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Research article

River pattern influences the composition of small indigenous species (SIS) of fish in deltaic Rajbari district, Bangladesh

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ABSTRACT

Bangladesh is endowed with diverse rivers providing huge ecosystem services, but the diversity status and the abundance of the small indigenous species (SIS) are not identical in all rivers due to the natural water flow regime and anthropogenic challenges. Therefore, the present study endeavors to elucidate the composition and conservation status of SIS fish from four rivers namely, the Padma, the Gorai, the Chandana and the Horai rivers of Rajbari District, Bangladesh. Data were meticulously collected through fish sampling in each season, field observations, focus group discussions, and individual interviews by using a semi-structured questionnaire spanning from May 2021 and April 2022. The number of SIS in the Padma, the Gorai, the Chandana and the Horai rivers of Rajbari were 60, 36, 33 and 26, respectively, whereas a predominant concentration of fishes was notably observed in the benthopelagic zone of these rivers. Among the 60 riverine SIS, 23 fish were common in the four rivers. Additionally, Cyprinidae (>30%) was observed to be the most abundant SIS in the studied rivers. The fishermen in the research area used seven major fishing equipment of which cast nets are the most common for catching fish species. The abundance of SIS during the rainy season was the highest for all the studied rivers than the other seasons and 12 SIS were available throughout the year. Notably, the least concerned SIS outnumbered the other categories whereas, more than 10% was under the vulnerable category in the four rivers. The leading threats to the fish diversity were pollution followed by illegal and overfishing, siltation, reduced depth, degeneration of rivers and others. Consequently, to safeguard the existing SIS, reducing human pressure, implementing fishing regulations strictly, establishing and administering fish sanctuaries, and raising public awareness can be helpful for the sustainability of aquatic resources in deltaic areas.

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1. Introduction

Freshwater fisheries have essential role in future food and nutrition security [1] and the inland waterbodies of Bangladesh such as rivers, canals, ponds, *haor*, *baor* and lakes are rich in diversified aquatic resources [2–4]. In this dynamic aquatic landscape, the production from culture fisheries is increasing day by day whereas, the demand for indigenous captured fishes is increasing portraying the perplexing link between the traditional and modern preferences [5]. Despite the open water fisheries from inland being one of the major sources of total fish production, their share of the production rate has decreased to 27.79% in 2015 from 38.68% in 2000 [6]. A significant portion of freshwater fisheries are dominated by small indigenous species (SIS), also known as small fish or SIS or locally as *choto mach* having a maximum length of less than 25 cm [2,7]. Traditionally, people of Indian subcontinents are dependent for their diet on various small indigenous fish species harvested from nearby water resources. According to Thilsted and Wahab [8], SIS can eliminate nutritional deficiency, especially to the rural people in South and Southeast Asia, being a good source of essential macro and micronutrients. More than 140 species are identified as small indigenous fish species among 260 freshwater fish species available in Bangladeshi freshwaters [2]. Nonetheless, the diversified riverine fishes are declining due to climate change, habitat loss, river disruption, river flow alteration, water pollution, and increased sedimentation all of which are currently pressing problems in Bangladesh [3,9]. SIS are harvested with other larger fishes using different fishing gears of different sizes. Prior studies have meticulously documented that the collection of fish species harvested using similar traditional gears highlights attributable to divergences in ecological niches and water depth [4,10].

Across each continent, many intermittent rivers undergo cessation of flow or desiccation due to having temporary flow regimes naturally or due to anthropogenic-driven effects. Those arid riverbeds play a crucial role as seed and egg banks for unique aquatic biota through the experience of wet and dry phases [11]. Bangladesh has also been gifted with numerous rivers, but the aquatic biodiversity status including SIS are not identical in all the rivers. Shifting back towards advanced and sustainable utilization of indigenous freshwater resources in a country can be a chance for the improvement of the present food system [1,12]. There are few studies on the SIS of several rivers [2,13,14] in Bangladesh, but the diversity of SIS in a specific deltaic region has not been studied yet. The term 'deltaic area' denotes a place where the topography has been significantly altered by the sedimentation of nearby or occupying open water bodies, or where the environment has been markedly influenced by such expansive watersheds [14,15]. According to Freitas et al. [16], fish species richness is also correlated with associated land area components, exemplified by the aggregation of small fishes in the nearby paddy fields and forests during river flooding.

Rajbari is a small district (1118.8 km^2) of Bangladesh which can be regarded as a deltaic district as it is blessed with both perennial and semi-perennial rivers such as the Padma, the Gorai, the Chandana and the Horai [17]. It is located in between the latitudes of $22^\circ 40'$ and $23^\circ 50'$ North and the longitudes of $89^\circ 19'$ and $90^\circ 40'$ East. Plethora of SIS are available in the rivers, meandering canals, verdant crop fields and ponds during the rainy season of Rajbari [5]. Gathering information about SIS is necessary for making management plans and their effective implementation with fruitful outcomes. Freitas et al. [16] stated that investigations on fish assemblages in a freshwater ecosystem are fundamental challenges for the management of a specific environmental biodiversity. Information related to the biodiversity of SIS is important that signifies the extent of exploitation and this will be helpful for sustainable management of the resource for upcoming generations [4,7,18]. However, the study of SIS biodiversity and conservation status is scant in Rajbari. Recognizing the urgency of addressing this knowledge gap, the current study aims to focus on the biodiversity, seasonal patterns of availability and conservation status of river-origin SIS in Rajbari District, Bangladesh. The findings of the present study will provide an outline of the current status of SIS biodiversity, conservation requirements and a possible action plan for nearby waterbodies of the other deltaic areas and rivers.

2. Materials and methods

2.1. Research area

The current study was conducted across four rivers of Rajbari District, namely the Padma, the Gorai, the Chandana, and the Horai spanning from May 2021 to April 2022. Previously, the Chandana River was connected to the Gorai and Kumar River, but owing to the alteration in river direction, it is presently almost completely isolated. Though the River Chandana and the River Horai had less water flow than the Padma and the Gorai River, many indigenous fishes used those rivers as their habitat during the rainy season. The study is based on the hypothesis that river-system variations might greatly influence the diversity, availability, and seasonal variations of small indigenous fish species. Small indigenous species (SIS) of fish were collected from 8 spots of the 5 sub-districts of Rajbari District, namely Dadshi, Debagram, Mrigi, Kasba Majhail, Char Afra, Purba Maukuri, Dadpur, and Arabaria (Table 1 and Fig. 1).

2.2. Data collection method

A variety of Participatory Rural Appraisal (PRA) procedures were employed to gather data that was both qualitative (represented by linguistic terms) and quantitative (represented by cardinal numbers). These methods encompassed one-on-one interviews with fishermen using a semi-structured questionnaire, focus group discussion (FGD) with a checklist, key informant interviews (KII) involving subject matter experts, and direct field observation (Fig. 2). They were interviewed individually on fish type, zone of habitat, seasonality, gear used, economic importance and risks factors of SIS at their working place and home.

It is noteworthy that, the population of fishermen in the Rajbari District was 6183 [17]. Following Yamane [19] and Ho et al. [20], and using a 5% margin of error, the minimum sample size of 400 fishermen was determined employing Eq. (1):

Table 1
GPS coordinates of the selected study sites and the adjacent rivers of Rajbari.

