthalmichthys molitrix*	Silver Carp	River (exotic).	NL	NT
17		*Aristichthys nobilis*	Bighead Carp	River (exotic).	NL	DD
18		*Barbonymus gonionotus*	Java barb	River (exotic).	NL	LC
19		*Puntius conchonius*	Red Barb, Rosy Barb	Rivers, canals, beels (oxbow lakes), ponds, and inundated fields	LC	LC
20		*Amblypharyngodon mola*	Mola Carplet, Pale Carplet	Rivers, canals, beels (oxbow lakes), ponds, and inundated fields	LC	LC
21		*Osteobrama cotio*	Cotio	Rivers, canals, beels (oxbow lakes), ponds, and inundated fields	LC	LC
22		*Devario devario*	Sind Danio	Rivers, canals, beels, ponds and inundated fields	LC	LC
23		*Crossocheilus latius*	Gangetic Latia, Stone roller, Hill-stream Carp	Hillstream, rivers, canals, beels, ponds and inundated fields	EN	LC
24		*Puntius sophore*	Spotfi Swamp Barb, Pool Barb, Stigma Barb	Rivers, canals, beels (oxbow lakes), ponds, and inundated fields	LC	LC
25	Balitoridae	*Lepidocephalus guntea*	Peppered Loach, Guntea Loach	Swamps, streams, floodplains, and beels	LC	LC
26		*Lepidocephalichthys annandalei*	Annaldale Loach	Swamps, streams, floodplains and beels	LC	LC
27	Cobitidae	*Botia dario*	Necktie Loach, Queen Loach, Bengal Loach	Swamps, streams, floodplains and beels	EN	LC
Order: Siluriformes						
28	Clariidae	*Clarias batrachus*	Walking Catfish, Clarias Catfish, Freshwater Catfish	Rivers and wetlands (such as muddy ponds, canals, ditches, swamps and flodplains)	LC	LC
29		*Clarius gariepinus*	African catfish	Rivers and wetlands (such as muddy ponds, canals, ditches, swamps and flodplains)	NL	DD
30	Siluridae	*Wallago attu*	Freshwater Shark, Wallago	Rivers, beels, reservoir, baors and enters the floodplains and roadside ditches	VU	VU
31		*Ompok pabda*	Pabda catfish, two-stripe Gulper catfish	Rivers Reservoir, Haor, Beel	EN	NT
32		*Ompak pabo*	Pabda, Kala Pabda	Beel, River, and Haor.	CR	NT
33	Heteropneustidae	*Heteropneustes fossilis*	Stinging Catfish, Fossil Catfish, Liver Catfish	River, Beel, Haor.	LC	LC
34	Pangasiidae	*Pangasius hypophthalmus*	Pungas, Yellowtail Catfish, Pungas Catfish	Estuaries, rivers, haors, baors, beels and floodplains	NL	EN
35	Schilbeidae	*Ailia coila*	Gangetic Ailia	Rivers and connected hoars, baors, beels, and other flooded lands.	LC	NT
36		*Neotropius atherinoides*	Indian Potasi	Freshwater rivers, coastal rivers, tidal water rivers and	EN	LC

