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Research Article

Diversity of Fish Species in relation to Climatological Fluctuations in a Coastal River of Bangladesh

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In the Sandha river of Bangladesh, we investigated the temporal and geographical fluctuation in species of fish composition and diversity. The extent of our understanding of the fish variety in this river varies greatly on both a temporal and a geographical scale. From July 2021 to June 2022, fish specimens were gathered from five stations using various conventional fishing methods. During the study period, 5118 individuals from 67 species were collected which include 8 orders, 24 families, and 54 genera. Cypriniformes made up the majority of the order (32.84%), whereas Beloniformes and Tetraodontiformes made up the least number of species (1.49% each). Six species were listed as endangered (8.96%), seven as vulnerable (10.45%), nine as near threatened (13.43%), forty-three as least concern (64.18%), one with data deficient (1.49%), and one as not evaluated (1.49%) in Bangladesh. In order to quantify the temporal and geographical changes in community composition, diversity indices were calculated and put to use. Three (temperature, humidity, and rainfall) out of the four environmental factors (temperature, humidity, rainfall, and photoperiod) had a big impact on how species were distributed. At a similarity level of 79% and 75.5% separation, 2 substantial clusters were seen in the case of stations and 2 large clusters were detected in the case of months, respectively. However, at a similarity threshold of 20% separation, three different groups of fish species were found. Our research offers the most recent status data on fish distribution in the Sandha river. The knowledge acquired from this research is crucial for creating protection and management plans that will promote the long-term viability of fishery resources in the Sandha river and its nearby coastal tributaries.

1. Introduction

The term "biodiversity" refers to the abundance, variation, and distribution of organisms on all biological levels, including those involving individuals, species, groups, and environments [1, 2]. The ability of biological systems to adapt to environmental alterations is influenced by biodiversity, which also supports ecological systems and produces goods and services from ecosystems that promote the well-being of humans [3, 4]. Moreover, biodiversity has aesthetic appeal in addition to inherent worth. It is possible that in the future, chemicals originating from aquatic organisms and plants may be used as medicines to prevent and treat more of our ailments. The sustainable growth of natural assets, including commercial fisheries, depends on biodiversity. Although it seems obvious that diversity is necessary for feasible, profitable fisheries, there is disappointingly scant data to back this up, notably from Bangladesh's coastal regions. Fisheries are essential to the maintenance of aquatic and terrestrial environments and human life. Fish contributes more than 25%

of the protein consumed worldwide [5]. The preservation of our fish populations is essential since many fishermen depend on them for their livelihood. However, there are real threats to the environment and biodiversity sustainability in freshwater situations across the planet [6].

Bangladesh's freshwater habitats are greatly enriched, sustaining about 260 finfish species and 24 species of prawns [7]. Bangladesh produced 4.6 million metric tons of fish overall in the 2020-2021 fiscal year, ranking third (3^{rd}) in the world for open-water fish production and fifth (5^{th}) for culture fish output [7]. The lives of more than 12 million fishermen in Bangladesh are being steadily threatened by the ongoing fall in fish catches despite the country's possession of extraordinarily fertile inland waterways covering around 45,000 km^2 [8–10]. As opposed to several other rivers in the coastal region, the Sandha river is one of the significant fish reservoirs in Bangladesh's southern coastal area [11]. The Sandha river plays a significant role in the lives and livelihoods of the local fishermen by offering them a stable supply of food and income for several families. As a result, the river has a crucial impact on how people live their lives and how communities that live along its southern coast rely on its supplies. Therefore, fish and their surroundings have a special link in the riverine ecology. The distribution of fish and the ecology of the river would be significantly impacted by any changes to the riverine environment. Fish abundance is connected to environmental variables that may change fish population patterns as well as biodiversity metrics. Aquatic biodiversity, their captures, and their conservation have experienced an unusual swapping as a consequence of the changing climate and human-induced degradation of aquatic ecosystems [12]; the Sandha river is not a break from this pattern. Physical and chemical parameters of water, climatic variables, and the availability of food all have an impact on the abundance and variety of species of fish [13, 14]. The diversity of freshwater species of fish in the river has been under stress owing to human deterioration brought on by urbanization, dam development, water abstraction for power generation and irrigation, and pollution during the past few decades [15]. Recently, developing nations have understood how critical it is to keep an eye on biodiversity in conserved regions [16].

Fish abundance and natural distribution are important for biodiversity conservation, and a thorough understanding of various management techniques is necessary to support the best possible exploitation of fish [10]. Instead of just counting the number of species within a community, diversity indexes serve as a tool for more accurate information provision. As far as we can tell, only the studies of Hanif et al. [17] and Ruma et al. [11] have documented fish composition and biodiversity indices in the Sandha river in Bangladesh. However, they did not work on the correlation between fish and their environment. In this work, we make an effort to learn more about the fish diversity and interactions in the Sandha river. Therefore, the purpose of the current research is to assess the diversity status, composition, and relationship between fish and changes in the environment in the Sandha river. In coastal areas, ecosystem-based riverine fishery management might be possible due to the findings of this study.

2. Materials and Methods

2.1. Study Area. During the months of July 2021 to June 2022, the present studies were conducted monthly to assess the Sandha river in Bangladesh's Pirojpur and Barisal districts (Figure 1). In order to gather information for this inquiry, five sample stations were chosen: Swarupkathi (station 1) in the Pirojpur district, Banaripara (station 2), Wazirpur (station 3), Babugonj (station 4), and Mirgonj (station 5) in the Barisal district of Bangladesh. The investigation was conducted in accordance with the Bangladesh Fisheries Research Institute's ethical norms.

2.2. Fish Specimen Collection. Samples were taken from adjacent fish landing centers during the catch and from fishermen who had been alerted in advance. Local fishermen use a variety of fishing gear (e.g., set gill nets, seine nets, drift gill nets, cast nets, moshari bar jal, hooks, and traps) in the studied area, which varies in specific species, size, and efficiency [18]. At each sample station, the same sampling techniques were used. The total number of distinct species discovered in each of the five locations was counted during the sampling session.

2.3. Identification of Collected Fish Samples. Depending on the main physical characteristics, collected fish species were arranged. The species that were tough to specify on the scene were brought to the laboratory of the Bangladesh Fisheries Research Institute, Riverine Sub-Station, Khepupara, Patuakhali, Bangladesh, with 5-10% buffered formalin solution. Samples were recognized by examining their morphological characteristics as well as their color which was previously described by Quddus and Shafi [19], Rahman [20, 21], Talwar and Jhingran [22], and Nelson [23]. According to FishBase (https://www.fishbase.se), IUCN global status, and IUCN Bangladesh [24], the taxonomy and conservation category of each species were allocated.

2.4. Fish Diversity Index. The following formulas were applied to calculate the Shannon-Wiener diversity index (H), Simpson's dominance index (D), Simpson's diversity index ($1 - D$), Margalef's richness index (d), and Buzas and Gibson's evenness index (E) in order to know the status of diversity of fish in the Sandha river for monthly sampling in each sampling stations.