Study site	Adjacent river	GPS coordinates
Dadshi	The Padma	23°46′32.5"N 89°41′47.7"E
Debagram	The Padma	23°45′46.9"N 89°44′58.6"E
Mrigi	The Gorai	23°40′41.6"N 89°26′51.0"E
Kasba Majhail	The Gorai	23°43′20.5"N 89°20′56.5"E
Char Afra	The Chandana	23°48′52.6"N 89°27′07.3"E
Purba Maukuri	The Chandana	23°37′17.3"N 89°33′16.5"E
Dadpur	The Horai	23°46′38.9"N 89°32′15.9"E
Arabaria	The Horai	23°42′15.8"N 89°36′00.7"E

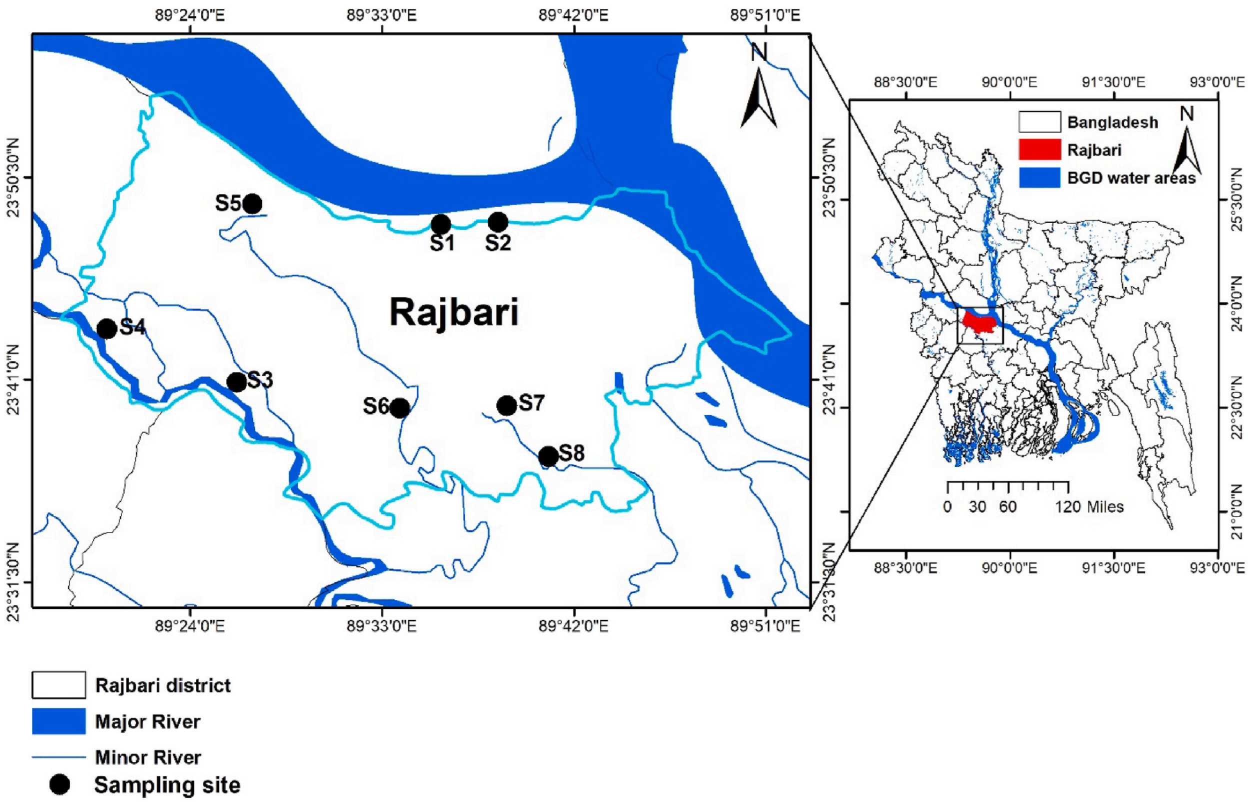

Fig. 1. Geographical map of study sites of Rajbari District (Source: ArcGIS software, version 10.3); here S1: Dadshi, S2: Debagram, S3: Mrigi, S4: Kasba Majhail, S5: Char Afra, S6: Purba Maukuri, S7: Dadpur, and S8: Arabaria.

$$n = \frac{N}{1 + Ne^2} \tag{1}$$

Here, n represents the sample size, N indicates the population, and e represents the margin of error. A total of 400 fishermen (100 from each river) were randomly selected as respondents from the study areas using the lists of fishermen from the Upazila Fisheries Office of Rajbari. Additionally, 50 key informants including the Upazila Fisheries Officer (UFO) and staff of non-government organizations (ACI, BRAC, Winrock International and WorldFish Bangladesh) were taken for crosschecking the collected data.

2.3. Collection of fish sample

The SIS were collected using gill nets (4 h hauling), seine nets (4 h hauling), cast nets (4 h hauling), push nets (4 h hauling), lift nets (deployed overnight), traps (operated overnight), and hook and line (deployed overnight), operated by professional fishermen. Thus, the sampling was done once per season. Identification of SIS was carried out following Rahman [21], Froese and Pauly [22], and Siddiqui et al. [23]. Cross-referencing with the Catalogue of Life 2017 Annual Checklist [24] and IUCN Red List of Threatened Species [25] was done to confirm the taxa's identification. However, confusing fish samples were fixed in 10% buffered formalin and identified based on morphometric and meristic attributes following Talwar and Jhingran [26] and Rahman [21] in the laboratory of the Department of Fisheries Biology and Genetics, Sher-e-Bangla Agricultural University, Dhaka 1207, Bangladesh.

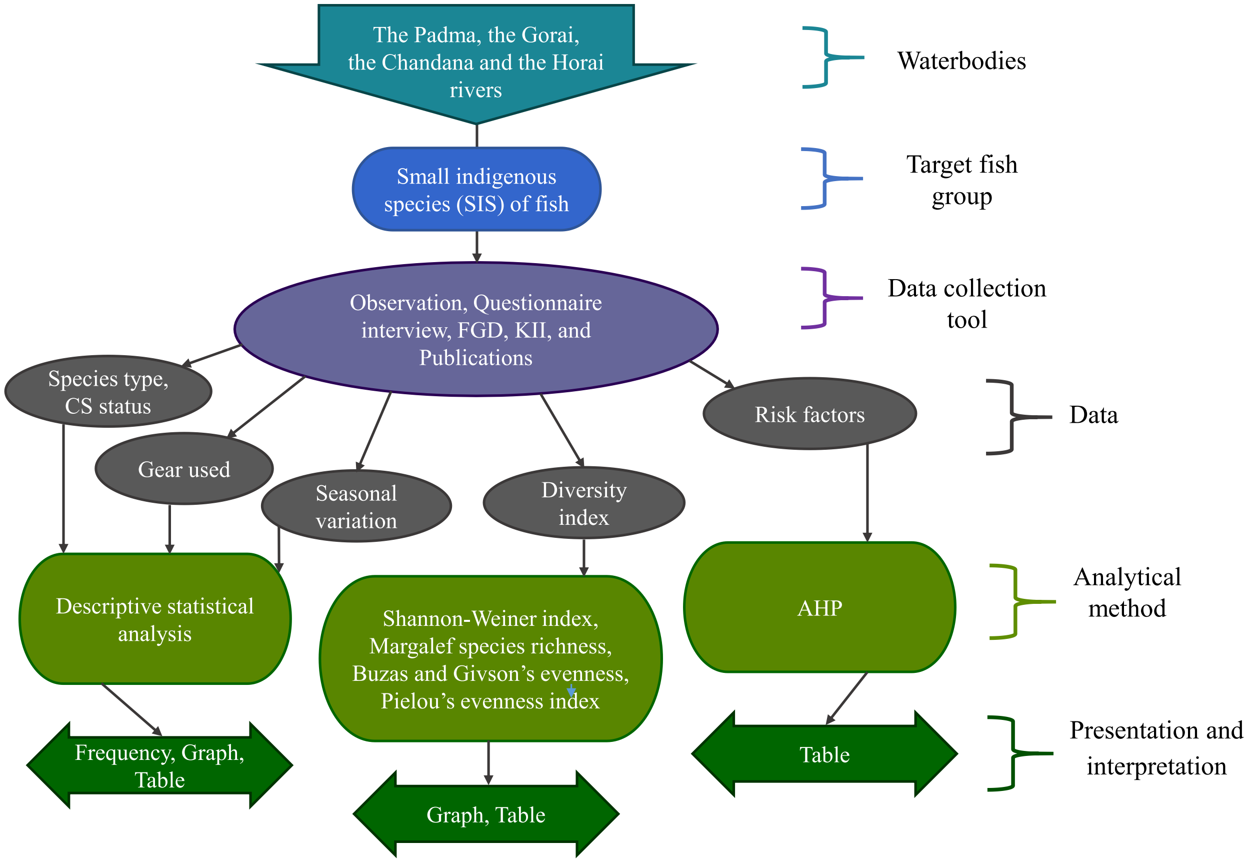

Fig. 2. A conceptual framework on research methodology (Here, FGD: Focus Group Discussion, KII: Key Informant Interview, CS: Conservation status, and AHP: Analytic Hierarchy Process).

