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Research Article

Fish Biodiversity at Kawadighi *Haor* of Northeastern Bangladesh: Addressing Fish Diversity, Production and Conservation Status

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ABSTRACT

This research was conducted to explore the status of fish species diversity and production in the Kawadighi *Haor* of northeastern Bangladesh. Data were collected biweekly through direct catch assessment surveys, focus group discussions, and personal interviews using a questionnaire. A total of 87 fish and prawn species belonging 14 orders and 30 families were identified in the *Haor*, where 18% species were abundantly available, 20% were commonly available, 42% were moderately available and 20% were rarely available. Among the recorded species, Cypriniformes, having 34 species, had the most species, followed by Siluriformes (20), Anabantiformes (11), Ovalentaria (4), Synbranchiformes (4), Clupeiformes (3), Decapoda (3), Osteoglossiformes (2), Anguilliformes (1), Beloniformes (1), Cyprinodontiformes (1), Gobiiformes (1), Mugiliformes (1), and Tetraodontiformes (1). The values of Shannon-Weaver diversity (H), Margalef's richness (*d*), and Pielou's evenness (*J*) indices were 2.98, 7.72 and 0.67 in Hawagulaia, 2.97, 7.52 and 0.67 in Patasingra and 2.61, 7.30 and 0.59 in Salkatua *beel*, respectively. The *haor's* average yearly fish production was 704.09 kg/ha. Small indigenous species (SIS) of fish dominated the *haor's* total production, accounting for 51.8 to 70.57 percent of the total contribution. The highest portion of fish produced in the non-stocked *beel* was SIS of fish but per hectare SIS of fish production of non-stocked *beel* was lower than the fingerling stocked *beels*. Aquaculture might have a good effect on fish production and biodiversity. The findings showed that Kawadighi *Haor* is a very productive and biodiversity-rich inland open waterbody that may function as a mother fishery. For the protection of current fisheries resources, multiple approaches including public awareness campaigns might be beneficial.

Keywords: Kawadighi *Haor*, species diversity, diversity indices, aquaculture, conservation

INTRODUCTION

Bangladesh is one of the countries facing challenges both in adequately feeding its burgeoning population and improving the living standards in its below standard population. To meet the challenge, the development of an indigenous food production system for local use and also for foreign earnings is now seen as critical for achieving higher living standards. Among the different production systems, aquaculture is an important one. Floodplain, *beel* and *Haor* resources should be included for horizontal expansion for aquatic food production. Although these resources have been stopped altogether or controlled by sluice gates, embankments, communication roads, pumps, FCD (Flood control and drainage) and FCDI (flood control, drainage and irrigation) project activities for five decades (Alam et al., 2015, 2017), these have colossal potential for huge increments in fish production through aquaculture. *Haor*, a marshy wetland ecosystem in Bangladesh's northeastern region, is literally a bowl or saucer-shaped depression with some different deeper areas (locally called *beels*) that resembles an inland sea during the monsoon (BHWDB, 2012; Pandit et al., 2015, 2021) and which becomes segregated into *beels* during the dry season.

Generally, open water natural fish diversity and production are decreasing gradually except for certain fingerling stocked and co-managed waterbodies (Jannatul et al., 2015; Aziz et al., 2021; Talukder et al., 2021). Some species are disappearing from individual waterbodies (Pandit et al., 2015). Still *Haor* is richer with various resources than other parts of the country. It has a great importance in the national economy, nutrition, and rural livelihoods (Hasan, 2007). However, it is reducing gradually. Now, the degradation of biodiversity of the aquatic environment is the prime concern to the environmentalists (Jannatul et al., 2015). Leaseholders of some *beels* of the *Haor* usually stock carp fingerling as part of aquaculture in their *beels* to increase fish production. However, no sufficient information is available on the impacts of fingerling stocking on the status of fish production and biodiversity for the Kawadighi *Haor*. To fill up some of the infprmation gaps, the current study is designed to analyze the existing status of biodiversity and richness of fish fauna in the Kawadighi *Haor*, as well as to estimate the impact of aquaculture activities on fish productivity and biodiversity. The Kawadighi *Haor*, formerly a mother fishery, is now a multifunctional (FCDI) project with a gross area of 22700 hectares, bounded by the Kushiyara River in the north, the Monu River in the south and west, and the foot of the Bhatera hills in the east. In the project area, the *Haor* covers about 12,295 ha with 63 *beels* and connecting canals located in the Rajnagar upazila under the Moulvibazar district, which is further connected to the Kushiara River by Koradoyer khal (canal). Prior to gathering this knowledge, we should be conversant on the level of fish production and species diversity and the thinking of different stakeholders about aquaculture for conservation and maximum sustainable yields (Galib et al., 2009). However, very limited information is available, infact, there is no available information for Kawadighi *Haor* concerning the above matters. The present research is focused on the current biodiversity situation, production, and conservation status of Kawadighi *Haor* fish species and people's perception of the impact of aquaculture.

MATERIAL AND METHODS

Study sites

Three out of the 63 *beels* (Hawagulaia, Salkatua and Patasingra) were selected as sampling sites with Hawagulaia being a non-stocked (no fingerlings were released) *beel* and Salkatua and Parasingra being stocked (fingerlings released) *beels*. The locations of the study sites are depicted on the map (Fig. 1).

Preparation of questionnaire

A preliminary questionnaire was created and pre-tested with a focus group discussion with a small sample of respondents to ensure that the study's goals are met. During pre-testing, special care was taken to include any additional information that was not intended to be requested and completed in the draft questionnaire. The questionnaire was updated, adjusted, and reorganized based on the feedback received during pre-testing.