Shannon-Wiener's diversity index (H) accounts for both the number of species and the pattern of populations among species [25, 26]. The following formula was used to determine the Shannon-Wiener diversity index:

$$H = \sum_{i=1}^{s} [\mathrm{Pi} \times \ln \mathrm{Pi}], \tag{1}$$

where Pi is the percentage of the sample that is made up of species and H is the Shannon-Wiener diversity index, s stands for the total population of a species, Σ is for the total population of all species, and ln is for the natural logarithm. For comparing diversity among different environments, one popular statistic is the Shannon-Wiener diversity index [27].

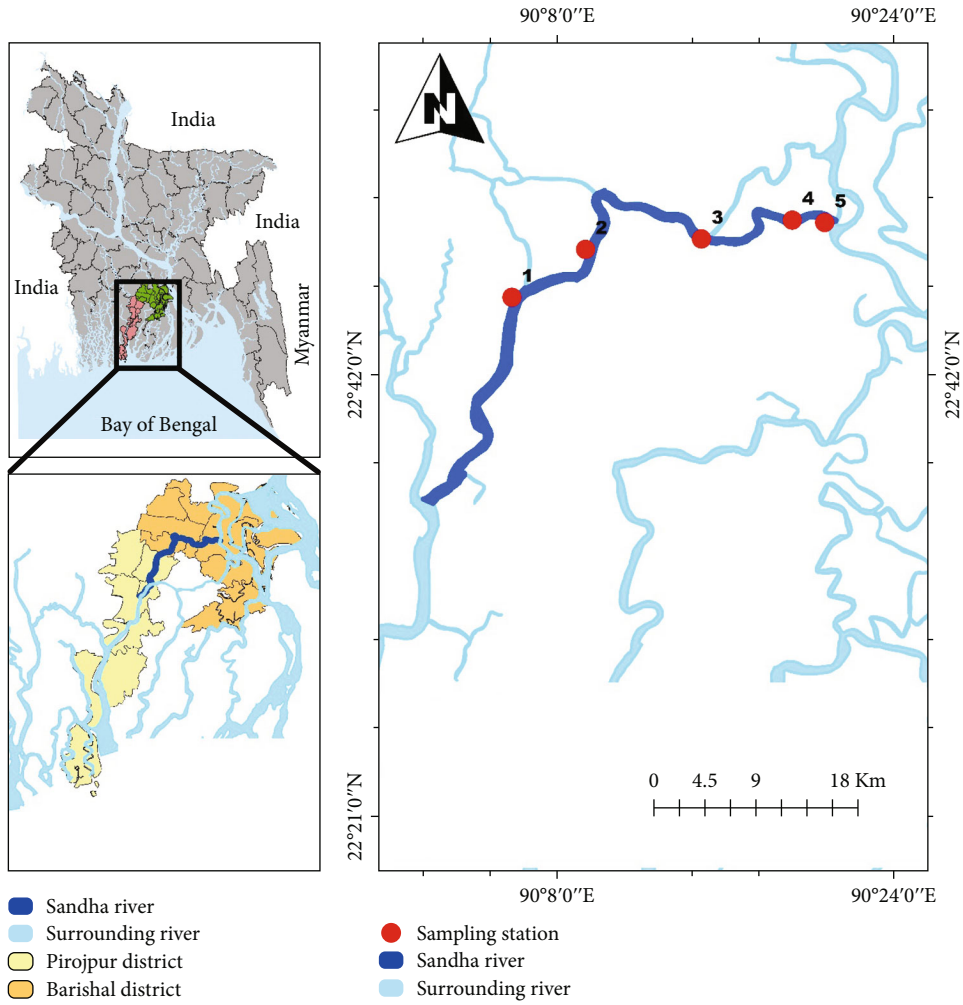

Figure 1: Location of sampling stations in the Sandha river of Bangladesh.

It presumes that organisms were chosen at random from a vast, independent community and that the sampling included members of every species [26].

A prominent technique for measuring habitat diversity that reflects both the number of species and the abundance is Simpson's dominance index (D). Simpson's dominance index is calculated by the equation of Simpson [28]:

$$D = \frac{\sum \text{ni}(\text{ni} - 1)}{N(N-1)}, \tag{2}$$

where ni represents the overall population of a certain species, N represents the overall population of all species, and Σ represents the sum of scores for each species.

Simpson's diversity index ($1 - D$), which reflects both the number of species and the abundance of each species, is frequently used to measure the biodiversity of the habitat. The calculation's formula is as follows [28]:

$$1 - D = 1 - \frac{\sum \text{ni}(\text{ni} - 1)}{N(N-1)}. \tag{3}$$

By applying the following formula, the Margalef richness index (d) was employed to measure species richness [29]:

$$d = \frac{(S-1)}{\ln N}. \tag{4}$$

Here, S is the number of total species, N represents the number of total individuals in the sample, and d represents the Margalef richness index. The Margalef richness index measures species richness and is extremely sensitive to sample size, despite its attempts to account for sampling effects. Both the absolute number of individuals and the density were used to determine the Margalef richness index [30].

Buzas and Gibson's evenness index [31] was calculated to measure the evenness by using the following formula:

$$E = \frac{eH}{S}, \tag{5}$$

where e is the base of the natural logarithm, H is the Shannon-Wiener diversity index, S is the number of species, and E represents the evenness index.

Table 1: The composition of fish species along with their contributions in the Sandha river of Bangladesh.