2.4. SIS categories

Based on the habitat of fish in the river, the SIS were categorized into 3 groups 'pelagic', 'benthopelagic' and 'demersal' zone. The upper zone indicates SIS living in the surface zone and feeding on plankton from the surface; and the bottom zone SIS includes fishes living at the bottom and feeding on benthos, whereas the middle zone SIS means fishes of the middle zone feeding on both plankton and benthos.

Moreover, the economic importance of SIS was classified into two classes such as- 'consumable' and 'trash' fish, where consumable SIS indicated the acceptance for consumption by the inhabitants of Rajbari.

For studying the seasonal change of SIS availability, fishes were categorized under six seasons based on the climate of Bangladesh. In this context, the terms 'summer', 'rainy', 'autumn', 'late autumn', 'winter' and 'spring' seasons corresponded to May–June, July–August, September–October, November–December, January–February, and March–April, respectively.

The conservation status of the SIS in both Bangladesh and the global aspect was recorded following the red list of IUCN [25].

2.5. Biodiversity indices

The diversity index is a calculative measure of species diversity in the community. For quantification of the diversity of SIS in the four rivers, Shannon-Weiner Index (H), Margalef Species Richness (d), Buzas and Givson's Evenness (E) and Pielou's Evenness Index (J′) were calculated following Eq. (2), Eq. (3), Eq. (4), and Eq. (5), respectively [2,3].

$$\text{Shannon-Weinerdiversityindex(H)} : \mathrm{H} = \sum [\mathrm{Pi} \times \ln(\mathrm{Pi})] \tag{2}$$

$$\text{Margalef species richness (d)} : \mathrm{d} = (S\text{–}1)/\log(N) \tag{3}$$

$$\text{Buzas and Gibson's Evenness (E)} : \mathrm{E} = \mathrm{e}^{H}/S \tag{4}$$

$$\text{Pielou's evenness index (J}') : \mathrm{J}' = H(S)\,/\,K(\max) \tag{5}$$

Here, N = Total number of individuals; Pi = Proportion of individuals in the sample belonging to the ith species; S = Total number of species; H = Shannon-Weiner diversity index; $H(S)$ = The Shannon-Wiener information function; K (max) = The theoretical maximum value for H (S) if all species in the sample were equally abundant.

2.6. Risk factors for SIS biodiversity reduction and ranking

Risks and vulnerability of the SIS biodiversity were listed by the fishermen. Analytic Hierarchy Process (AHP) was employed to contrast the risks of SIS biodiversity reported by the respondents in accordance with Saaty [27]; Huo et al. [28]; Lokare and Jadhav [29]; and Chaibate et al. [30].

2.7. Data analysis and presentation

The data summary was organized and evaluated for a conceptual understanding of the current study (Fig. 2). The quantitative data was created using descriptive statistics in frequencies and percentages in Microsoft Excel (version 2016).

Pearson's correlation analysis was conducted to compare co-variability among fish species of the rivers to characterize how these interrelationships varied across different seasons using SPSS software (version 27.0). Correlations were classified as high when r values were $\geq$0.65, moderate at 0.35 to <0.65, and low when values fell below <0.35 [31].

The data were visually represented in graphs, tables, and flowcharts. Moreover, ArcGIS software (version 10.3) was used to map the research location.

2.8. Descriptive data analysis

Categories of SIS based on waterbodies, scientific orders, zone, gear, seasonality, and conservation status were calculated as frequency and percentage. The basic method of frequency percentage was employed following Sunny et al. [4] and Nadia et al. [5].

2.9. AHP analysis

Analytic Hierarchy Process (AHP) is used to compare the risks of SIS biodiversity [27–30]. A pairwise comparison matrix A was formed as Eq. (6):

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} = \left(a_{ij}\right)_{ij}, \quad (6)$$

Here, a_{ij} is the component of row i column j of the matrix, n is the number of the evaluated risks, $a_{ji} = (1/a_{ij})$, and $a_{ii} = a_{jj} = 1$ and a_{ij} indicates the seriousness of the vulnerabilities i when compared to j.

The comparative seriousness between two risks is calculated based on a numerical range 1–9. Here, 1 represents similar importance; 3 represents moderately preferred; 5 represents strongly preferred; 7 represents very strongly preferred; 9 represents extremely preferred; 2, 4, 6, 8 represent intermediate values and reciprocals are used for inverse comparisons [28]. After arranging the matrix A, the priority vector of the risks is calculated as Eq. (7) [29,30,32].

$$A_{\text{norm}} = \begin{pmatrix} \overline{a_{11}} & \cdots & \overline{a_{1n}} \\ \vdots & \ddots & \vdots \\ \overline{a_{n1}} & \cdots & \overline{a_{nn}} \end{pmatrix} = \left(\overline{a_{ij}}\right)_{ij}. \quad (7)$$

The matrix A_{norm} entries $\overline{a_{ij}}$ are measured using the entries a_{ij} of the matrix A following Eq. (8) [30]:

$$\overline{a_{ij}} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \quad (8)$$

The Eigenvector (P) of risks are calculated using Eq. (9) and ranking was based on the Eigenvector values, and the higher value of Eigenvector reveals more seriousness than other risks.

$$p_i = \frac{\sum_{k=1}^{n} \overline{a_{ik}}}{n} \quad (9)$$

In AHP, the consistency ratio (CR) is calculated to evaluate the consistency of the priority made by the participants following Eq. (10) [29]:

$$\text{CR} = \frac{\text{CI}}{\text{RI}} \quad (10)$$

When $0 \leq \text{CR} \leq 0.1$, the evaluations made by the participants are consistent. If CR > 0.1, the judgment made by the participants is inconsistent; CI is the Consistency Index evaluated using Eq. (11):

$$CI = \frac{(\lambda\text{-}n)}{n\text{-}1} \tag{11}$$

Here, λ is evaluated following Eq. (12):

$$\lambda = \sum_{i=1}^{n} p_i * \sum_{k=1}^{n} a_{ki} \tag{12}$$

RI is random index changes based on *n*. The value of RI is taken from Chaibate et al. [30].

2.10. Ethical statement

There are no required permits from the Government of the People's Republic of Bangladesh to capture the species in the studied rivers. The ethical committee of the Faculty of Fisheries, Aquaculture and Marine Science; Sher-e-Bangla Agricultural University, Dhaka, 1207, Bangladesh granted the ethical approval for collecting SIS including near threatened and vulnerable species. Most of the endangered and vulnerable fish species were returned to the river after the identification of species in the collection spot. As it was challenging to identify all the species, the confusing fishes were initially anaesthetized using icy water (cold shock) to minimize fish suffering before being placed in fixatives.

3. Results

3.1. Number of small indigenous species (SIS) of fish in Rajbari district

A comprehensive total of 60 SIS was identified in the four rivers of the Rajbari district, explicitly from the Padma, the Gorai, the Chandana and Horai rivers, 60, 36, 33 and 26 fish species were recorded, respectively (Table 2 and Fig. 3). Among the 60 SIS, a total of 24 species showed ubiquity across the four rivers. SIS from 10 orders were available in the Padma River whereas, 9, 7 and 8 orders were found from the Gorai, the Chandana and the Horai River, respectively. Cypriniformes emerged as the dominant orders in the four rivers; on the other hand, the 2nd and 3rd dominant orders were Perciformes and Siluriformes, respectively (Fig. 4). The present study revealed that the benthopelagic SIS outnumbered the groups of demersal and pelagic in the studied rivers (Fig. 5a). Fifty-four SIS were found consumable, whereas, only 4 trash fishes such as- Panchax minnow (*Aplocheilus panchax*), Gangetic puffer (*Chelonodon patoca*), Rice-paddy eel (*Pisodonophis boro*) and Ocellated pufferfish (*Tetraodon cutcutia*) were found from the sampled rivers (Table 2). The proportion of trash SIS in the River of Padma, Gorai, Chandana and Horai were 6.67, 8.33, 9.10 and 15.38%, respectively (Fig. 5b).

3.2. Fishing gears

Variations of fishing gears and traps increased with the increasing number of SIS in the studied rivers. The cast nets were predominantly used for catching all the SIS from the Padma, Gorai, Chandana and Horai River. Whereas 55, 53, 51, 48, 46 and 22 SIS were harvested using seine net, gill net, drift net, push net, hook and line, and traps, respectively from the four rivers (Table 2).