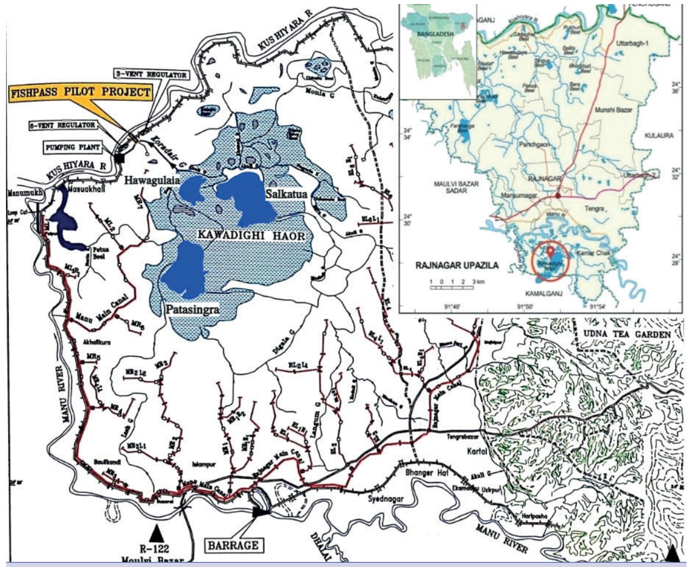

Figure 1. Kawadighi *Haor* indicating sampling sites (Modified from NERP, 1998).

Data collection procedure

Direct interviews with fishers, fish traders, and local communities were conducted to gather primary data. Cross checking was done through an interview with the upazila (sub-district) fisheries officer of Rajnagar upazila. Some focus group discussions were held using a semi-structured and structured questionnaire. Catch assessment surveys were conducted bi-weekly in each of the sampling sites during fishing from January to December 2014. The catches were identified by species and were recorded species-wise and by the number of specimens according to Rahman (2005), Shafi & Quddus (2001), and Talwar & Jhingran (1991). Based on public opinion and occurrence frequency (Percent of surveys where the researcher recorded the particular species), identified fish species were divided into four groups. The following are the categories: Abundantly Available (AA): Species seen on a regular basis all through the year (frequency > 75%); Commonly Available (CA): Species seen regularly but in limited numbers throughout the year (frequency from 51 to 75%); Moderately Available (MA): Species found occasionally in the research zone (frequency from 26 to 50%); and Rarely Available (RA): The species that are only seen infrequently and in limited quantities (frequency ≤ 25%) (Pandit et al., 2020, 2021).

Biodiversity tools and production measurement

Species diversity was analyzed using the Shannon-Weaver index (H) (Shannon & Weaver, 1963), species richness using the Margalef index (*d*) (Margalef, 1968) and evenness using Pielou's index (*J*) (Pielou, 1966).

The Shannon-Weaver index (H) is defined as:

$$\mathrm{H} = -\sum_{i=1}^{s} p_i \ln p_i$$

Where, H =Shannon-Weaver index, S = Number of species, $p_i = n_i/N$, n_i = Number of individuals of a species and N = Total number of individuals.

Margalef richness index (d) was calculated with the following formula:

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

Where,

S= Total number of species,

N= Total number of individuals.

Pielou's evenness index (J) is defined as:

$$J = H_{(S)}/H_{(max)}$$

Where,

$H_{(S)}$ =The Shannon-Weaver diversity index,

$H_{(max)}$ =The maximum possible value of the Shannon-Weaver index if all the values are identical.

Monthly net catches were determined using average catch rates and daily fishing effort for each of the gear types. The name of the species, the quantity, and weight of fish of various species in the daily catch, as well as the CPUE, were all reported on a monthly basis. Based on the monthly data, annual yield was calculated. The total fish production of each sampling site was calculated from the modified formula of Hurst & Bagley (1992) as:

Total catch from sampling sites for a specific gear = N × f × CPUE

Where, N is the number of fishing days per year,

f is the daily mean number of individual fishing unit and

CPUE is the mean daily catch per gear unit.

For monthly production, N was counted as days per month. In this way, the total catch was estimated summing the amount of catch by different gears monthly.

Data analysis

To minimize all possible errors and contradictions, the data was summarized, processed, and verified. Microsoft Excel, version 2010, was used to analyze the data. Different fish diversity indices, tables, pie charts, column diagram etc. were used to analyze and represent the data respectively.

RESULTS AND DISCUSSION

Fish biodiversity

A total of 87 fish and freshwater prawn species belonging 30 families under 14 orders was recorded from the Kawadighi *Haor* where 78 were indigenous fish, 6 were exotic fish and 3 were prawn species (Table 1). Among the families, Cyprinidae dominated with 20 species followed by Danionidae (10), Danionidae (10), Bagridae (7), Ambassidae (4), Channidae (4), Osphronemidae (4), Siluridae (4), Ailiidae (3), Clupeidae (3), Mastacembelidae (3), Palaemonidae (3), Botiidae (2), Cobitidae (2), and Notopteridae (2). Anabantidae, Aplocheilidae, Badidae, Anguillidae, Belonidae, Chacidae, Clariidae, Heteropneustidae, Gobiidae, Horabagridae, Mugilidae, Nandidae, Pangasiidae, Synbranchidae, Sisoridae, and Tetraodontidae contributed one species each.

In terms of orders, Cypriniformes had the most, with 34 species, followed by Siluriformes (20), Anabantiformes (11), Ovalentaria (4), Synbranchiformes (4), Clupeiformes (3), Decapoda (3), Osteoglossiformes (2), Anguilliformes (1), Beloniformes (1), Cyprinodontiformes (1), Gobiiformes (1), Mugiliformes (1), and Tetraodontiformes (1) (Figure 2).

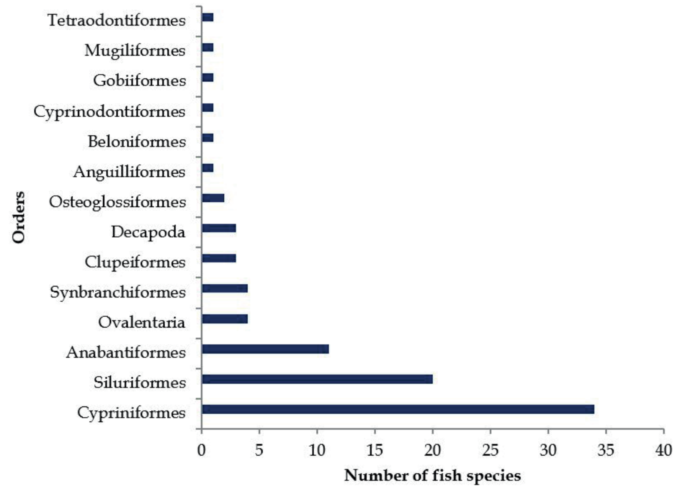

Figure 2. Fish species under different orders identified from Kawadighi *Haor*.

