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Fish Species Composition, Distribution, and Community Structure of a Himalayan Biodiversity Hotspot River Diyung, North East India

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Authors' Contribution
The study was conceived and designed by AMA and RD. All the data were collected by AMA, DN and LPM. AMA prepared the first draft of the manuscript with the assistance of IM. AMA, HP, RS conducted the data analysis and preparation of figures. AMA and SKB read and revised the manuscript. RD oversaw and acquired the funding for the entire research work.

Key words
Conservation, Dima Hasao, Diyung River, Environmental parameter, Fish diversity

ABSTRACT

The study provides information on the diversity, assemblage structure, distribution pattern, and composition of fish at several sampling locations along the river Diyung. In this study, fish fauna was collected from 8 selected stations of the river from January 2019 to December 2020. A total of 81 different fish species were identified, divided into 10 orders, 24 families, and 52 genera. The orders Cypriniformes, Siluriformes, Anabantiformes, and Synbranchiformes accounted for 88.88% of the total fish population and the remaining 12.12% is being contributed by other orders. The family Cyprinidae was found to be the most prevalent (40.74%). Minnows and barbs contributed the most (30.49%) among the 11 common groups of fishes identified. According to the IUCN status, 11.11% were near threatened (NT), 2.44% each of vulnerable and data deficient, 1.23% were endangered (EN), 6.17% were not evaluated (NE), and 76.54% were least concerned (LC). The Margalef species richness, Shannon-Weiner diversity indices showed higher diversity in the middle and lower stretches of the river. Subsequently, cluster analysis divided the samples into two different groups by sample sites. Group 1 comprised sites S6, S7, and S8 representing the lower stretches of the river and Group 2 comprised stations S1, S2, S3, S4 and S5, all of which were located in the middle and upper stream. The Canonical Corresponding Analysis revealed that environmental parameters have varied connotations with the fish occurrence, indicating species-specific adaptive potential. The parameters like temperature, turbidity, Dissolved Oxygen (DO) and velocity exhibited a positive correlation with fish abundance. Longest K-dominance curve formed at the station S-4 indicating the highest fish abundance. The findings will aid in the development of a reasonable exploitation and protection strategy for freshwater fish in the Diyung river.

INTRODUCTION

The freshwater ecosystem is home to a diverse, delicate, and endemic biota, representing roughly 6% of all species. India is a hotspot of freshwater fish diversity and contributes a large number of endemic biological resources to the world. In addition, Indian waterways are home to 11.7% of the world's fish species, with 295 endemic fish species found only in India recognized by the IUCN. North East India is one of the world's 36 biodiversity hotspots region for freshwater fish diversity (Kottelet and Whitten, 1996). The Himalayan biodiversity hotspot region stretches over 3000 km in Pakistan, Nepal, Bhutan, Northwestern, and Northeast India and includes the world's highest mountains and deepest gorges. Hill district of Assam forms part of the eastern Himalayas while Kumaon Garhwal hills, Northwest Kashmir form the western Himalayas (IUCN, 2021). The Eastern Himalayas Northeast region gives rise to numerous distinct habitats and ecosystems *viz.* rivers, streams, wetlands, canals and rivulets. Among many rivers, the mighty Brahmaputra flows through the States of Arunachal Pradesh and Assam, covering 900 km in length and having 42 tributaries. These rivers, in mountainous course pass through the gorge, carved out by erosional activities forming V-shaped valleys. Upon reaching the plains they form flat valleys, oxbow lakes floodplain

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wetlands. In the mountainous course, the water is rough and turbulent but on plains, they exhibit a contrasting phenomenon as marked by forming menders and regular changes in directions.

Freshwater fishes are deemed threatened for being sensitive to any quantitative and qualitative changes in their habitat (Duncan and Lockwood, 2001). The fish richness and abundance in any water body are the functions of geomorphic, biotic, and abiotic factors (Brown *et al.*, 2011). The geomorphic factors include connectivity, habitat form and the biotic factor includes migration, foraging, interaction in the food chain and dissolved oxygen, temperature, nutrients and salinity are the important abiotic factors (Menegotto *et al.*, 2019; Rau *et al.*, 2019). These physico-chemical parameters singly or synergistically change the water chemistry and flow regime nutrient dynamics and thus regulate the ecological process.