3.3. Seasonal variations

The availability of SIS in the four rivers were found higher in rainy season than that in the autumn, summer, spring, late autumn and winter seasons, respectively. The study also found higher seasonal variations of SIS in the Padma River than the Gorai, the Chandana and the Horai rivers, respectively (Fig. 6).

In each season, there were notable and statistically significant positive correlations observed among the species in the four rivers (Table 3). There were moderate to strong positive correlations between the Padma and the Gorai rivers ($r = 0.565$ to 0.742), between the Padma and the Chandana ($r = 0.577$ to 0.763), between the Gorai and the Horai ($r = 0.598$ to 0.843), and between the Chandana and the Horai ($r = 0.598$ to 0.723). While during all the seasons the Padma and the Horai rivers were weakly positively related (r ranging from 0.414 to 0.643).

3.4. Biodiversity index

Biodiversity indices explicitly Shannon's Diversity Index and Margalef Richness Index were highest in the Padma River while the lowest indices were found in the Horai River. On the contrary, the highest Buzas and Givson's Evenness and Pielou's Evenness Indices were resulted from the Horai River and the lowest from the Padma River (Table 4). Species evenness serves as an indicator for species stability within the ecosystem. The study also showed that most of the biodiversity indices of the Padma (Fig. 7a), the Gorai (Fig. 7b), the Chandana (Fig. 7c) and the Horai (Fig. 7d) rivers peaked during the rainy season while the lowest values were recorded in the winter season.

3.5. Conservation status

According to the IUCN Red List of Bangladesh [25], the least concerned SIS outnumbered the other categories in all the rivers.

Table 2
Seasonal availability, fish type, economic importance fishing gears and conservation status of river origin small indigenous species (SIS) of fish in Rajbari.

Scientific name of SIS	English name	Local name	Order	River	Zone of habitat	Economic significance	Gear	Season	Conservation status	
									Local	Global
Ailia coila (Hamilton, 1822)	Gangetic ailia	Kajuli	Siluriformes	Padma, Gorai	Pelagic	Consumable	GN, SN, CN, DN	All	LC	NT
Amblypharyngodon microlepis (Bleeker, 1853)	Indian carplet	Mola	Cypriniformes	Padma, Gorai Chandana	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	R, A, LA, S	LC	EN
Amblypharyngodon mola (Hamilton, 1822)	Mola carplet	Mola	Cypriniformes	Padma, Gorai Chandana	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	R, A, LA, S	LC	LC
Anabas testudineus (Bloch, 1792)	Climbing perch	Koi	Perciformes	Padma, Gorai, Chandana, Horai	Demersal	Consumable	GN, SN, CN, DN, T, HL	W, R, S, Sp	LC	DD
Aplocheilus panchax (Hamilton, 1822)	Panchax minnow	Kanpona	Cyprinodontiformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Trash	GN, SN, CN, DN, PN, T, HL	All	LC	LC
Apocryptes bato (Hamilton, 1822)	Goby	Chewa	Perciformes	Padma, Gorai	Demersal	Consumable	GN, CN, DN, PN, T	S, R, A	LC	LC
Aspidoparia jaya (Hamilton, 1822)	Jaya	Piali	Cypriniformes	Padma	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	R, A, LA, S	LC	EN
Aspidoparia morar (Hamilton, 1822)	Morari	Piali	Cypriniformes	Padma	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	R, A, LA, S, W	VU	EN
Badis badis (Hamilton, 1822)	Blue perch	Napti koi	Perciformes	Padma	Benthopelagic	Consumable	SN, CN, DN, T	W, R, S, Sp	NT	LC
Botia dario (Hamilton, 1822)	Bengal loach	Rani mach	Cypriniformes	Padma, Gorai	Demersal	Consumable	GN, SN, CN, DN, PN	S, R, A	EN	LC
Botia lohachata (Chaudhuri, 1912)	Reticulate loach	Rani mach	Cypriniformes	Padma	Demersal	Consumable	GN, SN, CN, DN, PN	S, R, A	EN	EN
Botia rostrata (Günther, 1868)	Gangetic loach	Putul mach	Cypriniformes	Padma	Demersal	Consumable	GN, SN, CN, DN, PN	S, R, A	DD	VU
Chanda nama (Hamilton, 1822)	Elongate glass-perchlet	Lomba chanda	Perciformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	CN, DN, PN, T	S, R, A, LA	LC	LC
Channa punctatus (Bloch, 1793)	Spotted snakehead	Taki	Perciformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	All	LC	LC
Chela cachius (Hamilton, 1822)	Silver hatchlet barb	Chela	Cypriniformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	All	VU	LC
Chelonodon patoca (Hamilton, 1822)	Gangetic puffer	Potka	Tetraodontiformes	Padma, Gorai, Chandana, Horai	Demersal	Trash	GN, SN, CN, DN, PN, T	All	DD	EN
Clarias batrachus (Linnaeus, 1758)	Walking catfih	Magur	Siluriformes	Padma, Chandana	Demersal	Consumable	GN, SN, CN, DN, PN, T, HL	R, A, LA	LC	LC
Clupisoma garua (Hamilton, 1822)	Garua bacha	Ghaura	Siluriformes	Padma	Demersal	Consumable	GN, SN, CN, DN, PN, T, HL	R, A, LA	EN	EN
Corica soborna (Hamilton, 1822)	Ganges river-sprat	Kachki	Clupeiformes	Padma, Gorai, Chandana, Horai	Pelagic	Consumable	GN, SN, CN, DN, PN, T	S, R, A	LC	LC
Crossocheilus latius (Hamilton, 1822)	Gangetic latia	Tatkeni	Cypriniformes	Padma	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T, HL	R, A, LA, W, Sp	EN	LC
Dermogenys pusillus (Kuhl & van Hasselt, 1823)	Wrestling halfbeak	Ek thota	Beloniformes	Padma, Gorai	Pelagic	Consumable	SN, CN, DN, PN	S, R, A, LA, Sp	LC	EN
Esomus danricus (Hamilton, 1822)	Flying barb	Darkina	Cypriniformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	CN, DN, PN, T, HL	Sp, R, A, LA, S	LC	LC
Eutropiichthys vacha (Hamilton, 1822)	Batchwa vacha	Bacha	Siluriformes	Padma	Pelagic	Consumable	GN, SN, CN, HL	S, R, A, LA	LC	LC
Gagata cenia (Hamilton, 1822)	Indian gagata	Gang tengra	Siluriformes	Padma	Demersal	Consumable	GN, SN, CN	S, R, A	LC	LC

(*continued on next page*)

Table 2 (*continued*)