Any comparison of current data is difficult because there has been no previous research on fish biodiversity in the Kawadighi *Haor*. While assessing the fish biodiversity in various wetlands in Bangladesh, many other researchers had a similar experience (Galib et al., 2013; Pandit et al., 2015; Talukder et al., 2021). A total of 93 bony fish species and 2 prawn species belonging to eight orders were found in *Beel* Kumari and Hilna *beel* of Northwestern Bangladesh (Alam et al., 2017). Similarly, 92 different fish and prawn species were recorded in the Sylhet-Mymensingh basin (Haroon et al., 2002). In the 2013-14 fiscal years, in the Dekar *Haor* of Sunamganj District, a total 65 species belonging to 23 families were recorded (Pandit et al., 2015). A total of 57 species from 20 families were found in the Tilai River (Ahmed et al., 2020) and 47 fish species were found in the Borulia *Haor* of Nikli, Kishoreganj (Nath et al., 2010), which are much less than the current study. These studies indicated the Kawadighi as being a fish harbor.

Present status of fish biodiversity

The present study found 18% AA, 20% CA, 42% MA, and 20% RA fish species in the study area (Figure 3). The local fishing community assumes that this is due to declining population trends. The maximum fish species of the Gurukchi River of the Sylhet District was RA (29.82%), followed by CA (28.07%), MA (22.81%), and AA (19.30%) (Pandit et al., 2020). Another study found 17.4% AA, 27.5% CA, 31.9% MA, and 23.1% RA fish species in the Dhanu River and adjacent *Haor* ecosystems (Pandit et al., 2021). Among 87 species, *Macrobrachium lamarrei* showed the highest relative abundance (38.476%) in the Kawadighi *Haor*, followed by *Puntius sophore*, *Macrobrachium malcolmsonii*, and others (Table 1).

Table 1. List of fish and prawn species recorded from the Kawadighi *Haor* during the study period.

Order	Family	Local name	Species	Relative abundance (%)	Present availability status	Conservation status	
						BD	World
Anabantiformes	Osphronemidae	Boro kholisha	*Trichogaster fasciata* (Bloch & Schneider, 1801)	4.036	AA	LC	LC
		Choto kholisha	*T. chuna* (Hamilton, 1822)	0.032	MA	LC	LC
		Lal kholisha	*T. lalius* (Hamilton,1822)	2.297	AA	LC	LC
		Naptani	*Ctenops nobilis* McClelland, 1845	0.007	RA	LC	NT
	Anabantidae	Koi	*Anabas testudineus* (Bloch, 1792)	0.773	CA	LC	LC
	Nandidae	Meni/Bheda	*Nandus nandus* (Hamilton, 1822)	1.016	AA	NT	LC
	Badidae	Napit koi	*Badis badis* (Hamilton, 1822)	0.024	MA	NT	LC
	Channidae	Shol	*Channa striata* (Bloch, 1793)	0.060	MA	LC	LC
		Taki	*C. punctata* (Bloch, 1793)	0.820	CA	LC	LC
		Cheng	*C. orientalis* (Bloch & Schneider, 1801)	0.052	MA	LC	VU
		Gozar	*C. marulius* (Hamilton, 1822)	0.007	RA	EN	LC
Beloniformes	Belonidae	Kaikka	*Xenentodon cancila* (Hamilton, 1822)	0.812	CA	LC	LC
Mugiliformes	Mugilidae	Khorsula	*Rhinomugil corsula* (Hamilton, 1822)	0.008	RA	LC	LC
Gobiiformes	Gobiidae	Baila	*Glossogobius giuris* (Hamilton, 1822)	0.158	CA	LC	LC
Ovalentaria	Ambassidae	Gol chanda	*Pseudumbassis ranga* (Hamilton, 1822)	1.723	AA	LC	LC
		Lomba chanda	*Chanda nama* (Hamilton, 1822)	3.867	AA	LC	LC
		Kata chanda	*Pseudumbassis baculis* (Hamilton, 1822)	0.671	MA	NT	LC
		Lal chanda	*Parambassis lala* (Hamilton,1822)	0.051	CA	LC	NT
Synbranchiformes	Mastacembelidae	Tara baim	*Macrognathus aculeatus* (Bloch, 1786)	0.075	MA	NT	LC
		Boro baim	*Mastacembelus armatus* (Lacepède, 1800)	0.151	CA	EN	LC
		Chirka baim	*M. pancalus (Hamilton,1822)*	0.164	CA	LC	LC
	Synbranchidae	Kuchia	*Monopterus cuchia* (Hamilton, 1822)	0.018	MA	VU	LC
Cyprinodontiformes	Aplocheilidae	Kanpuna	*Aplocheilus panchax* (Hamilton, 1822)	0.128	CA	LC	LC
Cypriniformes	Danionidae	Chela	*Salmostoma phulo* (Hamilton, 1822)	0.167	CA	NT	LC
		Chela	*Securicula gora* (Hamilton, 1822)	0.003	RA	NT	LC
		Chela	*S. bacaila* (Hamilton, 1822)	0.061	MA	LC	LC
		Kash khaira	*Chela laubuca* (Hamilton, 1822)	0.002	RA	LC	NE
		Darkina	*Rasbora daniconius* (Hamilton, 1822)	0.103	CA	LC	LC
		Chebli	*Devario devario* (Hamilton, 1822)	0.027	MA	LC	LC

Table 1. Continue.