Serial No.	Family	Scientific Name of Species	English Name	Habitat	Conservation status*	
					IUCN Local status	IUCN Global status
				their tributaries, haors and beels.		
37		*Clupisoma garua*	Garua Bacha, Gagra	River, Beels, Baors, lakes, flooded low lands.	EN	LC
38	Bagridae	*Sperata aor*	Long-whiskered Catfish	River, Beel,	VU	LC
39		*Mystus cavasius*	Gangetic Mystus	Rivers, Beels, baors, lakes, flooded low lands, and canals.	NT	LC
40		*Mystus tengara*	Tengara Catfish	Weedy, sandy, muddy places of pools, streams, canals, and river	LC	LC
41		*Mystus vittatus*	Striped Dwarf Catfish	Estuarine and tidal rivers throughout Bangladesh.	LC	LC
Order: Osteoglossiformes						
42	Notopteridae	*Chitala chitala*	Humped Featherback, Clown Knife Fish	Rivers, beels, haors, reservoirs, canals, and ponds.	EN	NT
43		*Notopterus notopterus*	Grey Featherback, Freshwater Knife Fish	Haor, Baor, Beel and Sundarbans.	VU	LC
Order: Cluoeiformes						
44	Clupeidae	*Gudusia chapra*	Indian River Shad	In reservoirs, haors, baors, ponds, and floodplains	VU	LC
45		*Tenualosa Ilisha*	River Shad, Hilsha Shad	Coastal shelf, brackish water estuaries, and freshwater rivers.	LC	LC
46		*Corica soborna*	Ganges River-sprat	freshwaters and occurs in rivers and estuaries and reservoirs	LC	LC
47	Channidae	*Channa striatus*	Snakehead Murrel, Stripped or banded Snakehead, Common Snakehead,	Stagnant muddy water and grassy tanks, breed in ditches, ponds, and flooded paddy fields	LC	LC
48		*Channa marulius*	Giant Snakehead, Great Snakehead	Stagnant muddy water and grassy tanks, breed in ditches, ponds, and flooded paddy fields.	EN	LC
49		*Channa punctatus*	Spotted Snakehead, Green Snakehead	Stagnant water and muddy stream, fresh and brackish waters.	LC	LC
50		*Channa orientalis*	Asiatic Snakehead, Walking Snakehead	Rivers, lakes, ponds, mountain streams, and even brackish water.	LC	VU
Order: Perciformes						
51	Mastacembalidae	*Macrognathus aral*	One-stripe Spiny Eel	Riverine waterbodies and its adjacent floodplain areas	DD	LC
52		*Mastacembelus armatus*	Tire-track Spinyeel	Rivers, canals, streams, beels, ponds, and inundated fields	EN	LC
53		*Macrognathus pancalus*	Stripped Spinyeel, Barred Spiny Eel	Rivers, canals, beels, lakes, stocked ponds, floodplains and in roadside ditches	LC	LC
54	Belontiidae	*Colisa fasciata*	Stripped Spiny-eel, Barred Spiny Eel	Rivers, canals, beels, lakes, auto stocked ponds, floodplains, and in roadside ditches	LC	LC
55	Anabantidae	*Anabas testudineus*	Climbing Perch, Climbing Bass, Walking Fish	Low-lying swamps, marsh-lands, lakes, canals, pools, small pits and puddles	LC	LC
56	Gobiidae	*Brachygobius nunus*	Short Goby, Golden-banded Goby, Bumblebee Goby, Buzz Goby	Swamps, streams, mangroves, tidal creeks, and occasionally freshwater rivers	LC	NL
57	Nandidae	*Nandus nandus*	Mottled Nandus, Mud Perch	Rivers and floodplains, dried-up beds of tanks, beels, etc	NT	LC
58	Cichlidae	*Oreochromis niloticus*	Nile Tilapia	Freshwater (Exotic).	NL	LC
59	Ambassidae	*Chanda nama*	Elongate Glass-Perchlet, Asian Glass Fish	Fresh and brackish waters, clear streams, canals, beels, ponds and inundated paddy fields etc.	LC	LC
60	Sisoridae	*Hara hara*	Kosi Hara	Rivers, hill streams, creeks, and floodplains.	LC	LC
Order: Tetraodontiformes						
61	Tetraodontidae	*Tetraodon cutcutia*	Ocellated Pufferfish, Ocellated Blowfish	Freshwater ponds, beels, haor, baor, canals, wetlands, and rivers etc.	LC	LC
Order: Synbranchiformes						
62	Synbranchidae	*Monopterus cuchia*	Gangetic Mud Eel, Swamp Eel	Fresh and brackish waters, in burrows of rice fields, river basins, floodplains, and haor areas.	VU	LC
Order: Beloniformes						
63	Belonidae	*Xenentodon cancila*	Freshwater Garfish, Needle Fish, Silver, Needle Fish	Rivers, hoars, baors, beels, lakes and ponds, and inter-tidal brackish water rivers and their tributaries.	LC	LC
Order: Cyprinidontiformes						
64	Cyprinodontidae	*Aplocheilus panchax*	Blue Panchax, Panchax Minnow	Fresh and brackish waters and canals, rivers, beels, haors, ponds, ditches and inundated fields, etc.	LC	LC

