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Research article

Establishment of a fish sanctuary for conserving indigenous fishes in the largest freshwater swamp forest of Bangladesh: A community-based management approach

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ABSTRACT

Fish sanctuary is considered as an important structural management tool for restoring fish biodiversity and enhancing fisheries production. Therefore, this study was conducted in the Ratargul Swamp Forest (RSF) of Bangladesh to evaluate the impact of a fish sanctuary on native fish biodiversity in and around the forest ecosystem. The investigation was carried out through focus group discussions, personal interviews, and direct catch assessments during fishing operations by the local fishers. After two years of study, 65 species of indigenous fishes were recorded for 46 genera under 23 families covering 9 orders, where Cypriniformes and Cyprinidae are the dominant order and family, respectively. After the establishment of the fish sanctuary, there was an increasing tendency of fish population was observed in the RSF and the adjacent Shari-Goyain and Kapna Rivers. In the RSF, fish diversity indices such as Simpson dominance index (D), Shannon-Wiener diversity index (H), Margalef richness index (d), and Pielou evenness index (J) varied from 0.12-0.09, 2.77–2.98, 6.15–6.14, and 0.66–0.71, respectively indicating species diversity enrichment in the final year compared to baseline assessment year which is supposed to be associated with the impact of fish sanctuary establishment. That assumption is further supported by remarkable increase in average fish catch (11.38%). Local fishers and people adjacent to RSF perceive that sanctuary became useful for protecting biodiversity, increasing fish production as well as improving their livelihood conditions.

1. Introduction

Bangladesh possesses the largest river delta in Asia, consisting of more than 700 rivers, floodplains, *beels*, and *haor* areas (DoF, 2019; Pandit et al., 2021). Consequently, it has the third largest aquatic fish biodiversity in Asia, enriched with about 800 species of freshwater, brackish water, and marine fishes (Hussain and Mazid, 2001). Among those, a total of 253 fish species are found in the different freshwaters of Bangladesh (IUCN Bangladesh, 2015). However, around 64 species of those are now endangered, critically endangered, or in vulnerable conditions (IUCN Bangladesh, 2015). Indiscriminate fish harvest, climatic degradation, and numerous anthropogenic causes adversely affect the fish biodiversity in the natural waterbodies (Nagelkerken et al., 2017; Islam et al., 2019; Pandit et al., 2021, 2022; Tikadar et al., 2021). In particular, a considerable number of freshwater riverine fish species have become highly endangered due to habitat degradation as a consequence of extreme anthropogenic intervention (Rahman et al., 2012). However, the rivers are usually connected to many other waterbodies like *haors*, swamps, *beels*, lakes, floodplains, etc., which are also breeding and nursing places for many riverine species and thus closely associated with the fish stocks.

A *haor* is a type of complex wetland ecosystem covered with grass, weeds, and woody plants, consisting of hundreds of interconnected *beels*, canals, swamps, rivers, and streams (Hussain and Salam, 2007; Pandit et al., 2021). This *haor* region is located in the north-eastern part of Bangladesh and covers 25% area of this region (Pandit et al., 2015a, b). There are nearly 411 *haors* covering an area of approximately 8,000 km^2 scattered in Sunamganj, Sylhet, Moulvibazar, Habiganj, Netrakona, Kishoreganj, and Brahmanbaria districts (Pandit et al., 2015a; 2015b). The aquatic diversity of the *haor* region consists of 143 indigenous and 12 exotic fish species, together with a few species of freshwater prawns (BHWDB, 2012). Due to sudden flash floods and anthropogenic activities,

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the *haors* are currently dramatically silted up. Over-exploitation of fish is a common activity in the *haor* area (BHWDB, 2012; Pandit et al., 2015b, 2022). The term '*beel*' is a Bengali word generally used for relatively large surface, static waterbody that accumulates surface run-off water through an internal drainage channel. The estimated *beel* area of Bangladesh is about 114,161 ha, which is about 27.00% of the total inland waters of Bangladesh (Ahmed et al., 2007). Many aquatic species and fishes, including juveniles and larvae, take shelter in the *beel* as it is highly productive and enriched with nutrients, organic debris, and vegetation (Graaf, 2003). Swamp forests occur along riverbanks or lakes and tolerate periodic inundation. They form a complex ecosystem with vegetation and wetland forest and are critical in storing and maintaining ground and surface water (Roby and Nair, 2006; Keddy, 2010). Due to the accumulation of free water, they corroborate characteristic vegetation considering exclusive edaphic conditions (Gupta et al., 2006). Ratargul Swamp Forest (RSF) is the only recognized freshwater swamp forest in Bangladesh. It is located in the Gowainghat upazila of Sylhet district, covering an area of about 204 ha (Hossain et al., 2016). This area receives vast amount of water from the Shari-Goyain River, which is inundated by flash floods from Indian hill tracts (Talukder et al., 2021). According to Das et al. (2017), this forest ecosystem now shelters 62 indigenous fish species, including 28 threatened species. Additionally, 73 species of trees, 26 species of mammals, 20 species of reptiles, 175 species of birds, and 9 species of amphibians are available in this forest (Jahan and Akhter, 2018).

Fish sanctuary is a particular form of protected area in waters and is considered to be an important and efficient managing tool for the protection, conservation, and management of fisheries resources (Islam et al., 2016a; Khan et al., 2018). Generally, it can be defined as a prescribed area of particular waters together with buffer zone where fishing is strictly prohibited. Fish and other aquatic organisms can take shelter, survive, and reproduce without any disturbance (Islam and Hossain, 2019). In 1960–1965, the Department of Fisheries (DoF) established 23 fish sanctuaries in several floodplain waters under the Development and Management Scheme. Another 25 sanctuaries were established by the DoF under the same scheme in 1960–1965 based on the positive outputs of the previously established sanctuaries. Later on, under the Integrated Fisheries Development Project, 10 more fish sanctuaries were established by the DoF in 1987. Until 2007, a total of 464 permanent fish sanctuaries were established at different times in different waters, covering an area of about 1,746 ha (Ali et al., 2009). Besides, as a part of the *Hilsa* conservation programme, a total of six *Hilsa* sanctuaries were established by the DoF in the Meghna River in 2015 (DoF, 2015). It was reported that all the established fish sanctuaries have positive impacts on fish biodiversity and production (Ali et al., 2009). Therefore, many scientists have recommended establishing fish sanctuaries in the various freshwater environments of Bangladesh (Pandit et al., 2015a, 2021; Khan et al., 2018; Akter et al., 2020; Talukder et al., 2021).

The RSF is an ecologically protected area and a reputed tourist spot for its unique view of numerous aquatic flora and fauna. Some studies have already been conducted in the RSF considering plant diversity, aquatic faunal diversity, indigenous fish species diversity, factors affecting biodiversity, impact of ecotourism, etc (Choudhury et al., 2004; Islam et al., 2016b; Das et al., 2017; Jahan and Akhter, 2018). Those studies showed that fish diversity, as well as other ecosystem services of the forest, are in declining condition due to various manmade, natural, and government policy related drivers (Islam et al., 2016b). However, the availability of threatened fish species in different ditches of this swamp forest reflects its ecological potential to be a suitable site for fish conservation (Das et al., 2017). An ecosystem based management approach with local community participation is necessary for the sustainable utilization of the forest resources (Islam et al., 2016b; Das et al., 2017). Therefore, a community managed fish sanctuary was established through the project "Techniques Adoption and Formulation of Guidelines for Sustainable Management of *Haor* and *Beel* Fisheries" in the Rangakuri *Beel* of the RSF, implemented by the Department of Aquatic Resource Management, Sylhet Agricultural University, Sylhet for the conservation and restoration of fish biodiversity. Finally, the main objective of the present study was set to assess the impact of the fish sanctuary on the indigenous fish biodiversity in the RSF and adjacent waters.