Order	Family	Scientific name	English name	Code	Total	% contribution	IUCN status Bangladesh	IUCN status Global
Osteoglossiformes	Notopteridae	*Chitala chitala*	Clown knife fish	S45	19	0.37	EN	NT
	Notopteridae	*Notopterus notopterus*	Bronze featherback	S46	51	1.00	VU	LC
Clupeiformes	Engraulidae	*Setipinna phasa*	Gangetic hairfin anchovy	S14	148	2.89	LC	LC
	Engraulidae	*Thryssa purava*	Oblique-jaw thryssa	S15	143	2.79	LC	DD
	Clupeidae	*Corica soborna*	Ganges river sprat	S13	322	6.29	LC	LC
	Clupeidae	*Gonialosa manmina*	Ganges river gizzard shad	S12	115	2.25	LC	LC
	Clupeidae	*Gudusia chapra*	Indian river shad	S10	95	1.86	VU	LC
	Clupeidae	*Tenualosa ilisha*	Hilsa shad	S9	182	3.56	LC	LC
	Clupeidae	*Tenualosa toli*	Toli shad	S11	151	2.95	LC	VU
Cypriniformes	Cyprinidae	*Amblypharyngodon mola*	Mola carplet	S35	140	2.74	LC	LC
	Cyprinidae	*Chela cachius*	Silver hatchet barb	S24	56	1.09	VU	LC
	Cyprinidae	*Cirrhinus cirrhosus*	Mrigal carp	S33	7	0.14	NT	VU
	Cyprinidae	*Devario devario*	Sind danio	S27	56	1.09	LC	LC
	Cyprinidae	*Esomus danrica*	Flying barb	S23	115	2.25	LC	LC
	Cyprinidae	*Gibelion catla*	Catla	S32	12	0.23	LC	LC
	Cyprinidae	*Hypophthalmichthys molitrix*	Silver carp	S36	6	0.12	NE	NT
	Cyprinidae	*Labeo bata*	Bata	S31	5	0.10	LC	LC
	Cyprinidae	*Labeo calbasu*	Orangefin labeo	S30	4	0.08	LC	LC
	Cyprinidae	*Labeo gonius*	Kuria labeo	S29	4	0.08	NT	LC
	Cyprinidae	*Labeo rohita*	Roho labeo	S28	15	0.29	LC	LC
	Cyprinidae	*Osteobrama cotio*	Cotio	S34	21	0.41	NT	LC
	Cyprinidae	*Pethia conchonius*	Rosy barb	S21	128	2.50	LC	LC
	Cyprinidae	*Pethia ticto*	Ticto barb	S19	121	2.36	VU	LC
	Cyprinidae	*Puntius chola*	Swamp barb	S20	135	2.64	LC	LC
	Cyprinidae	*Puntius sophore*	Pool barb	S17	282	5.51	LC	LC
	Cyprinidae	*Puntius terio*	Onespot barb	S22	28	0.55	LC	LC
	Cyprinidae	*Salmostoma bacaila*	Large razorbelly minnow	S26	149	2.91	LC	LC
	Cyprinidae	*Salmostoma phulo*	Finescale razorbelly minnow	S25	99	1.93	NT	LC
	Cyprinidae	*Systomus sarana*	Olive barb	S18	14	0.27	NT	LC
	Cobitidae	*Acanthocobitis botia*	Mottled loach	S16	68	1.33	LC	LC
	Cobitidae	*Lepidocephalichthys guntea*	Guntea loach	S37	161	3.15	LC	LC
Siluriformes	Siluridae	*Ompok pabda*	Pabdah catfish	S61	13	0.25	EN	NT
	Siluridae	*Wallago attu*	Wallago	S60	30	0.59	VU	VU
	Plotosidae	*Plotosus canius*	Gray eel-catfish	S62	10	0.20	NT	NE
	Heteropneustidae	*Heteropneustes fossilis*	Stinging catfish	S55	21	0.41	LC	LC
	Schilbidae	*Ailia coila*	Gangetic ailia	S58	98	1.91	LC	NT
	Schilbidae	*Clupisoma garua*	Garua bachcha	S59	91	1.78	EN	LC
	Schilbidae	*Silonia silondia*	Silond catfish	S57	95	1.86	LC	LC
	Pangasiidae	*Pangasius pangasius*	Pangas catfish	S56	33	0.64	EN	LC
	Bagridae	*Mystus bleekeri*	Day's mystus	S52	59	1.15	LC	LC
	Bagridae	*Mystus cavasius*	Gangetic mystus	S51	13	0.25	NT	LC
	Bagridae	*Mystus vittatus*	Striped dwarf catfish	S50	146	2.85	LC	LC
	Bagridae	*Rita rita*	Rita	S54	19	0.37	EN	LC
	Bagridae	*Sperata aor*	Long-whiskered catfish	S53	19	0.37	VU	LC
Beloniformes	Belonidae	*Xenentodon cancila*	Freshwater garfish	S7	49	0.96	LC	LC

Table 1: Continued.

Order	Family	Scientific name	English name	Code	Total	% contribution	IUCN status Bangladesh	IUCN status Global
Synbranchiformes	Synbranchidae	*Monopterus cuchia*	Cuchia	S66	12	0.23	VU	LC
	Mastacembelidae	*Macrognathus aculeatus*	Lesser spiny eel	S65	19	0.37	NT	LC
	Mastacembelidae	*Macrognathus aral*	One-stripe spiny eel	S64	76	1.48	DD	LC
	Mastacembelidae	*Mastacembelus armatus*	Zig-zag eel	S63	33	0.64	EN	LC
Perciformes	Ambassidae	*Chanda nama*	Elongate glass perchlet	S47	89	1.74	LC	LC
	Ambassidae	*Parambassis ranga*	Indian glassy fish	S49	30	0.59	LC	LC
	Ambassidae	*Pseudambassis lala*	Highfin glassy perchlet	S48	55	1.07	LC	NT
	Latidae	*Lates calcarifer*	Barramundi	S8	50	0.98	LC	LC
	Sciaenidae	*Otolithoides pama*	Pama croaker	S38	147	2.87	LC	DD
	Nandidae	*Nandus nandus*	Gangetic leaf fish	S5	51	1.00	NT	LC
	Eleotridae	*Eleotris fusca*	Dusky sleeper	S39	14	0.27	LC	LC
	Gobiidae	*Apocryptes bato*	Goby	S41	139	2.72	LC	LC
	Gobiidae	*Glossogobius giuris*	Tank goby	S42	60	1.17	LC	LC
	Gobiidae	*Odontamblyopus rubicundus*	Rubicundus eelgoby	S40	170	3.32	LC	LC
	Gobiidae	*Pseudapocryptes elongatus*	Lanceolate goby	S43	125	2.44	LC	LC
	Gobiidae	*Taenioides cirratus*	Bearded worm goby	S44	234	4.57	LC	DD
	Anabantidae	*Anabas testudineus*	Climbing perch	S1	44	0.86	LC	LC
	Osphronemidae	*Trichogaster fasciata*	Banded gourami	S6	82	1.60	LC	LC
	Channidae	*Channa orientalis*	Walking snakehead	S4	24	0.47	LC	VU
	Channidae	*Channa punctata*	Spotted snakehead	S2	38	0.74	LC	LC
	Channidae	*Channa striata*	Striped snakehead	S3	35	0.68	LC	LC
Tetraodontiformes	Tetraodontidae	*Leiodon cutcutia*	Ocellated pufferfish	S67	43	0.84	LC	LC

Note: EN: endangered; VU: vulnerable; NT: near threatened; LC: least concern; DD: data deficient; NE: not evaluated.

2.5. Climatological Data. The data on air temperature (°C), humidity (%), rainfall (mm), and photoperiod (h/day) were collected from the Bangladesh Meteorological Department.

2.6. Statistical Analysis. The diversity of fish indices was measured in the initial data-processing stage, followed by statistical comparison. The study was carried out utilizing MS Excel (Microsoft 365) and Paleontological Statistics (PAST), a software program for the examination of paleontological data, version 4.03. PAST has developed into a complete statistical tool utilized not just by paleontologists but also by many other disciplines in the life and earth sciences, engineering, and even economics. Analysis of Variance (ANOVA) was conducted using R Programming version 4.2.1 to ascertain the regional variance of average species richness. To identify which of the five stations stands out from the others, Tukey's multiple comparison test is also applied at a 0.05 level of probability. For the purpose of examining correlations across months and stations, a dendrogram was generated using the hierarchical-clustering method [32].

3. Results

3.1. Species Abundance and Distribution. A sum of 5118 individuals, including 67 species categorized into 8 orders, 24 families, and 54 genera of fish, was recorded in this study (Table 1 and Table S1). *Corica soborna* had the highest number of individuals (322) which represents 6.29% of the total population while *Labeo gonius* and *Labeo calbasu* had the lowest number (4 each), which represents 0.08% of the total population. During the research period, station 1 had the highest population count of 1115 individuals, while station 5 had the lowest population count of 951. In all sample regions, the variation in monthly abundance was significant ($P < 0.05$). The highest number of individuals was recorded in June. Cypriniformes was the most prevalent order (32.84%), trailed by Perciformes (25.37%), Siluriformes (19.40%), Clupeiformes (10.45%), Synbranchiformes (5.97%), Osteoglossiformes (2.99%), Beloniformes (1.49%), and Tetra odontiformes (1.49%) (Figure 2).