Order	Family	Local name	Species	Relative abundance (%)	Present availability status	Conservation status	
						BD	World
Cypriniformes	Danionidae	Darkina	*R. rasbora* (Hamilton, 1822)	1.578	AA	NT	LC
		Darkina	*Esomus danricus* (Hamilton, 1822)	3.204	AA	LC	LC
		Piali	*Cabdio morar* (Hamilton, 1822)	0.006	RA	VU	LC
		Mola	*Amblypharyngodon mola* (Hamilton, 1822)	2.174	AA	LC	LC
	Cyprinidae	Goinna	*Labeo gonius* (Hamilton, 1822)	0.040	MA	NT	LC
		Bata	*L. bata* (Hamilton, 1822)	0.177	CA	LC	LC
		Boga	*L. boga* (Hamilton, 1822)	0.160	CA	CR	LC
		Kalibaush	*L. calbasu* (Hamilton, 1822)	0.203	CA	LC	LC
		Mrigal	*Cirrhinus cirrhosus* (Bloch, 1795)	0.066	MA	NT	VU
		Katla	*Gibelion catla* (Hamilton,1822)	0.048	MA	LC	LC
		Rui	*L. rohita* (Hamilton, 1822)	0.066	MA	LC	LC
		Silver carp	*Hypophthalmichthys molitrix* (Valenciennes, 1844)	0.045	MA		NT
		Dhela	*Osteobrama cotio* (Hamilton, 1822)	0.026	MA	NT	LC
		Lachu	*Cirrhinus reba* (Hamilton, 1822)	0.085	MA	NT	LC
		Sarpunti	*Systomus sarana* (Hamilton, 1822)	0.021	MA	NT	LC
		Thaipunti	*Barbonymus gonionotus* (Bleeker, 1849)	0.059	MA		LC
		Titpunti	*P. ticto* (Hamilton, 1822)	3.092	RA	VU	LC
		Punti	*P. phutunia* (Hamilton, 1822)	0.154	CA	LC	LC
		Punti	*P. chola* (Hamilton, 1822)	1.999	AA	LC	LC
		Jatipunti	*P. sophore* (Hamilton, 1822)	17.174	AA	LC	LC
		Carpio	*Cyprinus carpio* Linnaeus, 1758	0.111	AA		VU
		Bangna	*Gymnostomus ariza* (Hamilton, 1807)	0.003	RA	VU	LC
		Grass carp	*Ctenopharyngodon idella (Valenciennes, 1844)*	0.017	MA		NE
		Bighead carp	*Hypophthalmichthys nobilis* (Richardson, 1845)	0.005	RA		DD
	Cobitidae	Gutum	*Lepidocephalichthys guntea* (Hamilton, 1822)	0.046	MA	LC	LC
		Pahari gutum	*Canthophrys gongota* (Hamilton, 1822)	0.035	MA	NT	LC
	Botiidae	Rani	*Botia dario* (Hamilton, 1822)	0.037	MA	EN	LC
		Putul	*B. lohachata* Chaudhuri, 1912	0.026	MA	EN	NE
	Clariidae	Magur	*Clarias batrachus* (Linnaeus , 1758)	0.073	MA	LC	LC
	Siluridae	Boal	*Wallago attu* (Bloch & Schneider, 1801)	0.019	MA	VU	VU
		Boali pabda	*Ompok bimaculatus* (Bloch, 1794)	0.025	MA	EN	NT

Table 1. Continue.

Order	Family	Local name	Species	Relative abundance (%)	Present availability status	Conservation status	
						BD	World
Siluriformes	Siluridae	Madhu pabda	*O. pabda* (Hamilton, 1822)	0.037	MA	EN	NT
		Pabda	*O. pabo* (Hamilton, 1822)	0.009	RA	CR	NT
	Heteropneustidae	Shingi	*Heteropneustes fossilis* (Bloch, 1994)	0.263	CA	LC	LC
	Chacidae	Chaca/ kaua	*Chaca chaca* (Hamilton, 1822)	0.001	RA	EN	LC
	Ailiidae	Garua	*Clupisoma garua* (Hamilton, 1822)	0.008	RA	EN	LC
		Bacha	*Eutropiichthys vacha* (Hamilton, 1822)	0.036	MA	LC	LC
		Kazuli	*Ailia coila* (Hamilton, 1822)	0.048	MA	LC	NT
	Horabagridae	Batashi	*Pachypterus atherinoides* (Bloch, 1794)	0.074	MA	LC	LC
	Bagridae	Air	*Sperata aor* (Hamilton, 1822)	0.010	RA	VU	LC
		Tengra	*Mystus vittatus* (Bloch, 1794)	2.928	AA	LC	LC
		Tengra	*Batasio tengana* (Hamilton, 1822)	0.031	MA	EN	LC
		Guizza	*S. seenghala* (Sykes, 1839)	0.004	RA	VU	LC
		Kabasi tengra	*Mystus cavasius* (Hamilton, 1822)	0.075	MA	NT	LC
		Gulsha	*M. bleekeri* (Day, 1877)	0.829	CA	LC	LC
		Buzuri tengra	*M. tengara* (Hamilton, 1822)	1.018	AA	LC	LC
	Pangasiidae	Thai pangas	*Pangasianodon hypophthalmus* (Sauvage, 1878)	0.009	MA		EN
	Sisoridae	Jainzza	*Gogangra viridescens* (Hamilton, 1822)	0.010	MA	LC	LC
Osteoglossiformes	Notopteridae	Foli	*Notopterus notopterus* (Pallas, 1769)	0.011	MA	VU	LC
		Chital	*Chitala chitala* (Hamilton,1822)	0.003	RA	EN	NT
Clupeiformes	Clupeidae	Chapila	*Gudusia chapra* (Hamilton, 1822)	0.445	CA	VU	LC
		Ilish	*Tenualosa ilisha* (Hamilton, 1822)	0.001	RA	LC	LC
		Ketchki	*Corica soborna* (Hamilon, 1822)	3.407	AA	LC	LC
Tetraodontiformes	Tetraodontidae	Potka	*Leiodon cutcutia* (Hamilton, 1822)	0.005	RA	LC	LC
Decapoda	Palaemonidae	Golda chingri	*Macrobrachium rosenbergii* (de Man, 1879)	0.069	MA	LC	LC
		Icha	*M. lamarrei* (H. Milne-Edwards, 1837)	38.476	AA	LC	LC
		Kalo icha	*M. malcolmsonii* (H. Milne-Edwards, 1844)	4.146	AA	LC	LC