2. Materials and method

2.1. Establishment of fish sanctuary

2.1.1. Location of the fish sanctuary

The RSF is located in Gowainghat upazila of Sylhet district in Bangladesh consisting of five *beels* namely Rangakuri, Athalukuri, Chilukuri, Mendukuri, and Charukuri. A 0.5 ha fish sanctuary was established in March 2019 in the Rangakuri *Beel* covering an area of around 10 ha. The fish sanctuary is located at 25°00′48.62″ N latitude and 91°55′31.02″ E latitude in the RSF (Figure 1). The sanctuary was constructed in order to conserve, protect, and restore fish biodiversity and enhance fish production in the adjacent wetlands of RSF. The depth of water inside the sanctuary remained at 1.5–2.5 m in dry seasons during the study period.

2.1.2. Sanctuary preparation

At first, the site for sanctuary establishment was decided based on suitable water depth followed by the preparation of an artificial structure at the selected site to provide a safe hiding place for fishes. During construction, about 320 bamboo poles (approximately 9.14–13.72 m in length) were placed surrounding the selected area where each bamboo pole is held down about 1.0 m in the bottom soil to keep it in a strong and vertical position. About 80 long bamboos with branches tied with bamboo poles by using galvanized iron wire (GI) and nylon rope to encircle the boundary as well as fix aquatic weeds, branches, and roots of different trees. Inside the fish sanctuary, 200 branches and 30 roots of trees were tied by GI wire with the different bamboo poles. Thus, the bamboo poles, branches, and roots of trees were a nice fish habitat and shelter for fishes and other aquatic organisms. Branches and roots of different trees like hijal (*Barringtonia acuitangula*), black-berry (*Syzygium cumini*), and jarul (*Lagerstroemia speciosa*) were used. Additionally, water hyacinths (*Eichhornia crassipes*) were used to provide sheds to the fishes. Red flags and a large sign board were used for the demarcation of the sanctuary area and buffer zone. Fishing was strictly prohibited within 500 m of the fish sanctuary.

2.2. Establishment of pen

2.2.1. Pen preparation

A pen was established beside the sanctuary for rearing mola (*Amblypharyngodon mola*) and dhela (*Ostreobrama cotio*) broods. A square-shaped 0.1 ha area was selected for pen preparation. The pen was constructed with 50 bamboo poles. Each of the bamboo poles were dug vertically around 1 m into the bottom soil of the selected area. The surroundings of the pen were thoroughly covered with a fine meshed net with the help of nylon rope. All the bamboos were tied with horizontal bamboo by using GI wire. The water depth of the pen remained between 1.5 and 2.0 m during the summer season.

2.2.2. Brood collection and transportation

Broods of mola and dhela were collected from different places in Gowainghat and Golapganj upazilas of Sylhet district. Brood fishes were transported in polybags of which two-third was filled with oxygen. After transportation, the collected broods were stocked in a pond nearby the RSF for rearing a few days before stocking into the pen.

2.2.3. Stocking of broods and releasing the offspring

A total of 60 kg of mola and 10 kg of dhela broods were stocked during April 2019 in the previously constructed pen and reared for two months. Soon after first breeding, all the fishes with offspring were

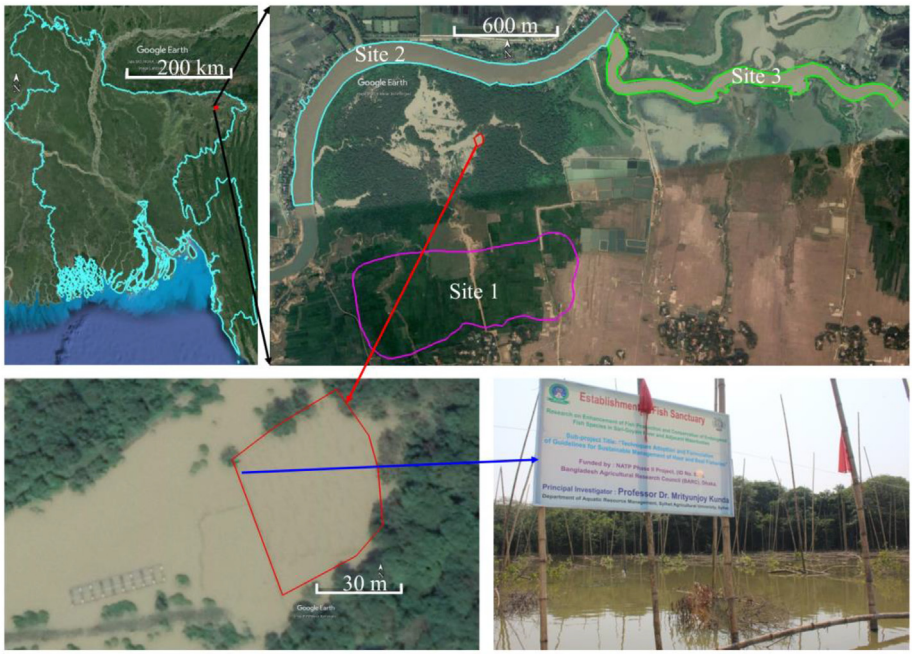

Figure 1. Map of study area showing site 1 (Floodplains of the Ratargul Swamp Forest), site 2 (The Shari-Goyain River), and site 3 (The Kapna River) [Google Earth Pro] with some camera pictures of the sanctuary.

allowed to leave the pen and spread to the surrounding waters by removing the net of the pen.

2.3. Community based management of fish sanctuary and pen

Community based management approach was used to manage the fish sanctuary. A management committee was formed mainly consisting of surrounding community people with an emphasis on fishers' community for the management and protection of the fish sanctuary and pen. The committee was formed including women, fishers, boatmen, and local leaders. A group leader was selected among committee members according to the opinions of all members. All the committee members agreed to follow the instructions for better management of the sanctuary and pen. The committee took on the responsibility of protecting the fish

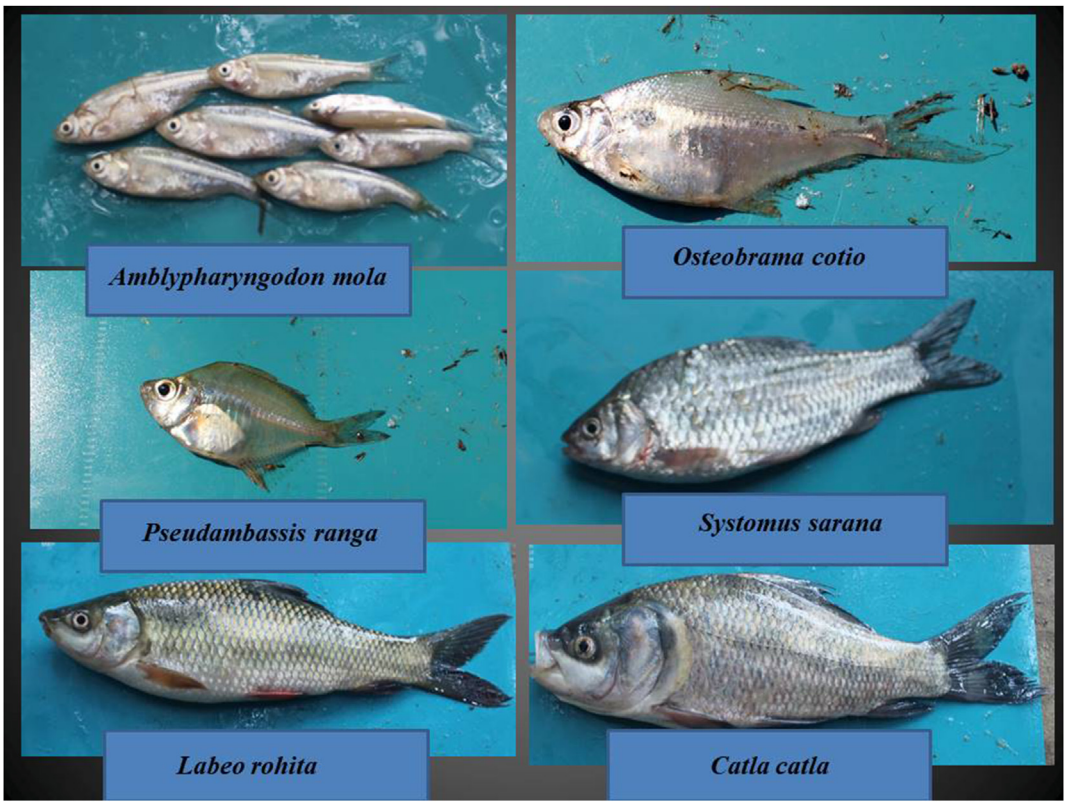

Figure 2. Collected fishes from the study area during catch assessment.

sanctuary, having received motivational training from the research team. A year-round ban on fish catch was imposed in and around 500 m of the sanctuary. To prevent fish poaching, two people were periodically selected as night guards among the committee members. All the members of the committee were very conscious about protecting the sanctuary and they are actively involved in the repair of the sanctuary, reintroduction of species, management of the pen, etc.