3.2. Fish Diversity Status. In order to depict the diversity of a sample or community, a biodiversity index uses a single number. For the time of the sampling period, the research regions' fish diversity status and species richness were assessed using the Shannon-Wiener index (H), Simpson's dominance index (D), Simpson's diversity index ($1 - D$), Margalef's richness index (d), and Buzas and Gibson's evenness index (E) equations (Table 2 and Figure 3). The Shannon-Wiener diversity index ranged from 3.685 to 3.866. Station 2 had the maximum Shannon-Wiener diversity index (3.866), whereas station 1 had the minimum (3.727). In July, Shannon diversity index values were greater

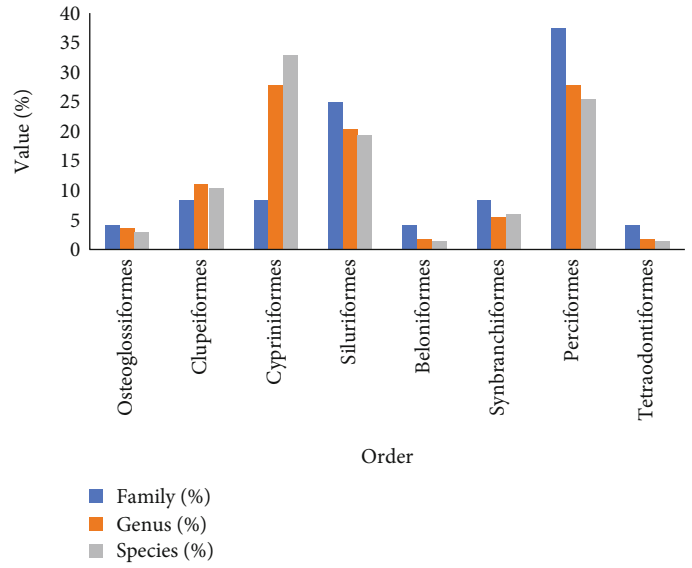

Figure 2: Graphical representation of species composition under different orders in the Sandha river of Bangladesh.

Table 2: The species status of the Sandha river of Bangladesh using different diversity indexes.

	No. of species	Shannon	Dominance	Simpson	Margalef	Evenness
Stations						
Station 1	62	3.727	0.031	0.969	8.694	0.670
Station 2	67	3.866	0.026	0.974	9.608	0.712
Station 3	66	3.845	0.027	0.973	9.375	0.709
Station 4	66	3.817	0.027	0.973	9.326	0.689
Station 5	65	3.756	0.031	0.969	9.333	0.658
Months						
July	66	3.859	0.027	0.973	10.450	0.719
August	64	3.776	0.028	0.972	10.250	0.682
September	62	3.763	0.031	0.969	9.989	0.695
October	57	3.722	0.029	0.971	9.257	0.726
November	58	3.748	0.028	0.972	9.467	0.731
December	54	3.685	0.031	0.969	9.026	0.738
January	60	3.803	0.027	0.973	9.955	0.747
February	59	3.728	0.030	0.970	9.693	0.705
March	54	3.770	0.027	0.973	8.895	0.803
April	58	3.716	0.031	0.969	9.452	0.709
May	57	3.690	0.032	0.968	9.301	0.703
June	64	3.770	0.031	0.969	10.070	0.678

Note: Shannon: Shannon-Wiener diversity index; Dominance: Simpson's dominance index; Simpson: Simpson's diversity index; Margalef: Margalef's richness index; Evenness: Buzas and Gibson's evenness index.

(3.859), but in December, they were lower (3.685). Simpson's dominance index (D) results were in the range of 0.026 to 0.032, which shows that there is less variety in the areas and months under study. After combining all of the samples from each sampling station, station 1 and station 5 had the greatest dominance index values (0.031), while station 2 had the least value (0.026). In the case of the month, May had the maximum monthly dominance diversity index value (0.032), while January, March, and July had the minimum value (0.027). Simpson's index of diversity ($1 - D$) scores can range from 0 to 1, station 2 having the greatest value (0.974) and stations 1 and 5 having the lowest values (0.969). In terms of months, January, March, and July had the greatest values (0.973), while May had the lowest values (0.968). The Margalef richness index (d) value was the highest at station 2 (9.608) and the lowest at station 1 (8.694). A greater Margalef richness value of 10.450 was reported in July, whereas a lower value of 8.895 was noted in March in