For the present study, a rain-fed river named Diyung, reported to be the largest river of the Dima Hasao district of Assam was selected that originated near the Hempeo Peak (Barail Ranges) at about 1700 m MSL, in the south-western part of the district (Ahmed *et al.*, 2021). The river transverses for about 240 km through dense tropical deciduous forests and is joined by several streams and rivulets *viz*. Brashang, Didaola, Kholong, Rubi, Abhung, and Dilaima, finally emptying into the river Kopili (a major southern tributary of the mighty river the Brahmaputra) at Diyungmukh. The river is characterized by riffles and deep pools with high water velocity, dissolved oxygen, and transparency.

Although considerable studies relevant to fish taxonomy, fish biology, ecology and conservation have been carried out so far in NE regions, such reports are not available from River Diyung. Furthermore, it is said that many species that were plentiful in earlier decades have become scarce in recent years. As a result, this research was carried out to create a checklist of fish species found in the Diyung River, as well as to determine their vulnerability status and suggest management options for their conservation.

MATERIALS AND METHODS

A total of 8 sampling sites were selected along the entire length of the river based on the likeness of geography, habitat forms, accessibility, and secondary information from local people. The selected sites were divided into upper, middle, and lower streams based on altitudinal variations and geographic variations (Table I and Fig. 1).

Sample collection

Fish specimens were collected at monthly intervals from January 2019 to December 2020. Experimental fishing was done using cast net (mesh size 4-10), gill net (15–20 mm) and some indigenous traps with the help of skilled local fishermen. Onsite identifications of some of the specimens were done and the rest were brought to the laboratory. During the collection of the specimen guidelines of the National Biodiversity Authority, Govt. of India was followed. Identification up to species level was done following the literature of Talwar and Jhingran (1991), Jayaram (1999) and Viswanath *et al*. (2007, 2011). Valid scientific names were taken from Eschmeyer's Catalog of Fishes and FishBase (Froese and Pauly, 2019). The fishes were photographed with a digital camera prior to preservation. The specimens were preserved in 6% aqueous formaldehyde solution. The current conservation status was evaluated by the International Union for Conservation of Nature (IUCN, 2021).

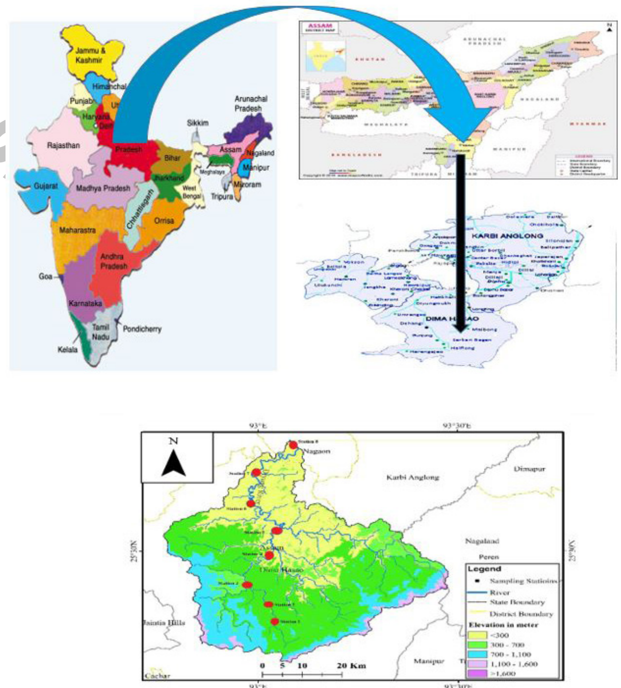

Fig. 1. Map of the study area.

Data on local ecological factors characterizing stream properties and its surrounding were collected and analyzed. This includes water quality parameters and stream characteristics. The pH, total dissolved solids (mg/l), electrical conductivity (µS/cm) and dissolved oxygen (mg/l) were estimated by a digital water testing kit (Systronics 371) and surface water velocity using a floating cork. Stream depth and width using measurement taps.