2.4. Awareness building activities

Awareness building activities were conducted considering as important tool for better management of the pen and *katha* in the RSF. Monthly meetings were organized by the project personnel with the fisher's community and local people about the management of the sanctuary and its benefits. Various types of awareness building activities like using selective gear with appropriate mesh size, harmful effects of poison fishing, *katha* fishing, fishing by dewatering, catching of fry from wild habitat, water pollution, etc. were discussed in the meeting. The importance of a sanctuary with buffer zones and the contribution of such sanctuary in increasing aquatic biodiversity and fish production were also discussed.

2.5. Data collection and fish sampling process

Baseline data were collected from March 2018 to February 2019 (baseline year) and March 2019 to February 2020 was considered as impact year for the study. Data were collected by direct sampling of fishes at four seasons per year viz. pre-monsoon (March–May), monsoon (June–August), post-monsoon (September–November), and dry/winter season (December–February). Weighing balance (Model: EK600i, Japan) and a camera (Model: Canon DS126491, Canon INC., Made in Taiwan) were used to take sample weight and capture pictures, respectively for further use and documentation.

2.5.1. Selection of sampling sites

RSF was declared as a 'Special Biodiversity Protected Area' by the by the Ministry of Environment and Forests of Bangladesh, where all types of fishing practices were strictly prohibited. In the pre-monsoon and monsoon seasons, it was possible to collect regular catch data from the surrounding floodplain areas of the RSF as it was inundated for 4–5 months. During the dry season, the river water went down and the forest wetlands became disconnected from the river which made it difficult to collect regular catch data from the area. However, there are a number of seasonal shallow wetlands surrounding the five *beels* which naturally dry up in the dry season. Local fishers catch fish from those seasonal ditches and data were taken accordingly.

For catch assessment survey the following sites (Figure 1) were selected:

1. Floodplains and *beels* of the RSF
2. Jalurmukh Bazar to Motorghat on the Shari-Goyain River
3. Two kilometers area of the Kapna River adjacent to RSF

2.5.2. Focus group discussions

A total of 25 focus group discussions were arranged across the study sites, each consisting of 5–8 members. A semi-structured questionnaire was used during the focus group discussions. Fishers among the group described the past and present status of the swamp forest, fish biodiversity, production, livelihoods, and various points related to fish harvest.

2.5.3. Personal interviews

To evaluate the previous and present conditions of the fisheries biodiversity and production in the study area, a total of 170 personal interviews of fishers were conducted using a semi-structured questionnaire. During personal interviews, fishers were asked about the past and present condition of the waters, especially the impacts of the fish sanctuary on fish biodiversity and production of the RSF and adjacent waters.

2.5.4. Catch assessment, sampling, and identification

Catch assessment was done once a month using seine net, cast net, gill net, and fish traps from each of the study sites. Questions were asked to the fishers about their daily catch according to previously made semi-structured questionnaire. Most of the species were identified by fishers' experience, our research team's expertise, and a pictorial checklist of freshwater fish species of Bangladesh.

The weight of the total catch and each sampled fishes were taken by using a balance (Model: EK600i, Japan). Total numbers of individuals were identified for each of the species. The big fish species were counted and weighed individually, but in case of small fishes, it was difficult to count all the fishes. Therefore, to count the number of small fishes in the total catch, the following formula was used,

$$\mathrm{N} = \frac{Ns \times Wt}{\mathrm{Ws}} \tag{1}$$

where, N is the number of individual small fish in the total catch, *Ns* is the number of individual small fish in each sample, *Wt* is the total weight of small fish found, and *Ws* is the weight of each sample.

Some specimen fish samples covering all different varieties were collected from the fishers during direct catch assessment (Figure 2). The collected samples were stored in a portable ice box and transported to the laboratory at the Department of Aquatic Resource Management, Sylhet Agricultural University, Sylhet for further identification and cross-checking. The collected fish samples were identified at species level by analyzing their morphometric and meristic characteristics according to standard procedures (Talwar and Jhingran, 1991; Siddiqui et al., 2007). The valid scientific names and present conservation status of the identified fish species were ensured by checking with the IUCN Red List (IUCN Bangladesh, 2015) and FishBase (Froese and Pauly, 2021). By using the outcomes of interview and the catch records of fishers, the identified fish species were categorized into four groups as i) abundantly available (AA): species plentifully observed throughout the year with higher frequency (frequency of occurrence: 76–100%); ii) commonly available (CA): species frequently observed throughout the year in small numbers (frequency of occurrence: 51–75%); iii) moderately available (MA): species observed infrequently in the study area in small numbers (frequency of occurrence: 26–50%); and iv) rarely available (RA): species observed occasionally in very small numbers and frequency (frequency of occurrence: 1–25%) based on their availability (Pandit et al., 2020, 2021). A comparison of the availability status was determined for each species.

2.6. Data processing and analysis

2.6.1. Fish diversity indices

Fish diversity was studied through Shannon-Wiener diversity index (Shannon and Wiener, 1949), Margalef species richness index (Margalef, 1968), Pielou's evenness index (Pielou, 1966) and Simpson's dominance index (Simpson, 1949).

$$\text{Shannon} - \text{Wiener diversity index (H)} = -\sum_{i=1}^{s}[Pi \times \ln(Pi)] \tag{2}$$

where,

Pi = ni/N
ni = No. of individuals of a species.
N = Total number of individuals.
S = Total number of species

$$\textit{Margalef species richness (d)} = (S\text{-}1)/\log(N) \tag{3}$$

$$\textit{Pielou evenness index (J)} = H(s)/H(max) \tag{4}$$

where, H (s) = Shannon-Weiner index.

H *(max)* = the theoretical maximum value for $H(s)$ if all species in the sample will be equally abundant

$$\text{Simpson's dominance index (D)} = 1 - \left(\frac{\sum n(n-1)}{N(N-1)}\right) \quad (5)$$

where,

n = The total number of individuals of a species,

N = The total individuals of all species.

2.6.2. Statistical analysis

Collected data about fish diversity indices and fish production were analyzed by Statistical Package for the Social Sciences version 20.0 and Microsoft Office Excel (version 2010). One-way Analysis of Variance was used for statistical analysis at 5% level of significance. To evaluate similarities in fish abundance and structural variation in fish communities, the software Plymouth Routines Multivariate Ecological Research version 6 was used to perform non-metric multidimensional scaling (nMDS) and cluster analysis.

2.7. Ethical approval

The unique experimental design was approved by the Ethics Committee of the Department of Aquatic Resource Management, Sylhet Agricultural University, Sylhet, Bangladesh.

3. Results

3.1. Present status of fishes from order to family to species diversity in the Ratargul Swamp Forest

During the study period, a total of 65 species of indigenous fishes were recorded in the RSF, belonging to 46 genera, 23 families, and 9 orders (Table 1). Among nine orders, Cypriniformes was found as the most dominant order covering 35.38% species of fish. The subsequent orders were Siluriformes (26.15%), Perciformes (21.54%), Synbranchiformes (7.69%), Clupeiformes (3.08%), and Beloniformes, Cyprinodontiformes, Osteoglossiformes, and Tetraodontiformes, each covering 1.54% species (Figure 3).