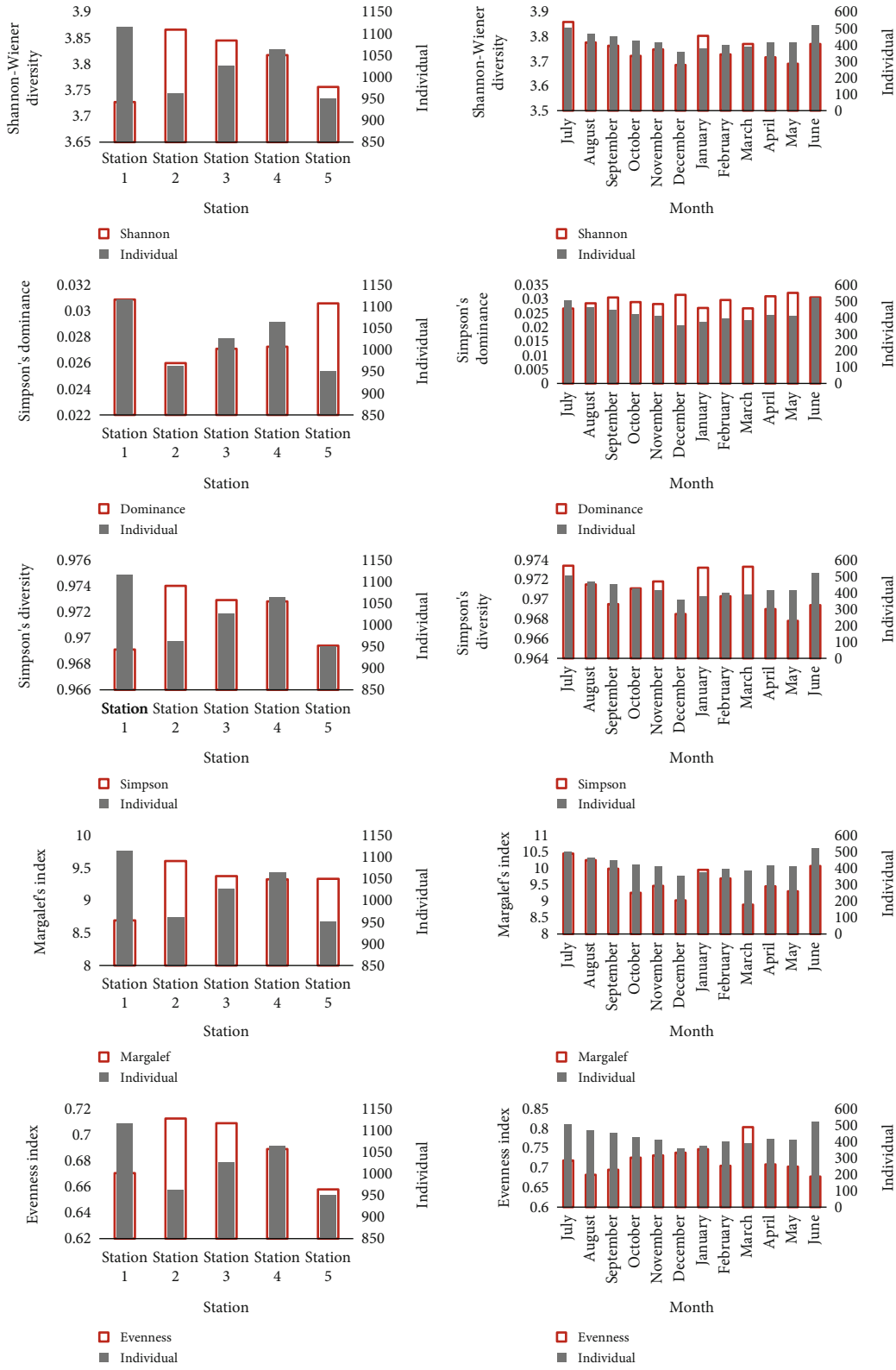

Figure 3: Different attributes of fish community during different sampling stations and months of the Sandha river of Bangladesh.

terms of the month. Buzas and Gibson's evenness (E) values can differ from 0 to 1, where the maximum Buzas and Gibson's evenness value is computed in station 2 (0.712), and the minimum value is calculated in station 5 (0.658). The uppermost Buzas and Gibson's evenness value was found in March (0.803) and the lowermost was found in June (0.678) in the case of months. There was no significant difference ($P > 0.05$) in the Shannon-Wiener diversity index

Table 3: Conservation category of fish species recorded from the Sandha river of Bangladesh.

Conservation categories	IUCN Bangladesh		IUCN global	
	Individual	Percentage	Individual	Percentage
Endangered	6	8.96	—	—
Vulnerable	7	10.45	4	5.97
Near threatened	9	13.43	5	7.46
Least concern	43	64.18	54	80.60
Data deficient	1	1.49	3	4.48
Not evaluated	1	1.49	1	1.49

(H), Simpson's dominance index (D), Simpson's index of diversity ($1 - D$), Margalef richness index (d), and Buzas and Gibson's evenness index (E).

3.3. Conservation Status. Among 67 species of fish recorded in the investigated region, 6 species are endangered (8.96%), 7 species are vulnerable (10.45%), 9 species are nearly threatened (13.43%), 43 species are of least concern (64.18%), 1 species is data deficient (1.49%), and 1 species is not evaluated (1.49%) (IUCN [24]) (Tables 1 and 3). According to the IUCN global status, 4 species are vulnerable (5.97%), 5 species are nearly threatened (7.46%), 54 species are of least concern (80.60%), 3 species are data deficient (4.48%), and 1 species is not evaluated (1.49%).

3.4. Diversity and Its Correlation with Climatological Parameters. Pearson correlation analysis indicated the meteorological parameters affecting the diversity of fish species in the Sandha river (Figure 4). Significant positive correlations between the Shannon-Wiener diversity index and rainfall ($r^2 = 0.599$, $P < 0.05$) were determined. Simpson's dominance index and Simpson's diversity index have no significant correlation with meteorological parameters. A strong positive correlation was found between Margalef's richness index and humidity ($r^2 = 0.602$, $P < 0.05$) and rainfall ($r^2 = 0.789$, $P < 0.01$). Significant negative associations with Buzas and Gibson's evenness index were found with the humidity ($r^2 = -0.610$, $P < 0.05$) and rainfall ($r^2 = -0.583$, $P < 0.05$). The number of species has a highly significant positive correlation with humidity ($r^2 = 0.718$, $P < 0.01$) and rainfall ($r^2 = 0.879$, $P < 0.001$). A strong positive correlation was found between the number of individuals and temperature ($r^2 = 0.722$, $P < 0.01$), humidity ($r^2 = 0.864$, $P < 0.001$), and rainfall ($r^2 = 0.934$, $P < 0.001$).

3.5. Cluster Analysis. A clear structural change in the fish communities between the five locations and the twelve months was discovered using cluster analysis. Two significant clusters were seen in the case of stations with a similarity level of 79% separation. The first cluster consists of station 1 and station 5, while the second cluster includes station 2, station 3, and station 4 (Figure 5(a)). But when it came to months, two significant clusters were seen at a similarity level of 75.5% separation. The first cluster consists of April, May, June, July, August, September, and October, and the second cluster includes November, December, January, February, and March (Figure 5(b)). Additionally, a cluster analysis utilizing the Bray-Curtis similarity matrix was used to assess the degree of similarity across fish species (Figure 6). Through the use of the Bray-Curtis similarity matrix, three main groups were discovered, the first of which contains 5 different fish species, the second contains 34 different fish species, and the third has 28 different fish species.

4. Discussion

Fish biodiversity research often reveals the variability of species of fish present in a given location. Documenting the current fish population, together with its ecosystem and biodiversity state, is crucial for adjusting to the world's changing conditions. Our study offers details on the species composition, geographical distribution, and temporal variation of species of fish in the Sandha river of Bangladesh. Generally, the susceptibility of different fish species varied with anthropogenic interference, natural disasters, and environmental deterioration [16, 33, 34].

In the current research, 67 species of fish were recorded, which were grouped into 8 orders, 24 families, and 54 genera. Hanif et al. [17] identified a total of 26 endangered species from the Sandha river. Ruma et al. [11] performed a bimonthly 1 year research on the fishery resources of the Sandha river and reported 55 species of fish, these results indicating an increase in diversity in the coastal water over the past several years. Actually, as a result of certain recent incentive-based management approaches, the quantity of fish species has grown significantly, and fishermen are capturing many fish [35, 36]. The current study exposed a large number of fish species compared to Hossain et al. [37], who observed 53 species of fish in the Meghna River estuary; Galib et al. [38], who identified 63 species of fish in the Choto Jamuna River; Islam et al. [39], who listed 52 species in the Payra river; Rahman et al. [40], who reported 47 species of fish from the Agunmukha river; and Tikadar et al. [41], who recorded 62 species of fish from the Gorai river of Bangladesh. Furthermore, there were many instances of fewer fish species documented than in previous studies conducted in Bangladesh. As an illustration, Shafi and Quddus [42] reported 139 fish species in Bangladesh's marine and brackish waters, Hossain et al. [43] documented around 161 species of fish from the Naaf river estuary, Hanif et al. [44] documented 98 fish species from four coastal district rivers of Bangladesh, and Roy et al. [45] recorded 81 species from the Andharmanik river. Fish biodiversity loss is seen as