Scientific name of SIS	English name	Local name	Order	River	Zone of habitat	Economic significance	Gear	Season	Conservation status	
									Local	Global
Glossogobius giuris (Hamilton, 1822)	Fresh water goby	Bele	Perciformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T, HL	All	LC	LC
Glyptothorax telchitta (Hamilton, 1822)	Copper catfish	Ghora kata	Siluriformes	Padma	Benthopelagic	Consumable	GN, SN, CN	S, R, A	VU	LC
Gonialosa manmina (Hamilton, 1822)	Ganges river gizzard shad	Chapila	Clupeiformes	Padma	Pelagic	Consumable	GN, SN, CN, DN, PN, T	S, R, A, LA	LC	LC
Gudusia chapra (Hamilton, 1822)	Indian river shad	Chapila	Clupeiformes	Padma, Gorai, Chandana	Pelagic	Consumable	GN, SN, CN, DN, PN, T	W, Sp, S, R	VU	LC
Heteropneustes fossilis (Bloch, 1794)	Stinging catfish	Shing	Siluriformes	Padma, Gorai	Demersal	Consumable	GN, SN, CN, DN, PN, T, HL	Sp, S, R	LC	LC
Labeo bata (Hamilton, 1822)	Bata labeo	Bata	Cypriniformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T, HL	All	LC	LC
Lepidocephalichthys annandalei (Chaudhuri 1912)	Annaldale loach	Puiya gutum	Cypriniformes	Padma, Gorai, Chandana, Horai	Demersal	Consumable	GN, SN, CN, DN, PN, T, HL	S, R, A	VU	LC
Lepidocephalichthys guntea (Hamilton, 1822)	Guntea loach	Gutum	Cypriniformes	Padma, Gorai, Chandana, Horai	Demersal	Consumable	GN, SN, CN, DN, PN, T, HL	S, R, A	LC	LC
Macrognathus aculeatus (Bloch, 1786)	One-stripe spinyeel	Tara baim	Synbranchiformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	All	NT	EN
Macrognathus pancalus (Hamilton, 1822)	Stripped spinyeel	Guchi baim	Synbranchiformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	All	LC	LC
Mastacembelus armatus (Lacepede,1800)	Tire-track spinyeel	Sal baim	Synbranchiformes	Padma, Chandana, Gorai	Demersal	Consumable	GN, SN, CN, DN, PN, T	All	EN	EN
Mystus bleekeri (Day, 1865)	Bleeker's mystus	Gulsha	Siluriformes	Padma, Chandana	Demersal	Consumable	GN, SN, CN, DN, PN, T, HL	W, Sp, S, R	LC	LC
Mystus tengara (Hamilton, 1822)	Tengara mystus	Bujuri tengra	Siluriformes	Padma, Chandana, Gorai, Horai	Demersal	Consumable	GN, SN, CN, DN, PN, T, HL	W, Sp, S, R, A	LC	LC
Mystus vittatus (Bloch, 1797)	Striped dwarf catfish	Tengra	Siluriformes	Padma, Gorai, Chandana, Horai	Demersal	Consumable	GN, SN, CN, DN, PN, T, HL	W, Sp, S, R, A	LC	LC
Nandus nandus (Hamilton, 1822)	Mottled nandus	Bheda	Perciformes	Padma, Gorai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T, HL	S, R, A	NT	LC
Osteobrama cotio (Hamilton, 1822)	Cotio	Dhela	Cypriniformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	All	NT	LC
Pethia guganio (Hamilton, 1822)	Glass barb	Mola punti	Cypriniformes	Padma	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	S, R, A, LA, Sp	LC	LC
Pethia ticto (Hamilton, 1822)	Ticto barb	Tit punti	Cypriniformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T, HL	All	VU	LC
Pisodonophis boro (Hamilton, 1822)	Rice-paddy eel	Baim	Anguilliformes	Padma, Gorai, Horai	Demersal	Trash	GN, SN, CN, DN, PN, T	W, Sp, R	LC	LC
Polynemous paradiseus (Linnaeus, 1758)	Paradise threadfin	Taposi	Perciformes	Padma	Demersal	Consumable	GN, SN, CN	R, A	LC	EN
Pseudambassis baculis (Hamilton, 1822)	Indian glassy fish	Kata chanda	Perciformes	Padma	Demersal	Consumable	CN, DN, PN, T	S, R, A, LA, W	NT	LC
Pseudambassis lala (Hamilton, 1822)	Highfin glassy perchlet	Lal chanda	Perciformes	Padma, Gorai, Chandana, Horai	Demersal	Consumable	CN, DN, PN, T	S, R, A, LA, W	LC	EN
Pseudeutropius atherinoides (Day, 1878)	Indian potasi	Batashi	Siluriformes	Padma, Gorai, Chandana, Horai	Demersal	Consumable	GN, SN, CN	S, R, A, LA, W	LC	LC

(*continued on next page*)

Table 2 (*continued*)

Scientific name of SIS	English name	Local name	Order	River	Zone of habitat	Economic significance	Gear	Season	Conservation status	
									Local	Global
Puntius chola (Hamilton, 1822)	Chola barb	Chola punti	Cypriniformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T, HL	Sp, S, R, A	LC	LC
Puntius sophore (Hamilton, 1822)	Spotfin swamp barb	Jat punti	Cypriniformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T, HL	W, Sp, S, R, A	LC	LC
Puntius terio (Hamilton, 1822)	One spot barb	Teri punti	Cypriniformes	Padma, Chandana	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T, HL	Sp, S, R, A	LC	LC
Rhinomugil corsula (Hamilton, 1822)	Corsula	Khorsula	Mugiliformes	Padma	Pelagic	Consumable	GN, SN, CN	Sp, R, A	LC	LC
Salmophasia bacaila (Hamilton, 1822)	Large razorbelly minnow	Chela	Cypriniformes	Padma	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T, HL	S, R, A, LA	LC	LC
Salmostoma phulo (Hamilton, 1822)	Finescale razorbelly minnow	Phulo chela	Cypriniformes	Padma	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T, HL	S, R, A, LA	NT	LC
Setipinna phasa (Hamilton, 1822)	Gangetic hairfin anchovy	Phaissa	Clupeiformes	Padma	Pelagic	Consumable	GN, SN, CN	Sp, S, R, A	LC	LC
Setipinna taty (Hamilton, 1822)	Scaly hairfin anchovy	Teli phasa	Clupeiformes	Padma	Pelagic	Consumable	GN, SN, CN	Sp, S, R, A	LC	EN
Tenualosa toli (Valenciennes, 1847)	Toli shad	Chandana ilish	Clupeiformes	Padma	Pelagic	Consumable	GN, SN, CN	Sp, S, R, A	LC	EN
Tetraodon cutcutia (Hamilton, 1822)	Ocellated pufferfish	Potka	Tetraodontiformes	Padma, Horai Chandana	Demersal	Trash	GN, SN, CN, DN, PN, T	R, A, LA, W, Sp	LC	LC
Trichogaster fasciata (Bloch & Schneider, 1801)	Banded gourami	Khalisha	Perciformes	Padma, Gorai, Chandana, Horai	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	R, A, LA, W, Sp	LC	LC
Trichogaster lalius (Hamilton, 1822)	Dwarf gourami	Ranga khailsa	Perciformes	Padma, Gorai, Chandana	Benthopelagic	Consumable	GN, SN, CN, DN, PN, T	R, A, LA, W, Sp	LC	LC
Xenentodon cancila (Hamilton, 1822)	Freshwater garfish	Kankila	Perciformes	Padma, Gorai, Chandana, Horai	Pelagic	Consumable	SN, CN, DN, PN, T	R, A, LA	LC	EN

Note, GN = Gill net; SN= Seine net; CN= Cast net; DN = Drift net; PN= Push net; T = Trap; HL= Hook and line; All = All seasons; S= Summer; R= Rainy; A = Autumn; L = Late autumn; W= Winter; Sp = Spring; LC = Least concern; NT= Near threatened; VU= Vulnerable; and EN = Endangered.
Source: Authors survey, 2021.

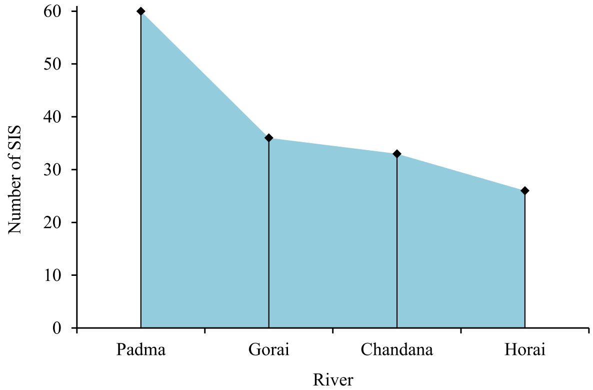

Fig. 3. Number of small indigenous species (SIS) of fish in the Padma, the Gorai, the Chandana and the Horai of Rajbari (Source: Authors Survey, 2021).

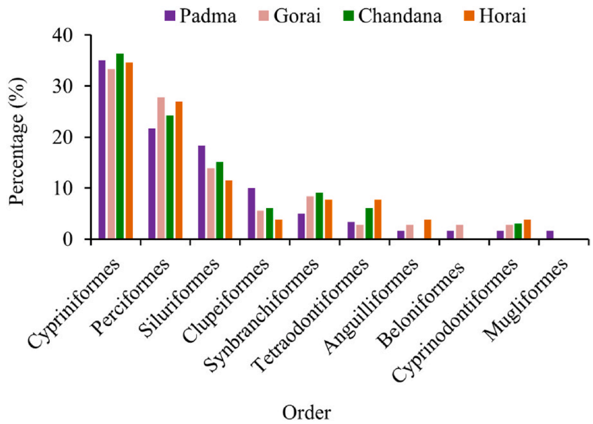

Fig. 4. Order of the available small indigenous species (SIS) of fish from the four rivers of Rajbari (Source: Authors survey, 2021).