Source: Field survey 2017-2018

Presence of exotic fish species

The study found a total of 09 exotic species recorded from the study area. They were Silver Carp (*Hypophthalmicthys molitrix*), Java Barb (*Barbonymus gonionotus*), Bighead Carp (*Aristichthys nobilis*), Grass Carp (*Ctenopharyngodon Idella*), Mirror Carp (*Cyprinus carpio var. communis, Cyprinus carpio, Cyprinus carpio var. specularis*) belonging to family Cyprinidae. Likewise, Pangasius species belonging to the family Pangasiidae, Nile Tilapia (*Oreochromis niloticus*) belonging to the family Cichlidae, and African Catfish (*Clarius gariepinus*) belonging to the family Clariidae respectively. The order Cypriniformes was observed to have the highest number of exotic species, indicating its dominance in terms of total number of exotic species. This trend is likely due to cultural fisheries interventions in the haor vicinity and the increasing number of exotic species being introduced over time.

Diversity index, richness, and evenness

In the context of biology, diversity refers to the variety of different species and their relative abundances. This diversity can be observed and studied at various levels, ranging from entire ecosystems down to the molecular structures that underlie genetics (Aslam M, 2009) [3]. The Shannon-Wiener

index (H) is used to quantify the diversity of species in a particular community. A higher value of H indicates a greater diversity of species in the community, while a lower value indicates a less diverse population. In cases where H equals 0, the community comprises only a single organism. Evenness is a measure of how individuals are distributed among different species, with low values indicating domination by one or a few species, and high values indicating that the distribution is relatively equal across all species present in the community. The value of a diversity index increases when both the number of species and the evenness of a population increase. The calculated data for ecological data typically results in a Shannon-Wiener index (H) value ranging from 1.5 to 3.5, with few cases exceeding 4.0. May (Cody ML and Diamond JM, 1975) [9] stated that for the Shannon-Wiener index (H) to exceed 5.0, a sample must contain 100,000 species assuming that the species have a normal abundance distribution. Table 3 presents the values of Shannon-Weaver diversity (H), richness (D), and evenness (e) indices on a monthly basis, which were calculated for the present study. The results showed that the values of H, D, and e for the study area were 2.47, 6.28, and 0.65, respectively. The value of the diversity index ranged from 1.47 (in November) to 2.966 (in December), the richness index ranged from 4.189 (in November) to 8.767 (in May), and the evenness index ranged from 0.4597 (in November) to 0.7752 (in May) shown in (Table 2). Biligrami (1988) [4] suggested that a desirable range for the Shannon-Weaver diversity index in aquatic ecosystems is between 3.0 and 4.5, indicating higher levels of fish diversity. The current findings do not indicate a favorable state regarding the condition of the water body, and other parameters do not meet the standards necessary to classify Halakuki Haor as a healthy aquatic ecosystem.

Table 2: Species number, variations, and diversity (H), Richness (D), Evenness (e) from the study

Season	Month	No of species	No of individuals	Diversity (H)	Richness (D)	Evenness (e)
Winter	December	50	3035	2.966	6.851	0.6954
	January	49	3956	2.885	7.679	0.6830
	February	55	2845	2.467	7.765	0.6268
Summer	March	38	1965	2.332	5.675	0.6253
	April	41	1267	2.757	6.675	0.7413
	May	49	1645	2.906	8.767	0.7752
Rainy	June	39	1248	2.634	6.039	0.7252
	July	32	1756	2.272	5.125	0.6127
	August	49	1636	2.625	6.226	0.6875
	September	41	2023	1.812	5.166	0.4892
Autumn	October	33	1645	2.266	5.243	0.6182
	November	32	2276	1.692	4.189	0.4597
All		64	25297	2.47	6.28	0.65