BD = Bangladesh, MA = Moderately Available, AA = Abundantly Available, RA = Rarely Available, CA = Commonly Available, NE = Not Evaluated, DD = Data Deficient, LC = Least Concerned, NT = Near Threatened, CR = Critically Endangered, EN = Endangered, VU = Vulnerable

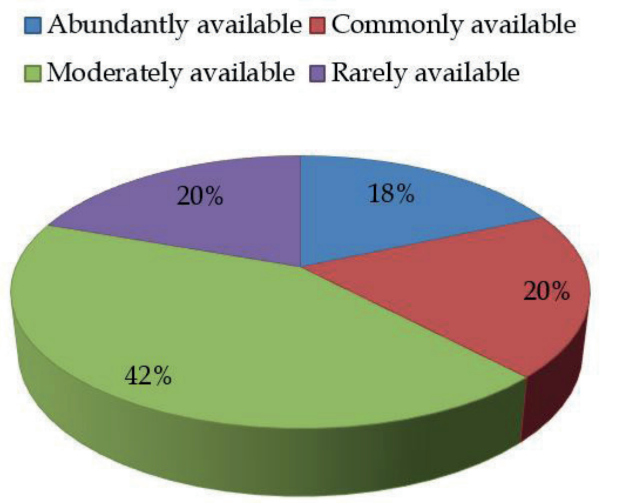

Figure 3. Current status of fish biodiversity.

Conservation status of fish

According to the worldwide conservation status (IUCN, 2021), the least concerning category (79 %) made up the largest proportion of the fish species, followed by near threatened (10 %), vulnerable (5 %), not evaluated (4 %), endangered (1 %), and data deficient (1%) (Figure 4). It is worth noting that in the research reason, globally vulnerable fish species such as *Channa orientalis*, *Cirrhinus cirrhosus*, and *Wallago attu* were found to be MA while *Cyprinus carpio* were found to be AA. The availability status of *Pangasianodon hypophthalmus* were recorded as moderately available and is considered as endangered species globally. A recent study found a very similar result: 84.6% were least concerned, 9.9% were near threatened, 3.3% were vulnerable, and 2.2% were not evaluated (Pandit et al., 2021).

The least concerned category occupied the highest position in terms of national conservation status with 45 species 52%, near

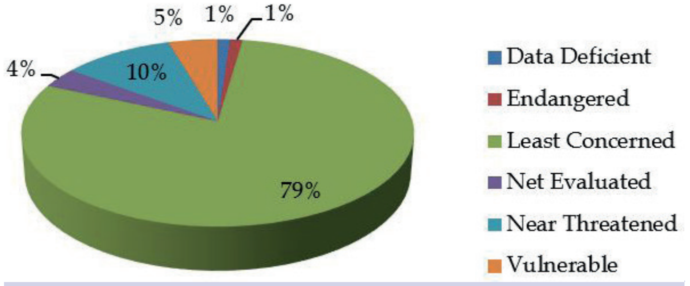

Figure 4. Global conservation status of fish species.

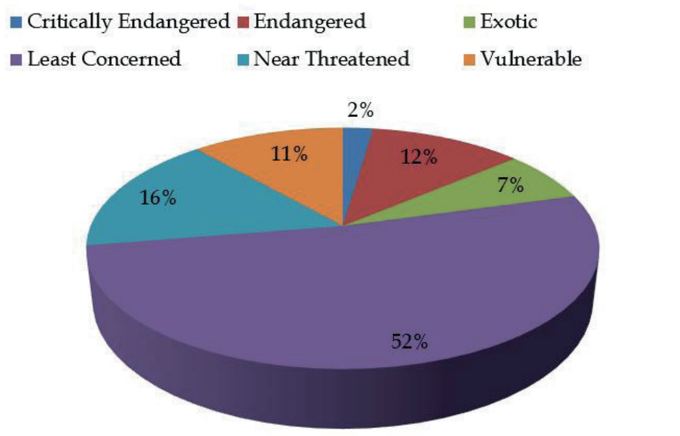

Figure 5. National conservation status of fish species.

threatened 16%, endangered 12%, vulnerable 11%, exotic species 7%, and critically endangered 2% (Figure 5). The highest 53.8% species were occupied by least concerned category, followed by 17.6% near threatened, 12.1% endangered, 11.0% vulnerable, 3.3% critically endangered , and 2.2% data deficient in the Dhanu River and its adjacent area by Pandit et al. (2021) which is very similar to the current result.

Species diversity indices

The values of Shannon-Weaver diversity (H), Margalef's richness (*d*) and Pielou's (*J*) evenness indices are presented in Table 2. As shown in Table 2, H, *d* and *J* were 2.98, 7.72 and 0.67 in Hawagulaia, 2.97, 7.52 and 0.67 in Patasingra and 2.61, 7.30 and 0.59 in Salkatua *beel*, respectively.

In floodplain lakes of India, values of H ranging from 3.61- 3.95, *J* ranging from 0.85- 0.94 and *d* ranging from 0.08- 0.12 were recorded by Mondal et al. (2010). SIS of fishes were dominant in the present study area, *d* was higher, and *J* was lower than Mondal et al. (2010). A similar H index (3.145-2.789) was found in the Meghna River estuary (Hossain et al., 2012). In the Ratargul freshwater swamp forest of Bangladesh, a higher H, *d*, and *J* value were found as 3.690±0.191, 9.497± 1.314, and 0.971±0.003, respectively (Das et al., 2017). H ranging from 3.12-2.9, *d* 3.02-2.70 and *J* 0.82-0.88 were found in Konoskhai *Haor* of Northeastern Bangladesh (Iqbal et al., 2015). In the Surma River of Sylhet district of Bangladesh, mean values of H 2.30±0.14, *d* 6.99±0.86 and *J* 1.93±0.23 were recorded (Chowdhury et al., 2019). The biodiversity parameters of the present study are in line with the previous records and any differences are maybe due to associated spatial, hydrological, and biological combined conditions of the concerned area.