Among 23 families, the Cyprinidae was the most diversified, consisting of 27.69% of total native fish species. The subsequent families were followed by Bagridae (13.85% species), Cobitidae (6.15%), Mastacembelidae (6.15%), and Osphronemidae (6.15%). The families Ambassidae, Channidae, and Siluridae each consisted of 4.62% species. Each of Clupeidae and Schilbeidae covered 3.08% species and other families each of them contributed 1.54% species (Figure 4). Among the recorded indigenous species of fish, the maximum number of species (37) was found in the least concern category (LC), followed by 12 species as near threatened (NT), 8 species as vulnerable (VU), 7 species as endangered (EN) and only 1 species as data deficient (DD) (Table 1).

3.2. Seasonal variation of species diversity indices in the Ratargul Swamp Forest

Among the four seasons, the highest number of fish species in the RSF was recorded in the monsoon (61), followed by the post-monsoon (54), winter (47), and the lowest number of species recorded in the pre-monsoon season (36) (Figure 5).

Diversity, dominance, evenness, and richness indices were also calculated for four seasons in the RSF to evaluate the seasonal variation of fish species diversity. The highest value of Simpson dominance index (D) was 0.17 in the dry season and the lowest was 0.08 in the post-monsoon. The highest value of Shannon-Wiener index (H) was found in post-monsoon (2.98) and lowest value was found in dry season (2.58). Margalef richness index (d) values varied from 5.09 (dry season) to 6.26 (monsoon). The maximum value of Pielou evenness index (J) was 0.80 (post-monsoon) and the minimum value was 0.68 (dry season) (Figure 6).

3.3. Impact of fish sanctuary on fish diversity indices in the Ratargul Swamp Forest and adjacent waters

To estimate changes in species diversity, the diversity indices were calculated where no significant changes were observed between the baseline and final year at 5% level of significance. In the RSF, Simpson dominance index (D) was 0.12 in the baseline year and after one year it was found to be 0.09. The Shannon index (H) increased from 2.77 to 2.98 and the Margalef richness index (d) decreased from 6.15 to 6.14. Pielou evenness index (J) also increased from 0.66 to 0.71 (Table 2).

In case of the Shari-Goyain River, Simpson dominance index (D) was 0.13 in the baseline year and after one year it was found 0.12. The Shannon-Weiner index (H) increased from 2.57 to 2.61 and the Margalef richness index (d) decreased from 5.72 to 5.48. Pielou evenness index (J) also increased from 0.63 to 0.64 (Table 2).

In case of the Kapna River, Simpson dominance index (D) was 0.14 in the baseline year and after one year it was calculated 0.1. The Shannon-Wiener index (H) increased from 2.71 to 2.89 and the Margalef richness index (d) decreased from 6.31 to 6.30. Pielou evenness index (J) also increased from 0.67 to 0.72 (Table 2).

3.4. Impact of fish sanctuary on the species availability status in the Ratargul Swamp Forest and adjacent waters

During the present study, 65 species of fishes were observed in the RSF, where the numbers of fish species were stable, but the availability status of many species was found to be increasing in the RSF. The availability status of fishes was positively changed after one year of the establishment of the sanctuary. Abundantly available and commonly available species were increased in their numbers by comparing baseline status 10 and 11 to 15 and 21, respectively (Table 3). After one year of the establishment of the sanctuary, 56.92% of the total fish population remained stable, 35.38% were found to be increasing and only 7.69% were found to be decreasing (Table 1).

During the study period, a total of 58 species of different fish species were recorded in the Shari-Goyain River. Before the sanctuary was established, the abundantly available and commonly available fishes in this river were 15.51% and 24.14%, respectively. However, after one year those were increased to 20.68% and 29.31%, respectively. Conversely, the moderately available and rarely available species decreased from 29.31% and 31.03%–27.58% and 22.41%, respectively (Table 3). These results indicate the positive impact of the established sanctuary.

Total 57 species of fishes were recorded in the Kapna River throughout the study period. Before the establishment of the sanctuary, the abundantly available, commonly available, and moderately available fishes were 17.54%, 22.81%, and 26.32%, respectively. But, after one year of the establishment of the sanctuary it was found 22.81%, 29.82%, and 28.07%, respectively. Conversely, the rarely available species decreased from 33.33 to 19.29% (Table 3).

3.5. Non-metric multidimensional scaling (nMDS)

To study seasonal commonalities in fish abundance in the RSF, nMDS analysis was performed. Results of nMDS revealed 40% similarity across all seasons. Two distinct groups were formed in 60% similarities in fish abundance where monsoon, post-monsoon, and winter showed a single group and pre-monsoon showed a separate group (Figure 7).

Cluster analysis revealed a clear structural variation in fish communities among the three sites at different sampling time (Figure 8). At the similarity level of 55.75% separation, two major clusters were observed for both baseline data and final sampling data. The first cluster consists of

Table 1. List of available fish species in and around the Ratargul Swamp Forest.

Sl. no.	Taxonomic position	English name	Local name	IUCN status in BD	Availability status		Population status
					Baseline	Impact year	
	Beloniformes						
	Belonidae						
1	*Xenentodon cancila*	Freshwater garfish	Kakila	LC	MA	MA	ST
	Clupeiformes						
	Clupeidae						
2	*Gudusia chapra*	Indian river shad	Chapila	VU	AA	AA	ST
3	*Corica soborna*	Ganges river-sprat	Kaski	LC	RA	RA	ST
	Cypriniformes						
	Cyprinidae						
4	*Amblypharyngodon mola*	Mola carplet	Mola	LC	RA	AA	IN
5	*Amblypharyngodon microlepis*	Indian carplet	Mola	LC	MA	CA	IN
6	*Esomus danricus*	Flying barb	Darkina	LC	MA	CA	IN
7	*Rasbora daniconius*	Slender barb	Darkina	LC	MA	CA	IN
8	*Osteobrama cotio*	Cotio	Dhela	NT	RA	MA	IN
9	*Devario devario*	Sind danio	Chepchela	LC	MA	MA	ST
10	*Salmophasia bacaila*	Large razorbelly minnow	Narkeli chela	LC	RA	MA	IN
11	*Salmophasia phulo*	Finescale razorbelly minnow	Fulchela	NT	MA	AA	IN
12	*Catla catla*	Catla	Catla	LC	MA	RA	DE
13	*Cirrhinus cirrhosus*	Mrigal carp	Mrigal	NT	MA	MA	ST
14	*Cirrhinus reba*	Reba	Laso	NT	RA	RA	ST
15	*Labeo calbasu*	Black rohu	Kalibaosh	LC	CA	CA	ST
16	*Labeo gonius*	Kuria labeo	Gonia	NT	CA	MA	DE
17	*Labeo rohita*	Rohu	Rui	LC	MA	MA	ST
18	*Pethia guganio*	Glass barb	Mola punti	LC	RA	CA	IN
19	*Systomus sarana*	Olive barb	Sarpunti	NT	RA	RA	ST
20	*Puntius sophore*	Spotfin swamp barb	Jat punti	LC	AA	AA	ST
21	*Pethia ticto*	Ticto barb	Tit punti	VU	MA	MA	ST
	Balitoridae						
22	*Acanthocobitis botia*	Mottled loach	Balichata gutum	LC	RA	RA	ST
	Cobitidae						
23	*Botia dario*	Queen loach	Rani mach	EN	MA	MA	ST
24	*Lepidocephalichthys guntea*	Guntea loach	Gutum	LC	AA	AA	ST
25	*Lepidocephalichthys annandalei*	Annaldale loach	Gutum	VU	RA	MA	IN
26	*Canthophrys gongota*	Gongota loach	Bag gutum	NT	MA	CA	IN
	Cyprinodontiformes						
	Aplocheilidae						
27	*Aplocheilus panchax*	Blue panchax	Kanpona	LC	CA	CA	ST
	Osteoglossiformes						
	Notopteridae						
28	*Notopterus notopterus*	Grey featherback	Kanla	VU	MA	MA	ST
	Perciformes						
	Badidae						
29	*Badis badis*	Blue perch	Napit koi	NT	RA	RA	ST
	Gobiidae						
30	*Glossogobius giuris*	Bareye goby	Baila	LC	AA	AA	ST
	Channidae						
31	*Channa orientalis*	Smooth-breasted snakehead	Raga	LC	CA	CA	ST
32	*Channa punctata*	Spotted snakehead	Lati	LC	AA	AA	ST
33	*Channa striata*	snakehead murrel	Shol	LC	CA	MA	DE
	Ambassidae						
34	*Chanda nama*	Elongate glass perchlet	Lomba chanda	LC	CA	AA	IN
35	*Parambassis lala*	Highfin glass perchlet	Ranga chanda	LC	CA	CA	ST
36	*Pseudambassis ranga*	Indian glass fish	Gol chanda	LC	AA	AA	ST
	Nandidae						
37	*Nandus nandus*	Mud perch	Bheda	NT	RA	CA	IN
	Anabantidae						
38	*Anabas testudineus*	Climbing perch	Koi	LC	AA	AA	ST