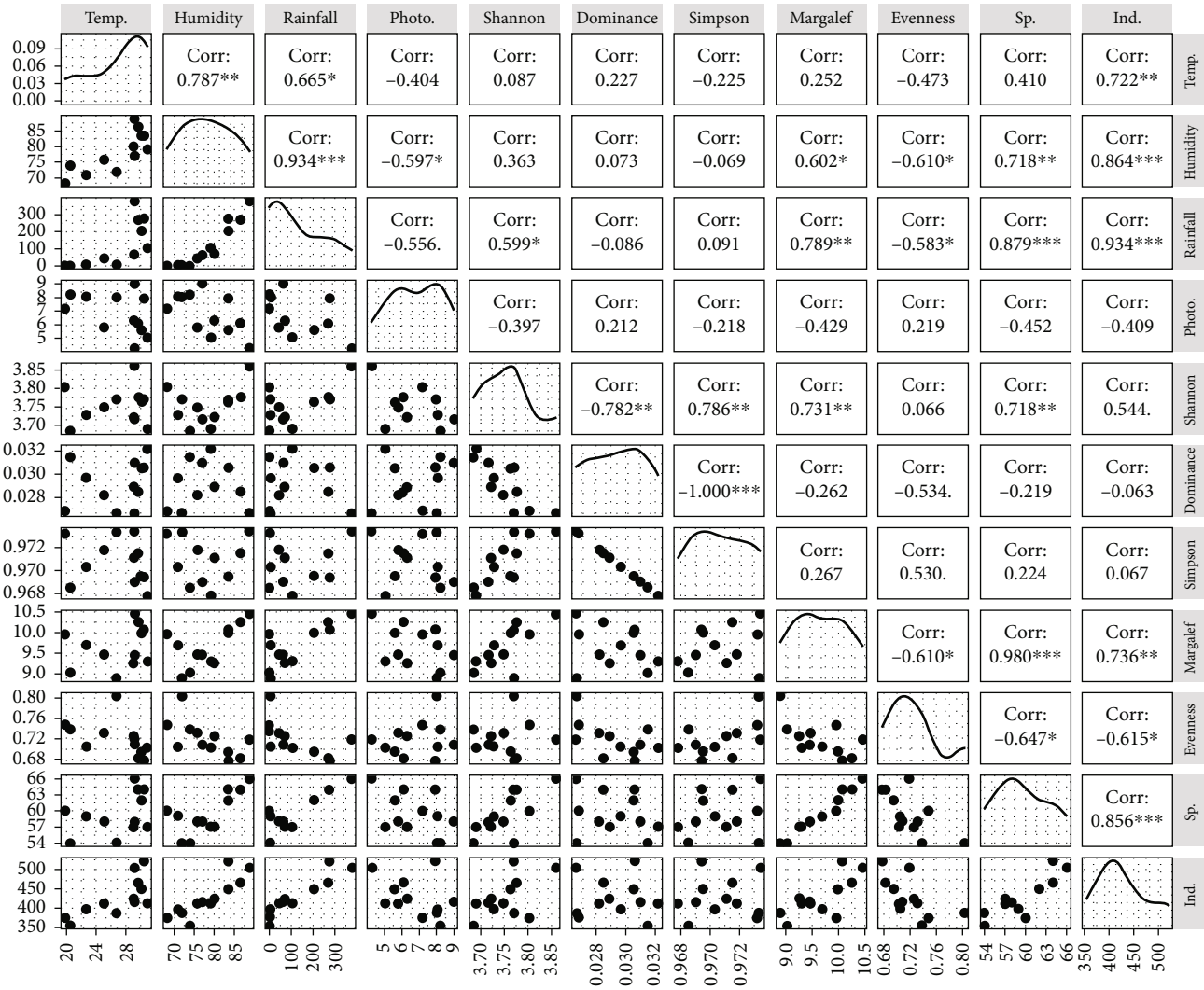

Figure 4: The correlation between species diversity and meteorological parameters in the Sandha river of Bangladesh. Note: Temp.: temperature; Photo.: photoperiod; Shannon: Shannon-Wiener diversity index; Dominance: Simpson's dominance index; Simpson: Simpson's diversity index; Margalef: Margalef's richness index; Evenness: Buzas and Gibson's evenness index; Sp.: number of species; Ind.: number of individual. Regression coefficient (r^2) values are coded as the number for each relationship, a single asterisk indicates a statistically significant difference of means with $P < 0.05$, double asterisks indicate statistically significant differences of means with $P < 0.01$, and triple asterisks indicate statistically significant differences of means with $P < 0.001$.

a worrying dilemma, and its protection is the only way to address this problem [46].

Across the period of study, station 1 had the maximum number of individuals counted (1115), whereas station 5 had the lowest number (951), which may have been caused by variations in the station's various parameters, including water temperature, depth, water current, and the dearth of nutrients [47]. Furthermore, a contributing element to the loss of fishery diversity is an increase in fishing pressure. The greatest number of individuals was spotted at station 1, whereas the smallest number of individuals was recorded at station 5. This could be because there was little to no human involvement at station 1 and a significant amount of human involvement at station 5. Our study included a large number of species of fish, the majority of which belonged to the orders Cypriniformes (32.84%) and Perciformes (25.37%). According to Hanif et al. [44] and Sultana et al. [48], the Cypriniformes are the most prevalent order. Many other rivers in Bangladesh have also experienced similar occurrences of the Cypriniformes group. Because of the perfect climatic characteristics and river bottom which this order favors, the order Cypriniformes had the highest number of individuals in this research region compared with the other orders [44]. The species that contributed the most to the composition were *Corica soborna* (6.29%), *Puntius sophore* (5.51%), *Taenioides cirratus* (4.57%), *Tenualosa ilisha* (3.56%), *Odontamblyopus rubicundus* (3.32%), and *Lepidocephalichthys guntea* (3.15%). These fish species were categorized as species of least concern because they have numerous populations throughout their natural distribution, and no significant threats are known to them (IUCN [24]).