Whereas 10, 11.11, 12.12 and 11.54% SIS under the vulnerable category was found from the Padma, the Gorai, the Chandana and the Horai rivers, respectively (Fig. 8a).

In accordance with the IUCN red list representing the worldwide fishes [25], 73.33, 75.00, 78.78 and 80.77% SIS from the Padma, the Gorai, the Chandana and the Horai rivers, respectively fall under the least concern (LC) category. Conversely, the highest near threatened (NT) SIS was recorded from the Padma River (21.67%) and the lowest in the Horai River (15.38%), respectively (Fig. 8b).

3.6. Reduction of SIS biodiversity

The fishermen's perceptions revealed that, in the study area, the leading causes for the depletion of SIS diversity were pollution, change of river direction, illegal and overfishing, reduced river depth, siltation, irregular seasonal change, urbanization, natural drought, flood, and lack of organizational support (Table 5). The value of λ (8.70) of the AHP indicates greater consistency in the pairwise comparisons and the 7% consistency ratio (CR) is also within the acceptable range (10%). The relative importance of each factor posing a risk to SIS biodiversity is apparent in the eigenvalues (Table 6). With a weight of 0.32, pollution tends to be the most significant problem, followed by overfishing and illegal fishing (0.19), siltation and reduction of river depth (0.15) and urbanization (0.14), irregular seasonal change (0.07) and so on. Thus, a wide variety of factors natural as well as manmade are responsible for the reduction of SIS biodiversity in the studied rivers.

4. Discussion

Availability of riverine fish is inherently contingent upon the type of river, season, water depth, water quality parameters, season, plankton availability in the river, harvest location and type of gears and nets utilized. The number of SIS in the Padma River was higher compared to the Gorai, the Chandana and the Horai River, respectively. The Padma and the Gorai River have continuous water flow and water depths are also high. So, more fish species are available in these main streams than in the temporary and moribund rivers. On the flip side, SIS are adapted with less water with a higher nutrient load, commonly available in the Chandana and Gorai River. From the Padma River, 60 SIS were found which was lower than the observation of Joadder et al. [33] where they recorded 45 SIS from the

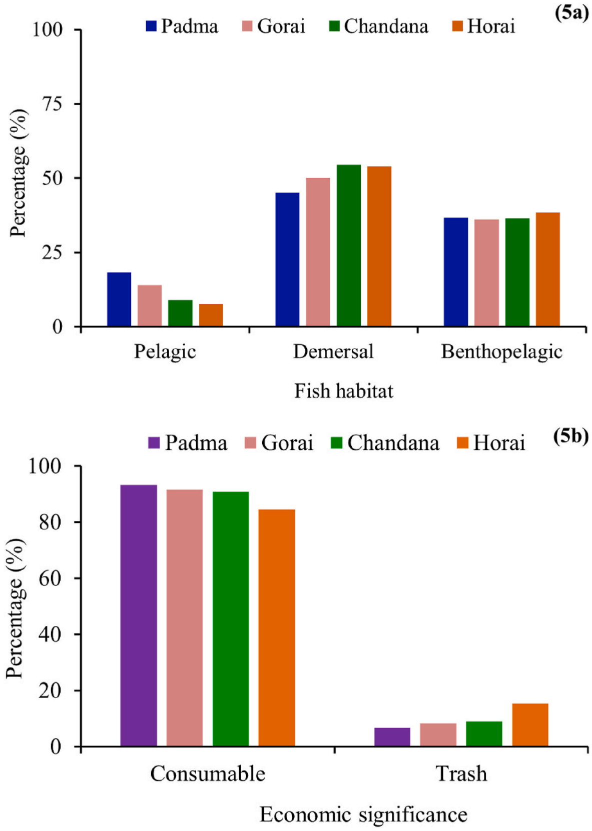

Fig. 5. (a) Zone of habitat and (b) economic importance of small indigenous species (SIS) of fish in the rivers of Rajbari (Source: Authors survey, 2021).

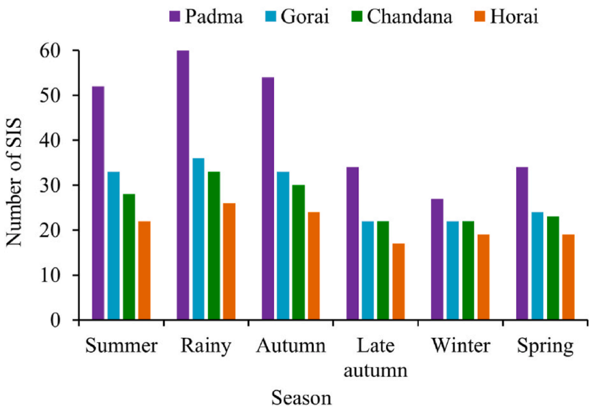

Fig. 6. Seasonal availability of small indigenous species (SIS) of fish in the rivers of Rajbari (Source: Authors survey, 2021).

same river at Rajshahi District. A study on the SIS diversity in the Gorai River revealed that there was 40 SIS from 7 orders and the Perciformes was dominated [2] which was lower than the current findings. Moreover, Saha et al. [7] and Saha et al. [34] found 22 and 28 SIS from the fish markets of West Bengal, India which was much lower than the present study. The study found Cypriniformes to be the dominant orders in the four rivers, on the other hand, the 2nd and 3rd dominant orders were Perciformes and Siluriformes, respectively, which is aligned with the study of Siddik et al. [35]. The pelagic SIS were lower than the demersal and benthopelagic SIS which might be influenced by the surface water quality and plankton availability. Moreover, in the study area, most of the SIS were benthopelagic fish which might be because those fishes can feed from other zones. In the course of the present study, it was found that puffer fishes (*Potka*) were discarded immediately after harvesting or during sorting for the poisonous effects of those fishes though such fish poisoning was a common scenario in Bangladesh previously [36]. Moreover, traditionally the people of the study area had not been eating *Pisodonophis boro* and *Aplocheilus panchax*. Though the trash fishes have little or no economic importance to the consumer,

Table 3
Pearson's correlation (r) between the species of four rivers during six seasons.

Variables		Padma	Gorai	Chandana	Horai
Padma	Summer	1			
	Rainy	1			
	Autumn	1			
	Late autumn	1			
	Winter	1			
	Spring	1			
Gorai	Summer	0.671**	1		
	Rainy	0.740**	1		
	Autumn	0.742**	1		
	Late autumn	0.725**	1		
	Winter	0.577**	1		
	Spring	0.565**	1		
Chandana	Summer	0.648**	0.776**	1	
	Rainy	0.736**	0.867**	1	
	Autumn	0.737**	0.845**	1	
	Late autumn	0.763**	0.757**	1	
	Winter	0.593**	0.749**	1	
	Spring	0.577**	0.777**	1	
Horai	Summer	0.596**	0.806**	0.723**	1
	Rainy	0.414**	0.701**	0.653**	1
	Autumn	0.484**	0.843**	0.656**	1
	Late autumn	0.578**	0.667**	0.696**	1
	Winter	0.643**	0.648**	0.599**	1
	Spring	0.523**	0.598**	0.598**	1

Note, double asterisks (**) indicate correlation in significant at the 0.01 level (2-tailed).
Source: Authors survey, 2021.

Table 4
Diversity index of the small indigenous species (SIS) of fish in the four rivers of Rajbari.

Diversity Indices	River			
	Padma	Gorai	Chandana	Horai
	S = 60, N = 4638	S = 36, N = 3009	S = 33, N = 2548	S = 26, N = 1532
Shannon's Diversity Index	3.85	3.47	3.38	3.18
Margalef Richness Index	7.00	4.37	4.08	3.41
Buzas and Givson's Evenness	0.78	0.89	0.89	0.93
Pielou's Evenness Index	0.94	0.97	0.97	0.98

Note, S= Species number and N= Number of individuals.
Source: Authors survey, 2021.

undoubtedly the fish are of great importance in the ecosystem's functioning, resilience, and stability of ecosystems. These non-target species are linked to the food web and contribute to the ecosystem's general well-being.