(*continued on next page*)

Table 1 (*continued*)

Sl. no.	Taxonomic position	English name	Local name	IUCN status in BD	Availability status		Population status
					Baseline	Impact year	
	Osphronemidae						
39	*Trichogaster fasciata*	Banded gourami	Bara khailsha	LC	RA	CA	IN
40	*Trichogaster chuna*	Dwarf gourami	Boicha	LC	MA	AA	IN
41	*Trichogaster labiosa*	Thick-lipped gourami	Khalisha	LC	MA	MA	ST
42	*Trichogaster lalius*	Red gourami	Lal khailsha	LC	RA	RA	ST
	Siluriformes						
	Schilbeidae						
43	*Eutropiichthys murius*	Indus garua	Garua	LC	MA	CA	IN
44	*Ailia punctata*	Jamuna ailia	Bashpata	LC	CA	MA	DE
	Bagridae						
45	*Rita rita*	Rita	Rita	EN	MA	MA	ST
46	*Sperata seenghala*	Giant river-catfish	Guijja air	VU	MA	MA	ST
47	*Sperata aor*	Long-whiskered catfish	Ayre	VU	RA	RA	ST
48	*Hemibagrus menoda*	Menoda catfish	Ghagla	NT	CA	CA	ST
49	*Mystus bleekeri*	Bleeker's mystus	Gulsha tengra	LC	MA	CA	IN
50	*Mystus cavasius*	Gangetic mystus	Gulsha	NT	CA	AA	IN
51	*Mystus tengara*	Tengara mystus	Bujuri tengra	LC	AA	AA	ST
52	*Mystus vittatus*	Asian striped catfish	Tengra	LC	MA	AA	IN
53	*Batasio tengana*	Dwarf catfish	Jalu tengra	EN	MA	MA	ST
	Siluridae						
54	*Ompok pabda*	Two stripe gulper catfish	Pabda	EN	MA	CA	IN
55	*Ompok bimaculatus*	Butter catfish	Kani pabda	EN	MA	MA	ST
56	*Wallago attu*	Freshwater shark	Boal	VU	CA	CA	ST
	Chacidae						
57	*Chaca chaca*	Squarehead or angler catfish	Chaka	EN	MA	CA	IN
	Clariidae						
58	*Clarias batrachus*	Walking catfish	Magur	LC	MA	CA	IN
	Heteropneustidae						
59	*Heteropneustes fossilis*	Stinging catfish	Shing	LC	MA	MA	ST
	Synbranchiformes						
	Synbranchidae						
60	*Monopterus cuchia*	Gangetic mudeel	Kuchia	VU	RA	RA	ST
	Mastacembelidae						
61	*Macrognathus aral*	One-stripe spiny eel	Pata baim	DD	RA	RA	ST
62	*Macrognathus aculeatus*	One-stripe spiny eel	Tara baim	NT	MA	CA	IN
63	*Mastacembelus armatus*	Spiny eel	Sal baim	EN	AA	CA	DE
64	*Macrognathus pancalus*	Stripped spiny eel	Chikra baim	LC	AA	AA	ST
	Tetraodontiformes						
	Tetraodontidae						
65	*Tetraodon cutcutia*	Ocellated puffer fish	Potka	LC	MA	CA	IN

BD = Bangladesh, NT = Near Threatened, LC = Least Concerned, VU = Vulnerable, EN = Endangered, DD = Data Deficient, CR = Critically Endangered, IN = Increasing, ST = Stable, DE = Decreasing.

RSF and the Kapna River, and the second cluster consists of only the Shari-Goyain River. At the similarity level of 75.90%, three separate clusters were formed and above 93.56% similarity level, all baseline and final communities became separated.

3.6. Impact of fish sanctuary on the fish harvesting

Average fish catch {mean ± standard deviation (SD)} per fisherman was increased from 2.46 ± 2.23 to 2.74 ± 2.46 kg fisher $^{-1}$day $^{-1}$ (11.38% increased) in the RSF and adjacent waters (Figure 9).

3.7. Perceptions of fishers towards the effectiveness of the fish sanctuary

Most of the fishers (94%) mentioned that the fish species diversity was in decreasing trends before the fish sanctuary establishment. During the study period, perceptions of fishers towards the effectiveness of the fish sanctuary were evaluated, and 170 fishers were interviewed personally. Of the respondents, more than 90% indicated that the fish sanctuary is helpful for protecting indigenous and threatened fish species (Table 4).

4. Discussion

4.1. Present status of species diversity

About two decades ago, RSF was a natural fisheries resourceful zone of Bangladesh and supported about 94 species of freshwater fish fauna (Islam et al., 2016b). Due to some manmade, environmental, and policy factors, fish species diversity showed declining trends (32.98% declined) in the RSF as well as adjacent areas. That's why only 63 species of fishes were found in the 2014-15 fiscal year (Islam et al., 2016b). On the other hand, a total of 62 species of indigenous fishes belonging to 9 orders and 27 families were recorded from April to October 2016 (Das et al., 2017). However, though this study baseline survey was performed intensively in

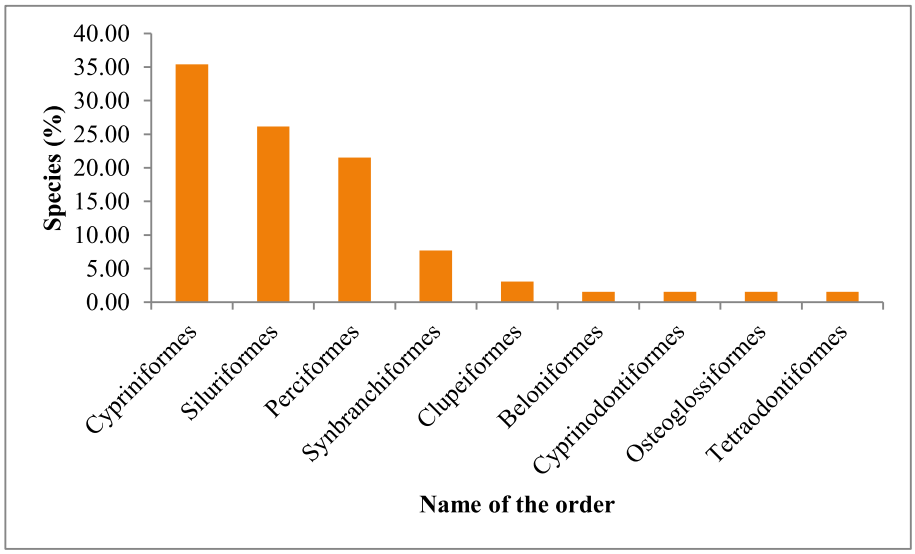

Figure 3. Order-wise distribution of fish species diversity in the Ratargul Swamp Forest.