Source: Field survey 2017-2018

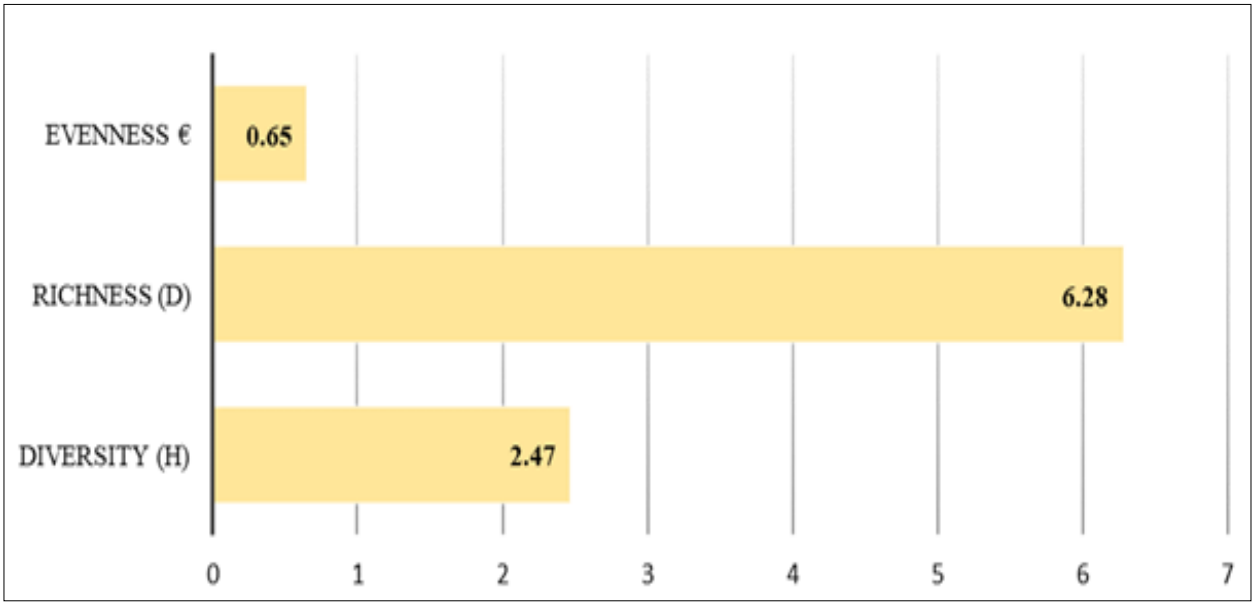

Fig 3: Present outputs of Shanon diversity index (Evenness, Richness, and Diversity)

Conservation Status of fish species

In terms of endangered fish species, the Hakaluki haor plays a crucial role as a habitat and breeding ground, and it is considered one of the four major "mother fisheries" in Bangladesh. According to Iqbal's (2015) [21] study, a total of 41 endangered fish species from 28 families were observed in the research area during the investigated period. In terms of conservation status following IUCN Bangladesh. 2015 [26], a total of 14 threatened fish species were recorded during the investigated period from the study area (Figure 4). Among them, 4 (6.25%) species were vulnerable, 8 (12.50%) species were endangered, and 2 (3.13%) species were critically endangered. Of all, 21.88% of species were considered threatened in the present study at Hakaluki Haor.