Fishers often select their fishing equipment based on the water basin, water depth, and target species; however, the mesh size of the net also varies depending on the size of the fish being pursued. This study evident 20 fishing equipment under 7 groups which is more or less similar to Rahman et al. [37] who found 19 gears under 9 categories used by the fishermen in a coastal district. In the study area, the cast nets were mostly used to harvest SIS. Whereas Roy et al. [10], *Chela cachius, Apocryptes bato, Mystus vittatus* and *Gudusia chapra* are caught using the push net and cast net, *Anabas testudineus* are harvested with traps and gill net in the Shibsa River. In the Shibsa River and Agunmukha River, the seine net was mostly used for harvest [10,37]. Nevertheless, Hanif et al. [2] found the highest use of set bag net in the Gorai River, which is dissimilar to the present result, and it might be due to different study sites and different study periods. Gear with smaller mesh sizes and tiny gaps are harmful to SIS as they are very small in size. For the high demand of SIS, fishers of the study area use such harmful gear [38]. The effect of hook and line is less harmful than the other gears for smaller fishes [39,40].

During the rainy season the number of available SIS was highest in the Padma River followed by the Gorai, the Chandana, and the Horai, respectively. A similar trend of SIS availability in rivers was found in the case of other seasons. Differences in river systems like water flow, direction, and channel might be the prominent factors for such fashion of seasonal variations. Hossain et al. [41] stated that the water temperature and rainfall are the most influencing factors for the species diversity in the river while higher dissolved oxygen remains in the river during the monsoon. Jahan et al. [13] reported that the majority of SIS were found during the rainy and fall seasons and the fewest SIS were recorded in the winter season. The findings of Mohsin et al. [42] were dissimilar to the present study where they did not find a major variation in the monthly abundance of finfishes in the Padma River. Fluctuation of environmental factors causes high variability in the number and abundance of fish species [43,44]. Plankton density is directly correlated with water quality indicators like dissolved oxygen, temperature, pH, transparency, electrical conductivity, total dissolved solids and so on. Thus,

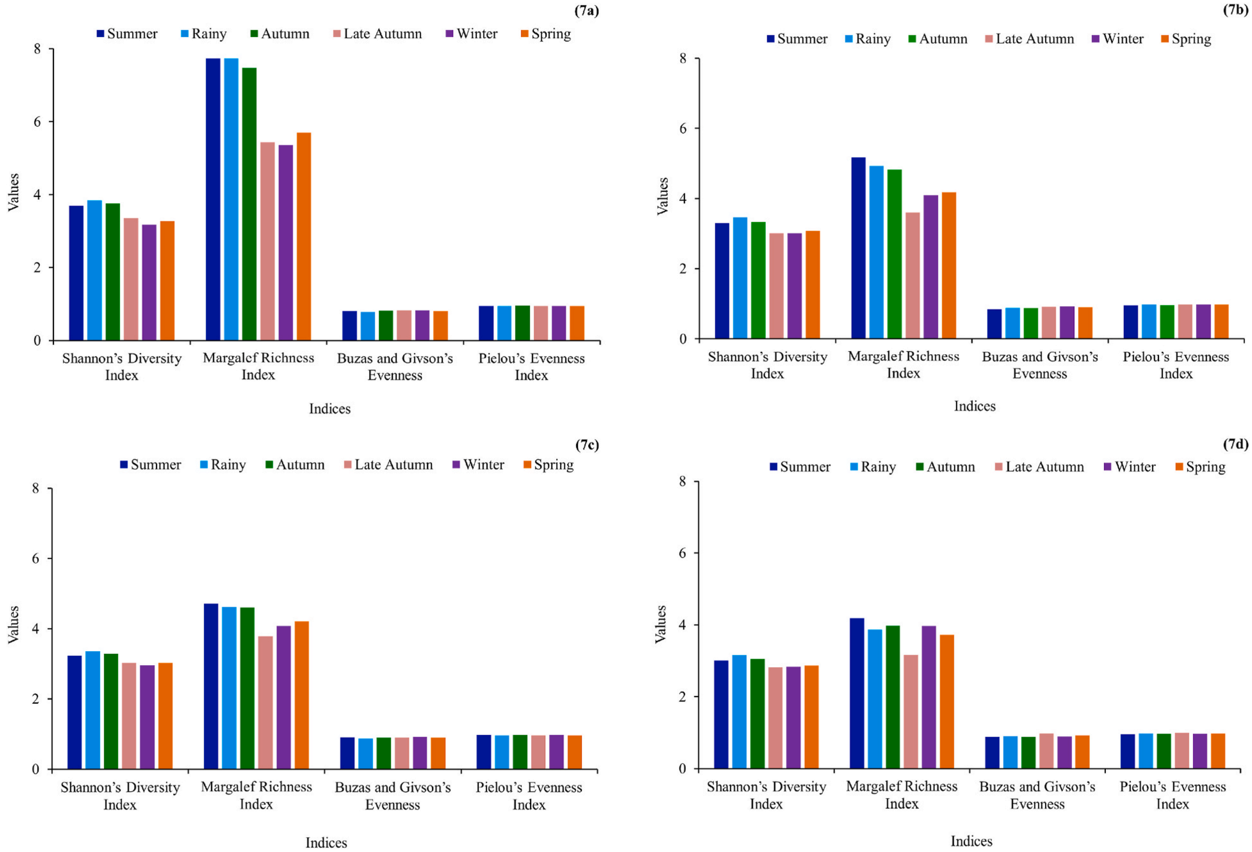

Fig. 7. Seasonal variations of diversity indices of small indigenous species (SIS) of fish in the (a) Padma (b) Gorai (c) Chandana, and (d) Horai River (Source: Authors survey, 2021).

improper water quality eventually lowers SIS production as primary production is the main food source in the natural waterbodies [45, 46]. Moreover, seasonal variation directly influences the spawning of fish. Low transparency during the dry season may be related to increased human activity in rivers and re-suspension, as well as easy distribution of inorganic particles in the water column. Insufficient river water during the winter season results in low fish catch per unit effort. Even during the dry season, the level of the water drops significantly, and some small rivers dry out completely.

Different seasons yield positive correlation patterns between the species in the rivers which suggests that as one river's species composition changes, the other river tends to exhibit a corresponding change. Several factors are responsible for such a phenomenon likely-hydrological connectivity within the same geographical area, shared watershed characteristics, rainfall and so on [47–49]. The highest correlation was found between the Gorai and the Chandana rivers (r = 0.867) during the rainy season, while the weakest correlation was between the Padma and the Horai rivers (r = 0.414) during the same season.

The biodiversity index is a vital tool to know the information about the rarity and commonness of a species in a community [2]. In the rivers of Rajbari District, Shannon's Diversity index was higher than the values of different spots in the Koto Panjang Reservoir, Indonesia [50]. Moreover, the Shannon's Diversity Index and Margalef Species Richness of the SIS in the Padma River was the highest than the others as the species variation of the Padma was higher than the other rivers. The Margalef Richness Index of the rivers ranged from 3.4 to 7.0 which is higher than the result of Sunny et al. [4] who recorded index values of 4.3–4.6 from two *haors*. Designing conservation areas and maintaining biodiversity mostly depend on assessing the diversity of fish species in a water body [51]. Lower species richness in the Chandana and the Horai River indicates lower variation of species as these rivers were observed as temporary rivers where the permanent water flow was partially reduced. Species that cannot show adaptation to the fluctuation of wet and dry periods become unavailable in the non-perennial rivers. Moreover, the evenness value of the Padma River was lower than the other three rivers as this parameter depends on the number of individuals of each species. Jewel et al. [3] found Pielou's Evenness Index of the Atrai River 0.748, which is higher than the values of the Gorai, the Chandana and the Horai River.