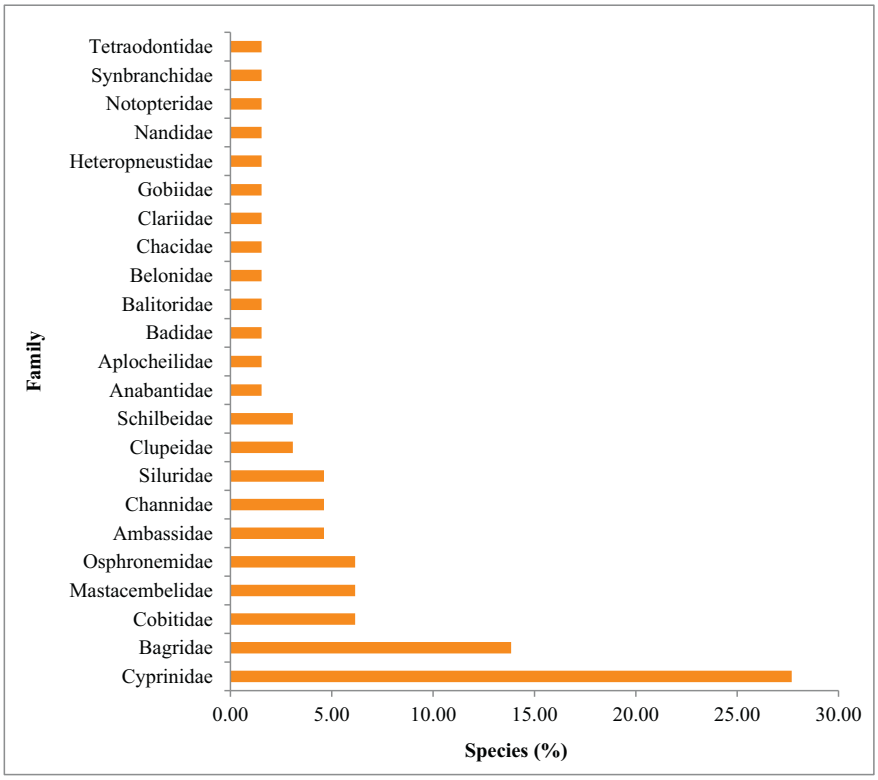

Figure 4. Family-wise distribution of species diversity in the Ratargul Swamp Forest.

different *beels* and ditches of the forest with adjacent floodplain areas and thus reckoned 65 species of native fishes covering 23 families and 9 orders. From the baseline survey, it was evidenced that fishes of RSF was declining rapidly and thus might have lost about 29 species (previous 94 to present 65 species) from that area within the last two to three decades (Islam et al., 2016b). Similar findings were found in the Hakaluki *Haor* where a survey conducted in 1993 reckoned 107 species of fishes. However, the number of fish species was reduced to only 75 species in 2009 and 63 species in 2018 (Roy and Sharif, 2009; Aziz et al., 2021). There may have been variations in the methodology of data collection by different authors, which might be a reason for species variation. But, some manmade and natural drivers are responsible for the reduction of species diversity.

Cypriniformes was the most dominant order based on species richness, followed by Siluriformes, and Perciformes. Islam and Hossain (2019) found that Cypriniformes was the greatest order, followed by Siluriformes, and Perciformes in the Dekar *Haor* Sanctuary. According to the percentage contribution of species, Cyprinidae was counted as the most diversified family comprising 27.69% of the total species and the subsequent families were Bagridae, Mastacembelidae, Cobitidae, ete.

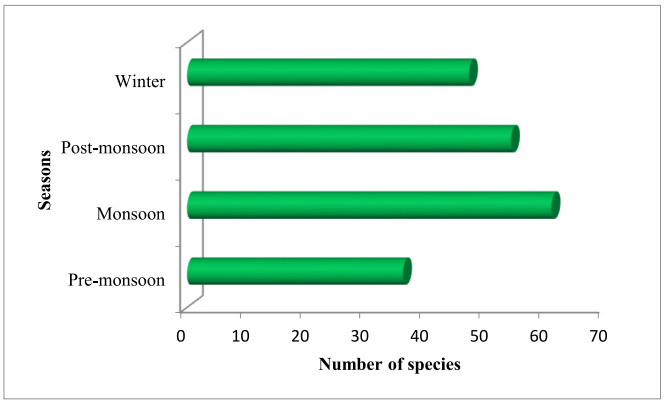

Figure 5. Numbers of fish species observed among different seasons.

Pandit et al. (2015b), Joadder et al. (2016), and Islam et al. (2019) also documented Cyprinidae as the most diversified family in their study areas.

According to IUCN Bangladesh (2015), among 65 observed species, 15 species are listed in the threatened category. Islam et al. (2016b) and Das et al. (2017) recorded 28 species of fish as threatened category in the RSF where 13 threatened species might disappear from the wetlands of the forest. Notably, the number of fish species was stable in the first impact year after sanctuary establishment.

4.2. Seasonal variation in species diversity indices

There was no significant change in the diversity indices among four seasons because RSF is a protected area for fisheries resources. Simpson dominance index (D) value usually ranges from 0 to 1, and the higher the range of values, the smaller the biodiversity represented (Ali et al., 2020). According to Simpson dominance index (D), the post-monsoon season was enriched with higher species diversity as lower value indicated higher diversity. This situation occurred due to reproduction of fishes during the pre-monsoon and monsoon seasons, and a greater assemblage of fish species was found in the swamp forest after monsoon inundation. In the post-monsoon season, the low river water flow and water availability stimulate the fish to accumulate at higher water depths for their existence, which made those easily harvestable by the fishers. The highest value of Shannon-Wiener index (H) was found in post-monsoon and lowest value was found in dry season. The H value usually ranges from 1.5 to 3.5 for ecological data. Iqbal et al. (2015) reported Shannon-Wiener index (H) within the range (2.90–3.12) in a *haor* of Bangladesh. Margalef richness index (d) values varied from 5.09 (dry season) to 6.26 (monsoon). Margalef richness index (d) values range from 3.71 to 6.70 and it depends on the numbers of species (Vyas et al., 2012). Evenness is a measure of relative diversity, and it reaches a high value when the entire area supports similar densities of species in a population, i.e. when all species in a population are distributed uniformly (Aziz et al., 2021). Evenness values range from 1 to 0. The maximum value of Pielou evenness index (J) was found during the post-monsoon and the minimum value was calculated in the dry season. The results indicate fish species are more evenly distributed during post-monsoon compare with other seasons.

4.3. Impact of fish sanctuary on the species availability status and diversity indices

An increase in the fish populations was observed after the fish sanctuary establishment. Present study identified a total of 65 fish species and

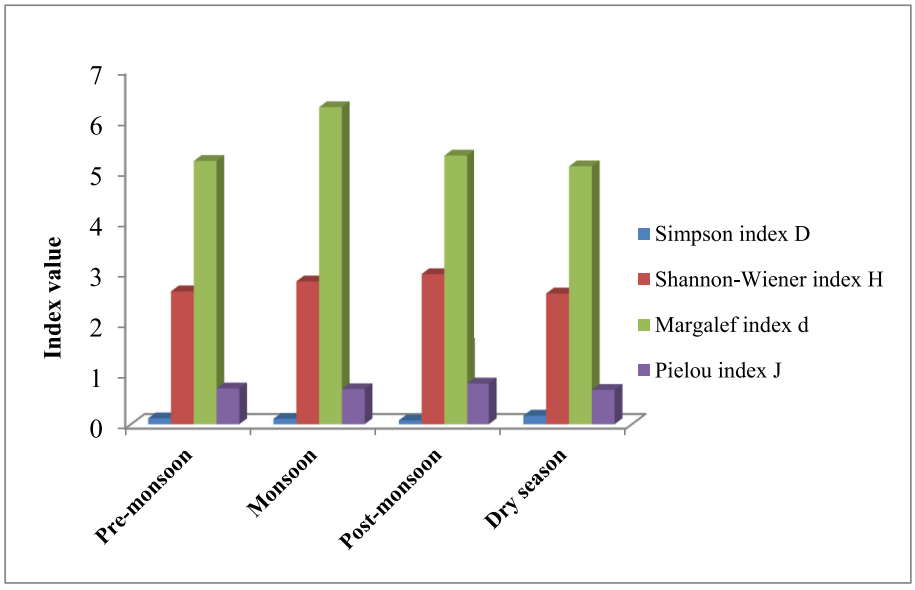

Figure 6. Fish diversity indices among different seasons in the Ratargul Swamp Forest.