Table 2. Shannon-Weaver diversity, Margalef's richness and Pielou's evenness indices of fishes of the three *beels*.

Study Area	Number of species (S)	Total Number of individuals (N)	LnN	Diversity, $H=\sum PilnPi$	Richness, $d=\frac{S-1}{lnN}$	lnS	Evenness, $J=\frac{H}{lnS}$
Patasinghra	86	81958	11.31	2.97	7.52	4.45	0.67
Shalkatua	86	115376	11.65	2.61	7.30	4.45	0.59
Hawagulia	83	41011	10.62	2.98	7.72	4.42	0.67

Species composition and production

Fish and prawns were divided into four categories: SIS of fish, large indigenous fish, large exotic fish, and prawn. SIS of fish contributed the most in all *beels*, accounting for 70.57%, 51.8%, and 63.43% in the Hawagulaia, Patasingra, and Salkatua *beel*, respectively. Large exotic fish contributed 13.72%, 26.52% and 16.11% in Hawagulaia, Patasingra and Salkatua *beel*, respectively whereas large indigenous fish was 11.4%, 26.52% and 16.11% in Hawagulaia, Patasingra and Salkatua *beel*, respectively (Fig 6). Prawn occupied the lowest position. The results show that SIS governs *Haor* production, even in the fingerling stocked *beels*, and revealed that SIS has a dominant capacity over the total fish production. Although SIS has taken over the majority of the non-supplied Hawagulaia *beel*, SIS production per hectare is lower than that of fingerling stocked *beels* (Table 3). It's possible that fingerling stocking has a good effect.

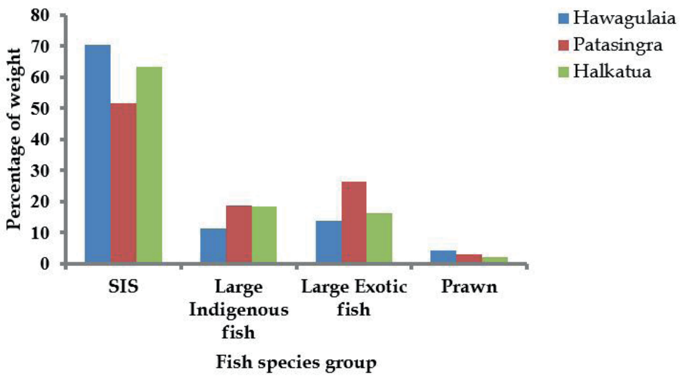

Figure 6. Composition of different fish groups and prawn.

Table 3. Production (kg/ha) of different fish groups and prawns.

Fish group	Hawagulaia	Patasingra	Salkatua
SIS of fishes	176.48	351.18	472.9
Large indigenous fish	28.5	151.87	137.1
Large exotic fish	34.3	220.92	104.1
Prawns	10.8	21.63	15.5
Total	250.08	745.6	729.6

Average annual SIS of fishes, large indigenous fish, large exotic fish, and prawn production of the *Haor* were 356.59, 139.84, 187.85, 19.81 and 704.09 kg/ha, respectively (Table 4). During the survey, the total fish and prawn production of Kawadighi *Haor* was 8656.789 MT. (Table 4).

Table 4. Annual production of different fish groups and prawns in the *Haor*.

Fish group	Haor total (MT)	Haor average (kg/ha)
SIS	4384.262	356.59
Large indigenous fish	1719.305	139.84
Large exotic fish	2309.62	187.85
Prawns	243.6018	19.81
Total	8656.789	704.09

Stakeholders' perception on the impact of aquaculture on fish production and biodiversity

There were positive and negative impacts on fish production and biodiversity. When the survey was implemented, 449 persons in the area (lease holders, fishermen, and the general public) expressed their opinions on stocking. The stakeholders' reactions are shown in Figure 7. Of the respondents, 54.12 percent made a positive comment, 35.86 percent expressed a negative comment, and the remaining 10.02 percent refused to comment. When asked whether they had complete freedom in collecting fish, the negative respondents said "no," and when asked if there is any chance of successful SIS breeding as a consequence, they said "yes", but they dewater the water bodies over the winter. From the preceding remark, it may be deduced that aquaculture may have a positive impact on boosting fish production and biodiversity in Kawadighi *Haor*.

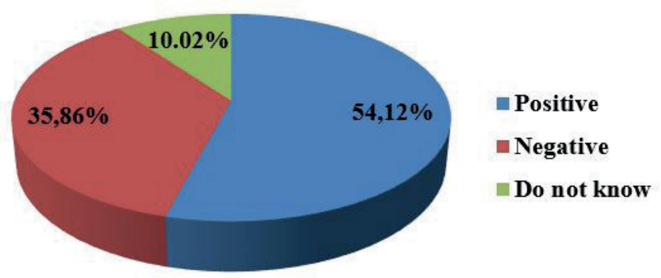

Figure 7. Stakeholders' perception on the impact of aquaculture on fish production and biodiversity in Kawadighi *Haor* (n=449).

Table 5 also indicates that in non-stocked *beel*, three large fish occupied third, fourth and ninth position among the top ten species, the rest were SIS. In the Patasingra *beel*, five large fish and the rest five were SIS and in the Salkatua *beel*, six were SIS. The freshwater shark fish *Wallago attu* occupied the third position in the non-stocked *beels* and second position in the stocked *beels* indicating a more or less successful recruitment. On the contrary, the number of exotic fish among the top ten species was highest in the Patasingra *beel* (4 species out of 10), followed by the Salkatua *beel* (3), and the Hawagulaia *beel* (2), which indicated that fingerling stocked *beels* have higher availability of non-native fishes. Alien fish species may control the local one, triggering elimination and disrupting original ecosystems.

Positive impacts of floodplain aquaculture on ecology and fish biodiversity were recorded by (Hossain et al., 2014). A positive impact of aquaculture on aquatic production and both a positive and negative impact on aquatic biodiversity were observed (Diana, 2009). All leaseholders claimed to be performing admirably in terms of fish production and biodiversity richness, both physically and ecologically. Aquaculture technology has a beneficial impact on fish productivity and biodiversity in the seasonal floodplain of Bangladesh (Rahman et al., 2010). However, there might be other factors that come into play, *viz.* depth, size, or management. Therefore, more in-depth research is necessary to find out if there are any other factors responsible.