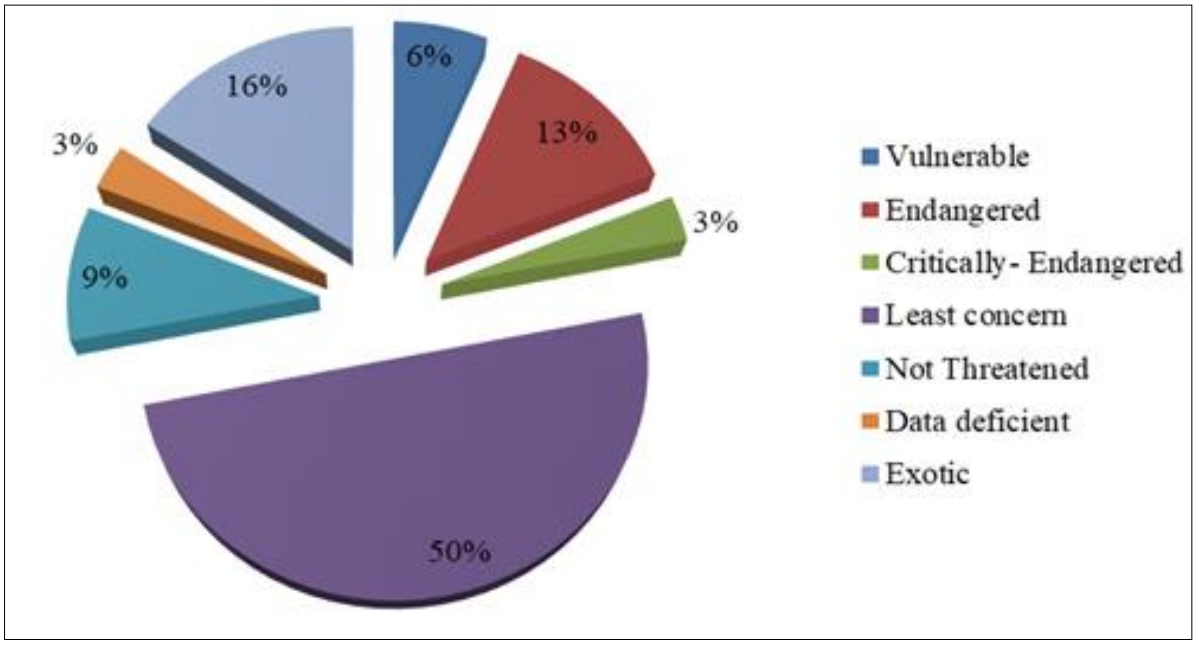

Fig 4: Percentile of fish species under conservation status based on IUCN 2015 [26].

Discussion

The present study on fish diversity of Hakaluki haor, Bangladesh represents a total of 64 species. Alternatively, Bangladesh has a total of 265 freshwater fish species (Rahman AKA, 2005) [37-40] and current research finds one-fourth of the total freshwater fish. A previous survey conducted in 1993 documented a total of 107 fish species, but the number declined to 75 and 41 in 2009, according to IPAC (2009) [20]. In 1994, a total of 130 indigenous fish species were reported to be present in the open water fisheries habitats in the area (FAP-06, 1994) [13]. A survey conducted between October 2001 and May 2002 reported a total of 107 fish species in the Hakaluki haor (CNRS, 2003) [7]. A study conducted by Rahman, *et al.* (2016) [30, 32] using the FGD method documented the presence of 75 fish species from 9 taxonomic orders in the Hakaluki Haor. This study represents that the fish species diversity of Hakaluki Haor is in decline over time by periods and species - level, but some species were having contributed to the stock equitably in past few years as shown in Figure 5 below.

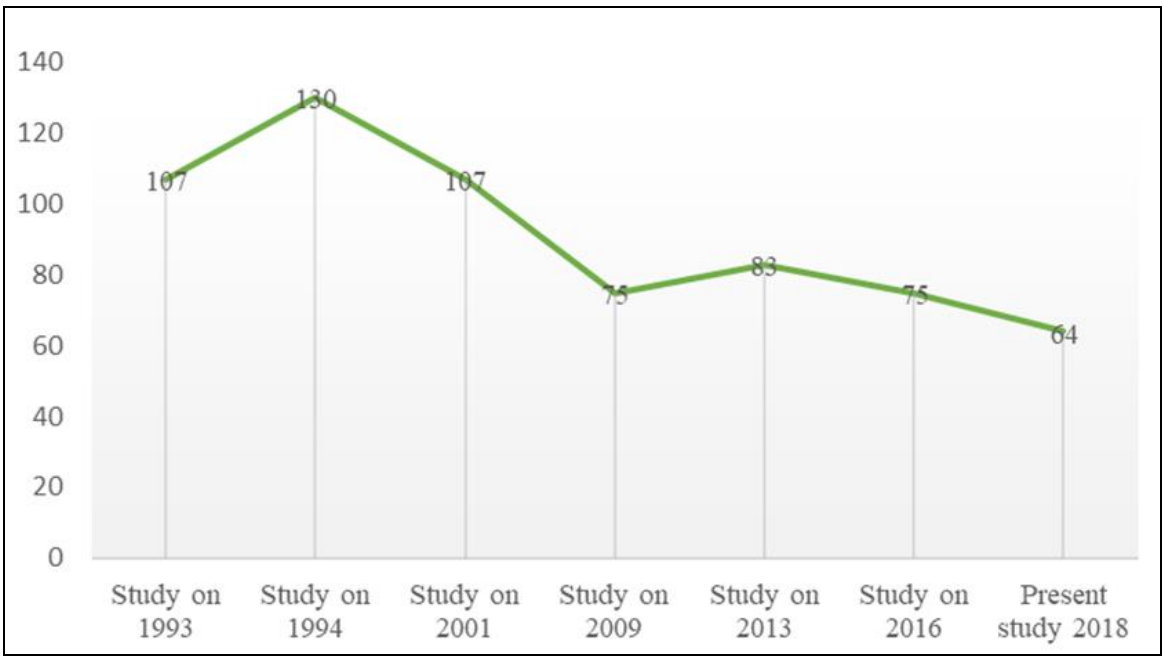

Fig 5: Trend of Fish Species from 1993 to 2018

The number of exotic fish is increased in Hakaluki Haor and the present study recorded 09 exotic species. (Iqbal, 2015; Hoque *et al*., 2021) [21, 19] found only 3 exotic species. These species are common in Bangladeshi fish farming, and they most likely managed to escape from adjoining freshwater aquaculture throughout an intense flood. These species can pose threat to native ichthyofauna (Mijkherjee et al.) [45].