Table 2. Values of fish diversity indices comparing baseline and impact year.

Sites	Simpson index		Shannon index		Margalef index		Pielou index	
	Baseline	Final	Baseline	Final	Baseline	Final	Baseline	Final
Ratargul Swamp Forest	0.12	0.09	2.77	2.98	6.15	6.14	0.66	0.71
Shari-Goyain	0.13	0.12	2.57	2.62	5.72	5.49	0.63	0.64
Kapna River	0.14	0.11	2.71	2.89	6.32	6.30	0.67	0.72
Mean ± SD	0.13 ± 0.01	0.11 ± 0.02	2.68 ± 0.10	2.83 ± 0.19	6.06 ± 0.31	5.98 ± 0.43	0.65 ± 0.02	0.69 ± 0.04

Table 3. Availability status of fish species comparing baseline and impact year.

Study sites	Categories	Baseline year		Impact year		Remarks
		Number of species	% of species	Number of species	% of species	
Ratargul Swamp Forest	Abundantly available	10	15.38	15	23.08	Increased
	Commonly available	11	16.92	21	32.31	Increased
	Moderately available	28	43.08	19	29.23	Decreased
	Rarely available	16	24.62	10	15.38	Decreased
Shari-Goyain River	Abundantly available	9	15.52	12	20.69	Increased
	Commonly available	14	24.14	17	29.31	Increased
	Moderately available	17	29.31	16	27.59	Decreased
	Rarely available	18	31.03	13	22.41	Decreased
Kapna River	Abundantly available	10	17.54	13	22.81	Increased
	Commonly available	13	22.81	17	29.82	Increased
	Moderately available	15	26.32	16	28.07	Increased
	Rarely available	19	33.33	11	19.30	Decreased

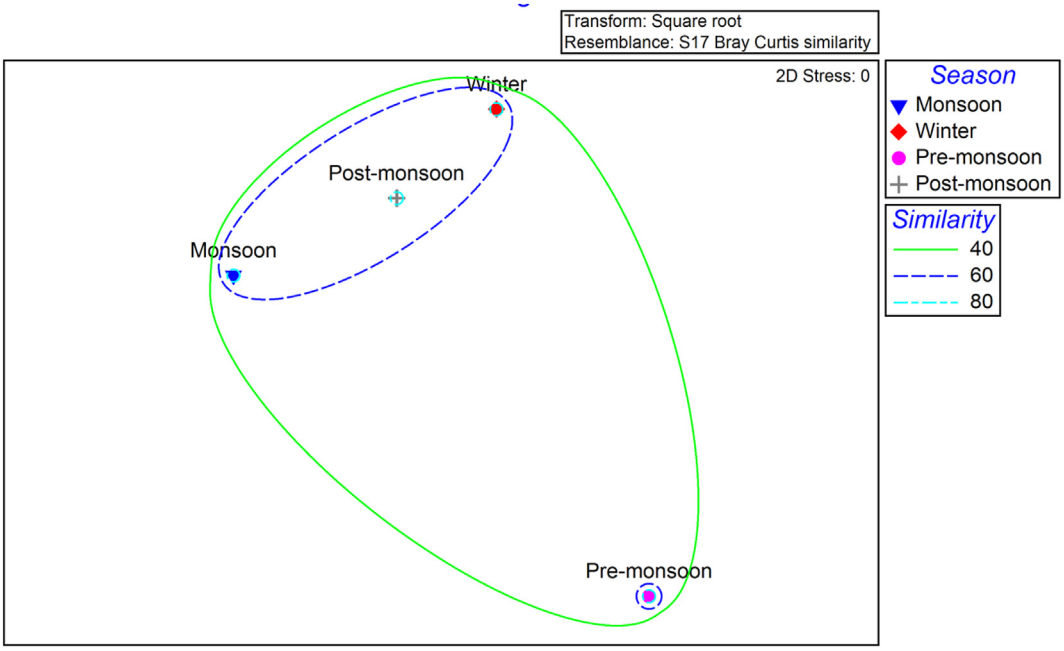

Figure 7. Two-dimensional ordination in nMDS showing the similarity of different seasons based on Bray-Curtis similarity matrix.

it was the same in the baseline and impact year. But, the availability status of most of the existing species positively increased. It was found that 56.92% of total fish population remained stable, 35.38% found increasing, and only 7.69% found to be decreasing. On the other hand, it was found that 59.34% of fish species was decreasing and only 2.20% was increasing in an unprotected river (Pandit et al., 2021) where fish sanctuary was absent. Khan et al. (2018) found that 7 indigenous species revived in the Kolavanga *Beel* sanctuary after five years of establishment. Haque (2013) also found increasing trends of indigenous fish species abundance (e.g. *Ompok bimaculatus, Puntius sarana, Nandus nandus, Labeo gonius, and Chitala chitala*) after the establishment of fish sanctuary in the Baikka *Beel.* The results indicate the creation of local habitat enhancement and protection in the sanctuary that influences the abundance of fishes in the area. Alam et al. (2017) also revealed that increasing trends of fish species in the sanctuary area and decreasing trends in the control *beel.*

The increasing tendency of fish availability was also recorded in the adjacent Shari-Goyain and Kapna Rivers. Pandit et al. (2021) found that 17.58% species was abundantly available, 27.47% was commonly available, 31.87% was moderately available and 23.08% was rarely available in the Dhanu River. The increasing trend of abundantly available and commonly available species and the decreasing trend of moderately available and rarely available species indicate that fish sanctuary is creating better habitat for their survival and is helpful for increasing their population size and abundance.

The species richness and proportion of individual species are shown by Shannon-Wiener index, whereas the relative number of individual and the fraction of common species showed on the evenness and dominance indices (Hossain et al., 2014). In the present study, Simpson dominance index (D) was lower in the impact year than the baseline year, which indicated enriched species diversity that might be due to the establishment of sanctuary. The Shannon-Wiener index (H) was positively increased in the RSF. Ali et al. (2020) found the H values 2.70–3.41 at the Andharmanik River sanctuary. Its value usually ranges from 1.5 to 3.5 and the values above 3.5 indicate more sustainable condition. Therefore, these results indicate that sanctuary is useful to create suitable conditions for fishes. The lowest Pielou evenness index value was recorded baseline year while the highest value was recorded in impact year which indicates that the species of fishes is more evenly distributed. Margalef species richness (d) index was recorded as 6.15 in the baseline year and 6.14 in the impact year which ensured that species were more evenly distributed in the impact year comparing to the baseline year.