Table 5. Top ten fish species (by weight) of the studied *beels*.

SL No	Hawagulaia beel	Patasingra beel	Salkatua beel
1	*Puntius sophore*	*Cyprinus carpio*	*Puntius sophore*
2	*Pethia ticto*	*Wallago attu*	*Wallago attu*
3	*Wallago attu*	*Puntius sophore*	*Cyprinus carpio*
4	*Cyprinus carpio*	*Pethia ticto*	*Pseudumbassis ranga*
5	*Pseudumbassis ranga*	*Hypophthalmichthys molitrix*	*Mystus vittatus*
6	*Trichogaster fasciata*	*Pseudumbassis ranga*	*Barbonymus gonionotus*
7	*Mystus vittatus*	*Ctenopharyngodon idella*	*Gudusia chapra*
8	*Mystus cavasius*	*Pangasianodon hypophthalmus*	*Hypophthalmichthys molitrix*
9	*Hypophthalmichthys molitrix*	*Trichogaster fasciata*	*Trichogaster fasciata*
10	*Nandus nandus*	*Mystus vittatus*	*Mystus cavasius*

Table 6. Factors affecting species diversity.

Serial Number	Components affecting species diversity	Number of respondents (%) n=449
1	Dewatering *beels* every year	93.98
2	Overfishing	90.86
3	Use of destructive fishing gear	86.85
4	Intensification of agricultural activities	68.81
5	Construction of road and embankment in and around the *Haor*	67.92
6	Use of pesticides	58.79
7	Sedimentation from adjacent river	56.79
8	Construction of barrage in adjacent river	52.78
9	Lack of proper fish ranching by Govt./NGO	28.95
10	Drought	22.93

Factors affecting fish biodiversity

Despite the abundance of fish species in the Kawadighi *Haor*, there are rising concerns about the long-term viability of fish biodiversity due to various anthropogenic and natural processes that are reducing biodiversity and habitats for the fishes in the *Haor* area and surrounding *beels*. Dewatering *beels* (93.98%), and overfishing (90.86%), followed by the use of destructive fishing gear (86.85%), the intensification of agricultural activities (68.81%), construction of roads and embankment (67.92%), use of pesticides (58.79%), sedimentation (56.79%), construction of barrage (52.78%), lack of proper fish ranching (28.95%), and drought (22.93%) are the most significant anthropogenic factors that have contributed to the reduction of species diversity in the Kawadighi *Haor* (Table 6). Each year lease holders dewater their *beels* and sublet them to another person who again dewaters the *beels* as some water is retained in the *beel* after the initial dewatering. A similar management problem was also found in the Dhanu River and adjacent *Haor* wetlands in the Kishoreganj district of Bangladesh (Pandit et al., 2021). Drying the *beels*, heavy rainfall, overfishing, siltation, use of destructive gear, temperature fluctuation, and the application of urea fertilizer to harvest fish all have a destructive effect on all fish fauna in Hakaluki *Haor* in northeast Bangladesh (Aziz et al., 2021). Furthermore, the absences of other income-generating opportunities for fishers, tourism, navigation, invasive fish species, and revenue-oriented leasing schemes have directly or indirectly affected fish biodiversity. Invasive fish species, in particular, may have severe effects on native species, triggering extinctions and changing natural ecosystems that were previously unknown owing to the fishermen's lack of awareness.

CONCLUSION

This research largely focused on the impact of aquaculture on the fish biodiversity and production of the Kawadighi *Haor*. Species diversity and production were found to be higher in the fingerling stocked *beels* than in the non-stocked *beel*. In contrast, the availability of many non-native fish species and their invasive tendencies indicated a worrisome current state of the fisheries resources in the *Haor*. Furthermore, ecosystem-based management of common aquatic resource pool with local community engagement is strongly advocated for the *Haor* in order to conserve fish diversity and sustainable fisheries production.

Conflicts of interest: The authors declare no conflict of interest.

Ethics committee approval: All procedures used in experiments involving human and animals (fish) were in compliance with the "Sylhet Agricultural University Ethical Committee's" ethical standards. Informed consent was obtained from all survey respondents.

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REFERENCES

Ahamed, S., Shajamal, M., Hasan, N. A., Hasan, K. R., Chowdhury, P., Kawsar, M. A., Akhter, P. & Mou, M. H. (2020). Status of fish biodiversity of Tilai River in the northern part of Bangladesh. *Journal of Entomology and Zoology Studies*, *8*(2), 1361-1367.

Alam, M. T., Hussain, M. A., Sultana, S. & Mazumder, S. K. (2017). Impact of sanctuary on fish biodiversity and production in two important *beels* of Bangladesh. *Advances in Biological Research*, *11*(6), 348-356.

Alam, M. T., Hussain, M. A., Sultana, S., Hasan, M. T., Haque, M. Z., Simon, K. D. & Mazumder, S. K. (2015). Water quality parameters and their correlation matrix: a case study in two important wetland *beels* of Bangladesh. *Ciencia e Tecnica Vitivinicola*, *30*, 463-489.

Aziz, M. S. B., Hasan, N. A., Mondol, M. M. R., Alam, M. M. & Haque, M. M. (2021). Decline in fish species diversity due to climatic and anthropogenic factors in Hakaluki *Haor*, an ecologically critical wetland in northeast Bangladesh. *Heliyon*, *7*(1), e05861. [CrossRef]

BHWDB (Bangladesh *Haor* and Wetland Development Board). (2012). Master Plan of *Haor* Area: Summary Report. Ministry of Water Resources. Dhaka: Government of the People's Republic of Bangladesh.