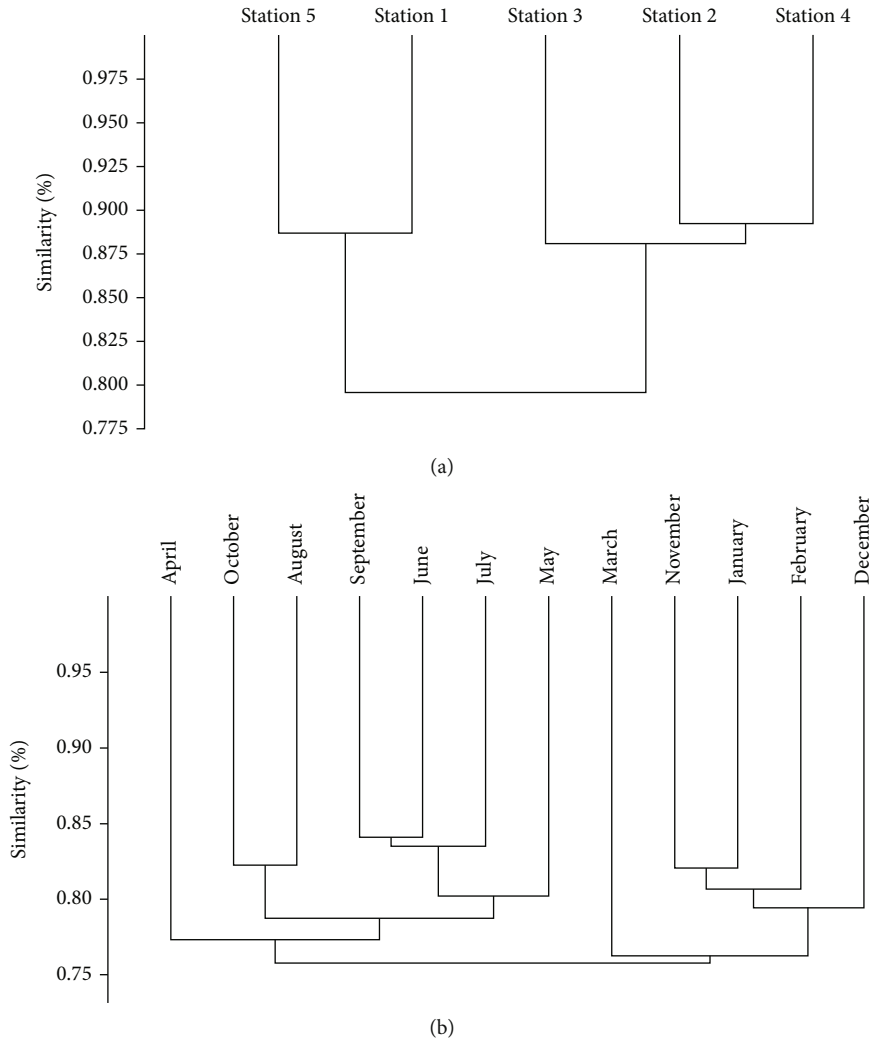

Figure 5: Dendrogram of clusters based on Bray-Curtis similarity matrix of different stations (a) and months (b) showing structural variability of the fish communities.

The goal of biodiversity indices is to sum up the diversity of a sample or group as a specific number [37]. Two factors make up the idea of "species diversity": the quantity of species or richness and the allocation of populations across organisms. The idea and its measurement are, nevertheless, treated formally in a complicated manner [49]. According to fish diversity indices, the variety of the fish fauna at various sample sites and throughout various months was substantially the same (Figure 3).

A river's Shannon-Wiener diversity index (H) contemplates both the variety of species and the distribution of individuals within those species [41]. The maximum Shannon-Wiener diversity index value always involves a large number of individuals, whereas the lowest biodiversity always involves a small group of individuals. During the research period, station 2 had the greatest Shannon-Wiener diversity index (3.866), whereas station 1 had the lowest (3.727). In July, Shannon diversity index values were higher (3.859), but in December, they were lower (3.685). Ruma et al. [11] reported that diversity indices (H) fluctuated from 3.011 to 3.575 on Bangladesh's Sandha river, Jewel et al. [50] reported that overall values of the diversity index (H) was 3.12 in Bangladesh's Atrai river, Tikadar et al. [41] recorded that the average value of the diversity index (H) was 1.478 in Bangladesh's Gorai river, and Roy et al. [45] reported that diversity indices (H) extended from 3.23 to 3.44 on the Andharmanik river of Bangladesh. Because there are many species and very minimal contamination of coastal water, the computed value of the Shannon-Wiener diversity index in the current investigation among different sampling sites and months was much greater. Additionally, Biligrami [51] advised better water body conditions for fish diversity when the Shannon-Wiener diversity index was between 3.0 and 4.5. This suggestion states that the Sandha river is a better body of water for fish species. Additionally, there are a number of factors that might affect the diversity index, including geographical area, survey duration, wind patterns, periodical fish movements for spawning and reproduction, fishing technique, seasonal nutrition variations, and choice of fishing gear.

Generally, Simpson's dominance index (D) value varies from 0 to 1, with greater values indicating lower biodiversity.

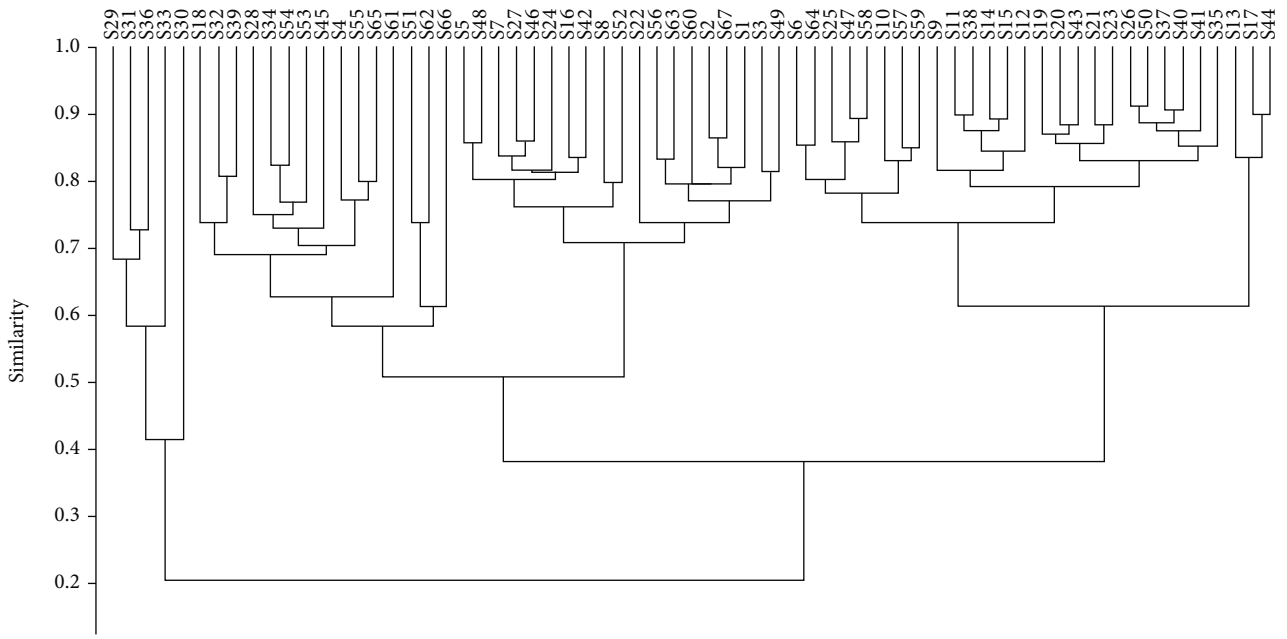

Figure 6: Spatial and temporal cluster of fish assemblage based on Bray–Curtis similarity matrix.

Simpson's dominance diversity index value for a specific month ranged from 0.027 in January, March, and July to 0.032 in May. The most diversity of species is thought to occur in the months of January, March, and July, while the lowest diversity is thought to occur in the month of May, according to Simpson's dominance index value. Simpson's dominance index value varies from 0.042 to 0.048 according to Rahman et al. [52] and from 0.055 to 0.06 according to Roy et al. [45]. Simpson's diversity index ($1 - D$) value similarly varies from 0 to 1, and the greater the number, the more diverse the species are. The months with the greatest Simpson's index of variety values were January, March, and July (0.973), while May had the lowest score (0.968). The most species diversity is thought to be occurring in the months of January, March, and July, while the least diversity is regarded as occurring in the month of May, according to Simpson's index of diversity value.