The abundance of fish species was documented during the winter. The catch per unit effort (CPUE) was observed to be highest during the winter season, specifically in January, while it was lowest during the rainy season, particularly in July and August, in terms of nets. According to the findings of Md. Golam (2016), the traps yielded the highest catch per unit effort (CPUE) in February while the lowest CPUE was

recorded from June to October. This observation is consistent with the findings of previous studies conducted by Iqbal (2015) [21] and Nath (2012) [34]. Ilish (*Tenualosa ilish*) was found in very small quantities (0.025%) in the Haor during the study. The true origin of this important migratory fish may necessitate additional research. Overharvesting, a lack of waterways and native floral species, the use of prohibited fishing nets and gear are the principal causes of ecological loss in Hakaluki haor. As a consequence, the diversity of species of Hakaluki haor is dwindling. Looking at the matter from a different angle, it has been observed that in other regions of the country, the surface temperature of the Hakaluki Haor rose by 5.21 °C between 1990 and 2001, and by 2.27 °C between 2001 and 2010. From 1990 to 2015, the mean surface temperature increased at a rate of 0.27 °C to 0.41 °C per year (Mohiuddin *et al*., 2021; Islam *et al*., 2021; Hossain *et al*., 2019) [33, 28, 18]. Therefore, the increase in temperature is a matter of concern for the wetland ecology. More investigation must be led in this regard.

Socioeconomic

From study findings, the fishermen and traders who used to sell fish from Hakaluki Haor are involved with fishing for 11 to 80 years. Fishing is their primary source of livelihood. They catch fish daily and their frequency of fishing is twice a day. Quantity of fish caught by individual fishermen along with the type of fish per day. Participants retorted that the present income from fishing had decreased as compared to five years ago. Table 3 shows that the present monthly gross income of the fishermen in the peak season is Tk. 4,000 (small-scale fishermen) to Tk. 38,000 (large-scale fisherman); and in the lean season, monthly gross income is Tk. 2,000 (small-scale fishermen) to Tk. 18,000 (large scale fishermen).

Table 3: Present Net Income Earned by the Fishermen

Season	Average fish caught (Kg.)	Price per Kg. (BDT)	Market Value per Kg. (BDT)	Expenditure to catch fish (BDT)	Net-income (BDT)
Winter (Peak Season)	60-300	400	24000 120000	20000 72000	4000 38000
The rainy season (Lean Season)	30-120	500	15000 60000	13000 42000	2000 18000

Source: Field survey 2017-2018

Alternative income

The Hakaluki haor area is primarily associated with a variety of occupations, including agriculture, fishery, handloom, micro-enterprises, and livestock rearing, as the most common ones.

Conclusion

In this study, the research focused on the analysis of changes in fish species diversity in Hakaluki Haor. A total of 64 fish species belonging to 12 taxonomic orders were identified, and the results of the Shannon-Wiener index revealed that the fish diversity in the haor is low. To preserve this wetland, the government should take necessary measures to address the changes in its physio-environmental elements. The government should also establish an effective framework and enact appropriate laws while raising public awareness about the significance of conserving biodiversity. In order to preserve the biodiversity and natural resources of Hakaluki Haor, several initiatives and measures are required. These include the restoration and conservation of swamp forests, sustainable management of fishery resources, and conservation of nature, replacement of resources to ensure the sustainability of wetland ecology, providing alternative sources of income, and strengthening community-based institutions. Coordination between different government ministries, such as the Ministry of Environment Forest and Climate Change (MoEFCC), Department of Fisheries (DoF), and Department of Land, is also necessary. Local organizations including NGOs should also take a more proactive approach by leveraging available resources, providing economic support, promoting technical innovation, building capacity, ensuring good governance, and promoting gender equality.

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