Chowdhury, M. A., Karim, M. A., Rahman, M. T., Shefat, S. H. T., Rahman, A. & Hossain, M. A. (2019). Biodiversity assessment of indigenous fish species in the Surma River of Sylhet Sadar, Bangladesh. *Punjab University Journal of Zoology*, *34*(1), 73-77. [CrossRef]

Das, S. K., Roy, N. C., & Hossain, M. A. (2017). Diversity of indigenous fish species in Ratargul freshwater swamp forest, Bangladesh. *International Journal of Scientific Research in Environmental Sciences*, *5*(2), 28-35. [CrossRef]

Diana, J. S. (2009). Aquaculture production and biodiversity conservation. *Bioscience*, *59*(1), 27-38. [CrossRef]

Galib, S. M., Naser, S. A., Mohsin, A. B. M., Chaki, N. & Fahad, F. H. (2013). Fish diversity of the River Choto Jamuna, Bangladesh: Present status and conservation needs. *International journal of biodiversity and conservation*, *5*(6), 389-395.

Galib, S. M., Samad, M. A., Mohsin, A. B. M., Flowra, F. A. & Alam, M. T. (2009). Present status of fishes in the Chalan *Beel*-the largest *beel* (wetland) of Bangladesh. *International Journal of Animal and Fisheries Science*, *2*(3), 214-218.

Haroon, A. K. Y., Halder, G. C., Rahman, S. L., Razzaque, M. A., Alam, M. & Amin, S. N. (2002). Sylhet-Mymensingh basin fish stock assessment. *Final Report. Bangladesh Fisheries Research Institute, Reverine Station, Chandpur, Bangladesh.*

Hasan, M. (2007). Fisheries problems and potential of the Chitra and Fatki rivers. *Bangladesh Journal of Fisheries*, *30*, 105-111.

Hossain, M. I., Hossain, M. Y. Tumpa, A. S. & Paul, A. (2014). Floodplain aquaculture: Impacts on ecology and biodiversity. *In:* Book of abstract. Sixth Biennial Fisheries Conference and Research Fair 2014. Dhaka: Bangladesh Fisheries Research Forum.

Hossain, M. S., Das, N. G., Sarker, S., & Rahaman, M. Z. (2012). Fish diversity and habitat relationship with environmental variables at Meghna river estuary, Bangladesh. *The Egyptian Journal of Aquatic Research*, *38*(3), 213-226. [CrossRef]

Hurst, R. J. & Bagley, N. W. (1992). Results of a trawl survey of barracouta and associated finfish near the Chatham Islands, New Zealand, 1985. New Zealand Fisheries Technical Report.

Iqbal, M. M., Kanon, M. H., Hossain, M. A., Hossain, A., Nasren, S., Islam, M. J. & Rahman, M. A. (2015). Diversity of indigenous fish species in Konoskhai *Haor*, Northeast Bangladesh. *Pujab University Journal of Zoology*, *30*(2), 073-079.

IUCN (2021). The IUCN Red List of Threatened Species. Version 2021-3 (1). Available online: www.iucnredlist.org (accessed on 30 November 2021).

Jannatul, M. S., Rashidul, K. M., Amzad, H. M., Arifur, R. & Iqbal, M. M. (2015). Finfish assemblage and biodiversity status of carps on halda river, Bangladesh. *Annals of Veterinary and Animal Science*, *2*(6), 151-161.

Margalef, R. (1968). Perspectives in Ecological Theory. Chicago: University of Chicago Press. ISBN 13: 9780226505053.

Mondal, D. K., Kaviraj, A. & Saha, S. (2010). Water quality parameters and fish biodiversity indices as measures of ecological degradation: a case study in two floodplain lakes of India. *Journal of Water Resource and Protection*, *2*, 85-92. [CrossRef]

Nath, P. C. D, Debnath, S. K., Sharmin, R., Benerjee, S., Faroque, M. G. & Ali, M. M., 2010. A study on the fish biodiversity of Borulia *Haor*, Nikli, Kishoregonj. *International Journal of Biological Science, 1*, 37-41.

NERP (Northeast Regional Water Management Project). (1998). Final Fishpass Pilot Project Completion Report (Main Report). Dhaka.

Pandit, D., Kunda, M., Harun-Al-Rashid, A., Sufian, M. A. & Mazumder, S. K. (2015). Present status of fish biodiversity in Dekhar *Haor*, Bangladesh: a case study. *World Journal of Fish and Marine Sciences*, *7*(4), 278-287.

Pandit, D., Kunda, M., Ray, D. & Harun-Al-Rashid, A. (2020). Availability and diversity of fish fauna in the Gurukchi River of Sylhet district in Bangladesh. *Journal of Sylhet Agricultural University*, *7*(1), 1-14.

Pandit, D., Saha, S., Kunda, M., & Harun-Al-Rashid, A. (2021). Indigenous Freshwater Ichthyofauna in the Dhanu River and Surrounding Wetlands of Bangladesh: Species Diversity, Availability, and Conservation Perspectives. *Conservation*, *1*(3), 241-257. [CrossRef]

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of theoretical biology*, *13*, 131-144. [CrossRef]

Rahman, A. K. M. (2005). Freshwater Fishes of Bangladesh. Dhaka: Zoological Society of Bangladesh. ISBN 984-32-2180.

Rahman, M. F., Barman, B. K., Brakel, M. L., Dewan, S. & Martin, V. (2010). Impacts of technological interventions on fish production and biodiversity of seasonal floodplains in Bangladesh. CBFC Working Paper 1. Penang, Malaysia: The WorldFish Center.

Shafi, M. & Quddus, M. M. A. (2001). Bangladesher Matshaw Sampad (Bangla). Dhaka: Kabir Publications.

Shannon, C. E. & Weaver, W. J. (1963). The Mathematical Theory of Communication. Urbana: University of Illinois Press.

Talukder, M. R., Hussain, M. A., Kunda, M., Rashid, A. H. A., Pandit, D. & Sumon, T. A. (2021). Checklist of fish species in the Shari-Goyain River, Bangladesh: Threats and conservation measures. *Indian Journal of Geo-Marine Science*, *50*(2), 48–155.

Talwar, P. K. & Jhingran, K. (1991). Inland Fishes of India and Adjacent Countries. Calcutta: Oxford and IBH Publishing Co. Pvt. Ltd.