The simplest way to assess biodiversity is Margalef's richness, which is just a count of the variety of species present in a particular region. The effort and sampling size have a significant impact on this measurement [53]. When used to measure pollution levels across sample sites, the Margalef index indicates inconsistencies due to the number of species involved [54]. In this investigation, the month of July had the greatest Margalef index value (10.450), indicating a significantly larger number of species or individuals, while the month of March had the lowest Margalef index value (8.895), indicating a significantly lower number of individuals than other months. According to Jewel et al. [50], the Atrai river's total Margalef index value was 5.87. In Bangladesh's Gorai river, Tikadar et al. [41] computed the Margalef index value and observed values ranging from 7.033 to 19.716. According to Roy et al. [45], the Margalef index values in the Andharmanik river varied from 6.48 to 8.18. Margalef's index may differ somewhat from the true diversity value since it improperly combines the evenness and species richness values and depends on sampling size [37]. This may have happened because there was not much precipitation, which made it difficult for fisherman to use their fishing equipment successfully [3]. Additionally, ecological factors have had an impact on the dispersal of the various species of fish [53]. The primary causes of ecological damage are the building of numerous bridges over the river, extensive erosion of the river during the monsoon, and building of a rambunctious earthen dam during a time when fishing is scarce. The evenness value runs from 1 to 0, and the lowest evenness value suggests the largest diversity of species. Maximum evenness was recorded in March (0.803), and June had the lowest value (0.678). June was regarded as the month with the most abundant diversity while taking into account the evenness value. The species evenness index between the sample region and the different months shows that the Sandha river's fish population is dispersed quite evenly. The results are also in line with those of Jewel et al. [50], who calculated an overall evenness index for the Atrai river of 0.66. Roy et al. [45] studied the Andharmanik river and found that the evenness index ranged from 0.67 to 0.73. The Shannon-Wiener diversity index (H), Simpson's dominance index (D), Simpson's diversity index ($1 - D$), Margalef richness index (d), and Buzas and Gibson's evenness index (E) did not significantly differ from one another. Because of this, it is reasonable to draw the conclusion that seasonal variations in the diversity of species are common in the studied region.

According to the findings, a significant number of the least-concerning species and a fraction of Bangladesh's endangered, vulnerable, and near-threatened species were found in the Sandha river. Six endangered species, seven vulnerable species, nine near-threatened species, and forty-three least-concerning species were discovered in the current

study. In a community of 48 species, 3 fish species were listed as endangered, 3 as critically endangered, and 8 as vulnerable by Rahman et al. [52]. In a community of 81 species, Roy et al. [45] discovered 1 critically endangered species, 3 near-threatened species, 8 endangered species, and 8 vulnerable species. Natural and anthropogenic dangers are getting worse every day, which is affecting the distribution of fish species nationwide [55]. The Sandha river serves as a significant nursery, feeding ground, and breeding habitat for many indigenous fish species as well as several anadromous fish species [11]. But in recent times, Bangladesh's riverine environment has undergone significant change as a result of pollution, human meddling, and climate change, all of which have ruined the riverine environment [35, 36, 56]. In Bangladesh, the number of fish species is dropping due to a number of issues, including habitat damage, water flow, unselective fishing of fingerlings, and fry harvesting [18, 57, 58]. The present focus of fish diversity conservation is mostly on species of fish that are commercially significant and in danger of extinction. It has taken a variety of actions to protect fish species in Bangladesh and throughout the globe, but we found that these efforts fell short in coastal regions. The research made use of the IUCN regulatory framework for evaluating the fish conservation status. In order to maintain nutritional, economical, and environmental balance, fish biodiversity must be protected [59].

The presence, distribution, richness, and variety of estuarine fish species are influenced by a variety of environmental conditions [37]. With the exception of temperature and photoperiod content, Pearson correlations showed that fish diversity indicators were substantially correlated with humidity, rainfall, and the number of individuals. Because the value of this parameter remained more or less consistent over all the stations during the research time, the fluctuation in water temperature had less of an influence on the distribution of species. Although there are differences in the temperature of water throughout the year, they depend on seasonal fluctuations in the sunshine as well as the influence of wind and wave action. Within estuaries, temperature has a significant impact on fish populations [60]. Fish death might result from an abrupt change in water temperature [61]. The key elements that cause species diversity and dispersion include rainfall. According to this study, there is an extreme correlation between the Sandha river's rainfall and its community's biodiversity of fish species. Additionally, rainfall affects the distribution of salinity [37]. According to this study, there is a strong relationship between the Sandha river's humidity and the variety of fish species in the local population. Hence, photoperiod has less of an effect on species biodiversity.

The degree of similarity among or between the stations, months, and species is mostly used to determine how similar one element is to another. Cluster analysis procedures are frequently used to explore community relationships based on distributional co-occurrence for similarity tests [47]. A clear distinction in the twelve month and species data between the five sample locations was found by the cluster analysis. Two significant clusters were seen in the case of stations at a similarity level of 79% separation which may be due to the water quality of the stations as stations 1 and 5 are situated closer to the coast, and two big clusters were seen in the case of months at a similarity level of 75.5% separation which may be due to seasonality. But when it came to fish species, three large clusters were discovered at a similarity level of 20% separation. The first cluster has 5 fish species, the second has 34 fish species, and the third has 28 fish species which may be due to hydrological and climatic factors as they affect the fish composition. Hossain et al. [37] discovered two distinct clusters of fish species in the Bangladeshi Meghna river with a similarity of 32%, Nasren et al. [62] discovered two cluster groups in the Ratargul swamp forest with a similarity of 72.9%, and Tikadar et al. [41] discovered two clusters with a similarity of 58.7%. Seasonality, which causes fluctuations in hydrological and climatic factors and therefore affects the fish composition in estuaries, is the main factor impacting this similarity and dissimilarity [63]. Fish-spawning activity is influenced by the season, which has an impact on capture content [64].

5. Conclusions

Freshwater fish conservation efforts should be focused on an inclusive knowledge of regional patterns of species richness. The techniques utilized in our study serve as a foundation for evaluating the present state of freshwater fish biodiversity in Bangladesh's Sandha river. This status data is crucial for choosing the best conservation and management tactics, as well as for bridging knowledge gaps in significant but significantly changed rivers like the Sandha river. The findings of this study revealed trends of the spatial and temporal diversity of the fish and community structure, as well as the contributions of various species to these trends. The recent study makes it clear that the Sandha river's fish fauna variety is in stable condition. Since the Sandha river has a biodiversity that is comparable to or higher compared to many other rivers in Bangladesh, it might be regarded as an ecological hotspot when considering the abundance of species. The fundamental elements needed to preserve the fish population in this river system are sustainable management techniques. To ensure sustainable fishing practices and improve habitat in the Sandha river to conserve fish species, quick action is required.

Data Availability

Data will be made available on request.

Conflicts of 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.

Supplementary Materials

Table S1: temporal and spatial abundance and distribution of fish species in the Sandha river of Bangladesh. *(Supplementary Materials)*

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