Freshwater riverine fishes are in a state of crisis with a higher proportion of species threatened with extinction than the terrestrial and marine species [52]. Moreover, in the studied rivers, 3.33% SIS including *Botia rostrata* and *Chelonodon patoca* were still data deficient which indicates that their status can be of any category. The threatened species can be conserved by eliminating the major threats to freshwater biodiversity including destructive fishing, habitat degradation, water pollution, river flow modification and entry of non-native species into the natural water bodies [52]. Banning regulations in case of threatened fish, mesh size regulations,

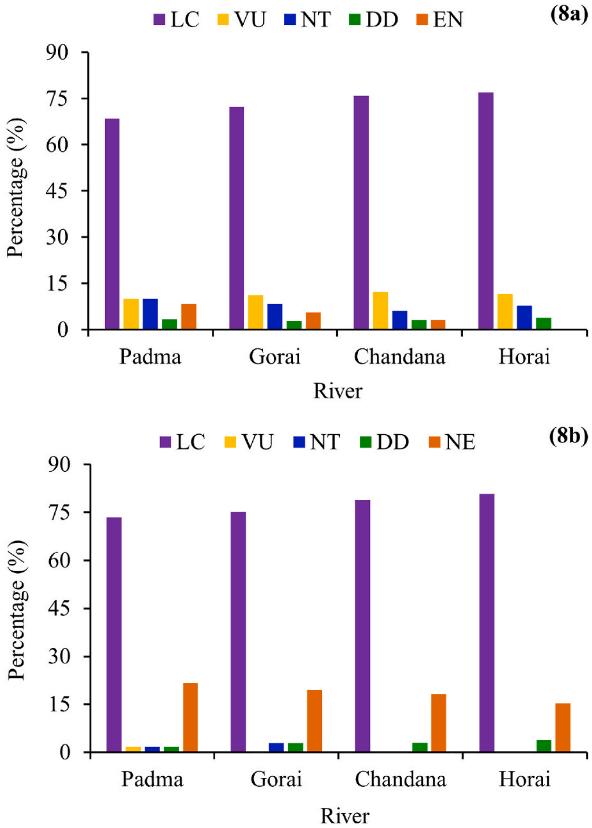

Fig. 8. Conservational status of small indigenous species (SIS) of fish according to IUCN Red list (2015) of (a) Bangladesh and (b) Global (Source: Authors survey, 2021).

Table 5
Pair-wise comparison of the risk factors for small indigenous species (SIS) of fish in Analytic Hierarchy Process (AHP).

	P	F	S	U	C	E	N	O
P	1	3	3	3	5	5	7	5
F	1/3	1	2	3	3	3	5	5
S	1/3	1/2	1	1	3	3	5	7
U	1/3	1/3	1	1	3	3	5	5
C	1/5	1/3	1/3	1/3	1	1	3	5
E	1/5	1/3	1/3	1/3	1	1	3	3
N	1/7	1/5	1/5	1/5	1/3	1/3	1	3
O	1/5	1/5	1/7	1/5	1/5	1/3	1/3	1

Note, P= Pollution; F= Illegal and overfishing; S= Siltation and reduction of river depth; U= Urbanization; C= Irregular seasonal change; E = Exploitation during breeding season; N= Natural calamities; and O= Lack of organizational support.
Source: Authors survey, 2021.

identifying breeding grounds and artificial breeding of fish in the river can be effective for sustainable management of the vulnerable SIS.

The major problems leading causes for the depletion of SIS diversity were pollution, change of river direction, illegal and overfishing, reduced river depth, siltation, irregular seasonal change, urbanization, natural drought, flood, and lack of organizational support. The present study aligns with Jewel et al. [3], Sunny et al. [4] and, Pandit et al. [18] found similar types of vulnerabilities of indigenous fish species in the different inland waters of Bangladesh. A study on the Gorai River and its distributaries revealed that, dramatic fall in water flow of the Gorai River results in death of around eight among fifteen rivers those are dependent on it as a parent stream [53]. Small indigenous species (SIS) are decreasing from their habitat due to overexploitation, habitat loss, pollution, illegal fishing gear used and so on [54]. From the current study, various recommendations can be suggested for protecting fish diversity based on surveys and firsthand observations for instance, river management by reducing the hazards, restoration, enforcement of law and initiating a banning period for the vulnerable or threatened species and effective extension service.

To allow the movement of aquatic organisms within nearby water bodies throughout flood and dry seasons, effective fish passages

Table 6
Synthesized matrices of risks in Analytic Hierarchy Process (AHP) from the decision of the participants of Rajbari.

	P	F	S	U	C	E	N	O	Eigen vector	Rank
P	0.37	0.51	0.38	0.33	0.30	0.30	0.24	0.15	0.32	1
F	0.12	0.17	0.25	0.33	0.18	0.18	0.17	0.15	0.19	2
S	0.12	0.08	0.13	0.11	0.18	0.18	0.17	0.21	0.15	3
U	0.12	0.06	0.13	0.11	0.18	0.18	0.17	0.15	0.14	4
C	0.07	0.06	0.04	0.04	0.06	0.06	0.10	0.15	0.07	5
E	0.07	0.06	0.04	0.04	0.06	0.06	0.10	0.09	0.06	6
N	0.05	0.03	0.03	0.02	0.02	0.02	0.03	0.09	0.04	7
O	0.07	0.03	0.02	0.02	0.01	0.02	0.01	0.03	0.03	8
Here, λ = 8.70; CI (Consistency Index) = 0.10; N = 8; RI (Random Index) = 1.41; and CR (Consistency Ratio) = 7%.										

Note, P= Pollution; F= Illegal and overfishing; S= Siltation and reduction of river depth; U= Urbanization; C= Irregular seasonal change; E = Exploitation during breeding season; N= Natural calamities; and O= Lack of organizational support.
Source: Processed results.

must be installed. Zaman and Naser [55] found that the Sariakandi fish pass between the Jamuna and the Bangali River in Bogra, Bangladesh helps in the well-ordered fish migration and movement for both small and large fish species, though the technology is not feasible during the winter and dry seasons. Road transport networks also must be modified with less-hampering structures. Even though the country's government has outlawed destructive gill nets like the *current jal*, many fishermen still operate them [4,56]. There are some rules and regulations governing the usage of fishing equipment, the size of net mesh, the time of day when the fishing is allowed, and the amount of catch in the nation, but unfortunately, they are not always followed, which results in a loss of fish diversity [3,10,57,58].

When a river flows downstream, several enterprises, including agriculture, hydropower, navigation, industry, and domestic consumption utilize its water as a resource. Thus, an integrated strategy of the local, national, and regional sectors should be assured for the long-term management of the natural water bodies. The protection of current fisheries resources can be achieved through reducing human influences, enacting fishing regulations, establishing fish sanctuaries, increasing public awareness, and extension services [59–61]. Community-based resource management will be effective for protecting the natural water bodies as well as indigenous species [60]. Li et al. [62] recommended the involvement of all local authorities related to the Yangtze River Basin, China for well-planned environmental monitoring and evaluation for fish biodiversity conservation and restoration.

5. Conclusion

The current study unequivocally reveals that, as a deltaic district, Rajbari is endowed with a diverse array of SIS across different groups of fishes those are being harvest using seven groups of fishing gears. The conservation status of the SIS indicated a precarious situation for a significant number of SIS, both locally and globally. The Padma and the Gorai rivers are permanent rivers with continuous water flow which exhibited heightened species richness of SIS. On the other hand, the Chandana and the Horai were partially and completely dried rivers, respectively. According to the present study, those native fishes were available in the monsoon season and its aftermath which decreased the species richness and diversity index. This pattern is not unique to Rajbari but extends to other deltaic districts or areas where the rivers are dried or drying continuously leading to potential extinction of numerous native species. In light of these findings, the rivers should be considered by ensuring continuous stream flow, rejuvenating the non-perennial river, sustainable protection, development of stream fish conservation strategies, annual sampling of specific river spawning behavior of native fishes, mesh size regulation, breeding as well as harvest period regulation of threatened species. The strategies necessitates a sophisticated blend of tight institutional rules, ecological engineering, and advanced pollution reduction methods. Continued research and exploration of other deltaic zones having different hydrological characteristics are needed for comprehensive and enduring conservation planning of the SIS biodiversity.

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Additional information

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CRediT authorship contribution statement

Zubyda Mushtari Nadia: Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Md. Abdul Baten:** Writing – review & editing, Writing – original draft. **Prosun Roy:** Writing – review & editing, Writing – original draft, Formal analysis. **Newton Saha:** Writing – review & editing, Writing – original draft, Methodology. **Kazi Ahsan Habib:** Writing – review & editing, Writing – original draft. **Sarower Mahfuj:** Writing – review & editing, Writing – original draft. **Mohammad Kamrujjaman:** Writing – original draft, Methodology. **Mohammad Rashed:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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