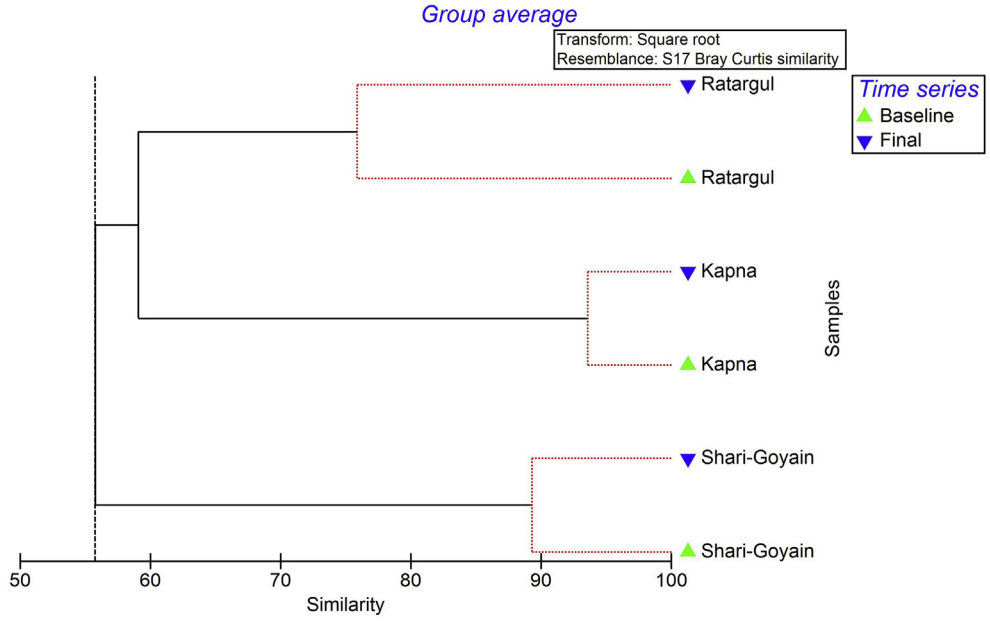

Figure 8. Dendrogram of clusters based on Bray-Curtis similarity matrix of different sites showing structural variability of the fish communities.

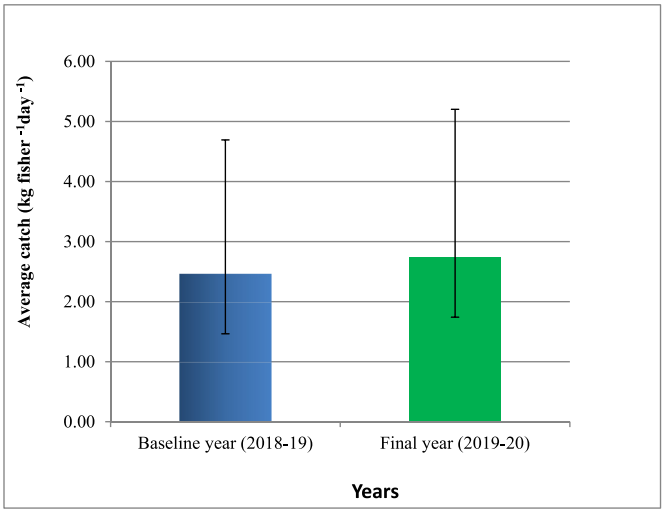

Figure 9. Changes in harvesting of fish (kg fisher $^{-1}$day $^{-1}$) in the Ratargul Swamp Forest.

In the Shari-Goyain River (just beside the swamp forest) Simpson dominance index (D) was 0.13 in the baseline year and 0.12 in the impact year which refers slightly enrichment of species diversity in the impact year. The Shannon-Wiener index (H) increased from 2.57 to 2.61 indicated the sanctuary is helpful to create favorable condition but not similar as RSF. The Margalef richness index decreased from 5.72 to 5.48. Pielou evenness index (J) also increased from 0.63 to 0.64. All of these findings demonstrated that the sanctuary is assisting in the enhancement of biodiversity in the Shari-Goyain River, but not in the same way that the RSF does. This might be associated with pollution such as sand mining, poison fishing, coal mine drainage, *katha* fishing, etc. (Talukder et al., 2021).

In case of the Kapna River, Simpson dominance index (D) and Margalef richness index (d) were decreased. On the other hand, Shannon-Wiener (H) and Pielou evenness (J) index were increased. It might be influenced by establishment of sanctuary on species enrichment in the impact year compared to the baseline year. The result of diversity indices on three waters revealed that sanctuary is creating more suitable condition in the RSF as well as in the Kapna and Shari-Goyain Rivers.

4.4. Non-metric multidimensional scaling (nMDS) and cluster analysis

Results from nMDS revealed a 40% similarity across all seasons. Tikadar et al. (2021) also found same results among all months.

Table 4. Perceptions of fishers towards the effectiveness of the fish sanctuary.

Sl. no.	Perceptions of fishers	Perception of the respondents (N = 170)	
		Numbers	Percentage
1	Sanctuary is helpful for protecting indigenous and threatened fish species.	154	90.58
2	The abundance of small indigenous species of fish is increasing.	146	85.88
3	Sanctuary is creating safe habitats for fishes during dry season.	141	82.94
4	Sanctuary is increasing fisher's daily catches and has influence on fisher's income.	132	77.64
5	Sanctuary is better management approach for increasing fish production.	126	74.12
6	Sanctuary is useful for conserve and restores aquatic biodiversity.	117	68.82
7	Sanctuary has impact on daily fish consumption of the local people.	114	67.05
8	Sanctuary has only benefited to fishers and others whose are related to fishing activities.	95	55.88
9	Sanctuary is creating conflicts among fishers.	28	16.47
10	Sanctuary is harmful for fishers catch and negatively impact on livelihoods of fishers.	7	4.12

Shamsuzzaman et al. (2017) showed 40%–60% similarity for all seasons in the Karnafully River estuary. Rashed-Un-Nabi et al. (2011) found 65% similarity between finfish and shellfish in all seasons in the Bakkhali River estuary and Barman et al. (2016) found 20% similarities in all seasons in the Karnafully River. Their findings are not similar to those in the present study due to different river systems, wetland waters, and sanctuary establishment.

The cluster analysis revealed a clear structural variation in fish communities among the three sites. At a similarity of 55.75%, two major clusters were observed. In the Karnafuli River, Barman et al. (2016) found a 50.5% similarity among three groups, while monsoon-2 showed separate clustering from other groups. Hossain et al. (2012) found two different clusters of fish species at a similarity of 32% in the Meghna River of Bangladesh.

4.5. Impact of fish sanctuary on catch composition

This is a clear view that fish sanctuary has positive influence on increasing fish production and abundance. Latif and Latif (2017) reported that the annual production of fishes was increased from 8.8 MT to 15.2 MT in 2012–2013. Joadder et al. (2016) reported that due establishment of fish sanctuary and adopting community based management technique in the *beel*, fish catch was increased at considerable amount believed by the greater portion of respondents (80%). Through comparing with the control *beel* Alam et al. (2017) found in the sanctuary fish production increased from 322.64 MT to 326.7 MT whereas in control *beel* production decreased from 408.10 MT to 400.13 MT. All of these almost coincides the result of the present study.

There are a few small flaws in the current study. The first is that fish samples were acquired from the local fishers rather than direct sampling through fishing by the hired fishers with specific gears. Other factors such as water quality, rainfall, temperature, etc. may influence fish diversity were not monitored. Finally, it is a very short term study to understand the whole impact of a local community managed fish sanctuary on the fisheries resources of the RSF and adjacent waters. The current study suggests long-term monitoring and research, which could lead to a better knowledge of fisheries management and conservation.

5. Conclusions

The findings of the study demonstrate that fish sanctuary is an important structural arrangement for the management of natural water resources. Diverse species of fishes can get shelter, breed, and spawn within the sanctuary area as it acts an excellent habitat for their protection. Consequently, the availability and production of fishes were increased in the sanctuary areas and adjacent waters. Thus, this study presented a detailed methodology for an effective supervision and management of a fish sanctuary. It can be implemented in other rivers, *haors,* and *beels* of Bangladesh because those are major inland fisheries habitats for indigenous freshwater fishes. Present study recommends long-term monitoring and research on the same, which may regenerate better understanding in fisheries conservation.

Declarations

Author contribution statement

Mrityunjoy Kunda; Debraj Ray: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Debasish Pandit: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ahmed Harun-Al-Rashid: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data associated with this study has been deposited at SSRN 3932095.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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