Table I. Characterization of each sampling site of Diyung river.

Stations	Site/ Code	Latitude and longitude	Elevation (m MSL)	Channel width (m)	Depth range (m)	Average flow (m/s)
Station1	Syamagram (SR)	25°08'12″N 93°01'42″E	388	8-10	0.20-0.60	1.05
Station 2	Lower Halflong Bridge (LHB)	25°11'58″N 93°01'21″E	340	20-30	0.25-1.50	0.97
Station 3	Samparidisha Village (SV)	25°14′12″N 93°00′35″E	298	30-35	0.50-2.70	0.96
Station 4	Dihingi Bazar Point(DBP)	25°25′24″N 92°59′34″E	148	50-75	0.30-4.20	1.03
Station 5	Thaijuwari Village (TJV)	25°32′21″N 92°59′06″E	126	35-40	0.20-4.60	0.95
Station 6	Purana Kungkruwari Village (PKV)	25°34′58″N 92°56′38″E	117	30-45	0.80-5.30	0.91
Station 7	Digandu PT-II (DP)	25°34′34″N 92°57′44″E	80	50-75	0.30-5.60	0.87
Station 8	Diyungmukh (DM)	25°48'27″N92°55'44″E	70	60-90	0.20-6.30	0.84

All the above-mentioned parameters were estimated in the field itself and turbidity (NTU) by the Nephlo-turbidity meter in the laboratory.

Statistical analysis

Species diversity can be defined as the number of species found in a given area within a certain time period. The Margalef's richness index (D), Shannon-Weiner diversity index (H), and Pielou's evenness index (J) were employed to measure the spatial-temporal variation of fish species diversity in this study. The K-Dominance plot was constructed by ranking the species in decreasing order of abundance to relate species richness and abundance (Hammer *et al*., 2001). Canonical correspondence analysis (CCA) was utilized to determine the link between fish diversity and ecological parameters using PAST software version 4.03 (Abell *et al*., 2008).

RESULTS

Fish species diversity

During the study, a total of 81 fish species belonging to 52 genera, 24 families, and 10 orders were recorded from different stretches of River Diyung (Table II). The order Cypriniformes formed the largest group with a contribution of 5 (20.85%) families and 42 (51.85%) species followed by Siluriformes with 7 (29.16%) families and 17 (20.98%) species, Anabantiformes with 9 (11.11%) species, Synbranchiformes with 4 (4.93%) species, Osteoglossiformes with 2 (2.64%) species, Perciformes with 2 (2.46%) species, Beloniformes with 2 (2.46%) species (Fig. 2A). Among the families, Cyprinidae represented 33 (40.74%) species, Bagridae 6 (7.4%) species, Channidae 4 (4.93%) species. Mastacembelidae, Sissoridae and Nemacheilidae and Psilorhynchidae 3 (3.70%) species and Botiidae, Notopteridae, Badidae, Belonidae, Schilbeidae, Ailiidae, Siluridae, and Ambassidae with 2 (2.47%) species and remaining families with 1 (1.23%) species each in the total fish population (Fig. 2B). The results of the current study would be valuable as baseline data for any forthcoming assessment of fish diversity. No exotic fish species were recorded from the entire stretches of the rivers during the study periods which indicates that the river is in good condition. The most dominant species and their relative abundance were *Opsarius bendelisis, Pethia ticto*, *P. conchonius*, *Psilorhynchus balitora*, *Devario aequipinnatus*, *Barilius barila*, *Salmostoma Bacaila*, *Puntius sophore*, *Paracanthocobitis botia, G. lissorhynchus*, *Garra nasuta*, *G. annadalei*, *Mastacembelus armatus*, *Tariqilabeo latius*, *Danio dangila*, *Chagunius chagunio*, *Glossogobius giuris*, *Channa gachua*, *Channa punctata*, *Psilorhynchus homaloptera*, *Badis assamensis*, *Schistura fasciata*, *Cirrhinus reba*, *Chanda nama*, *L. dyocheilus*, *Sperata aor*, *Xenentodon cancila*.

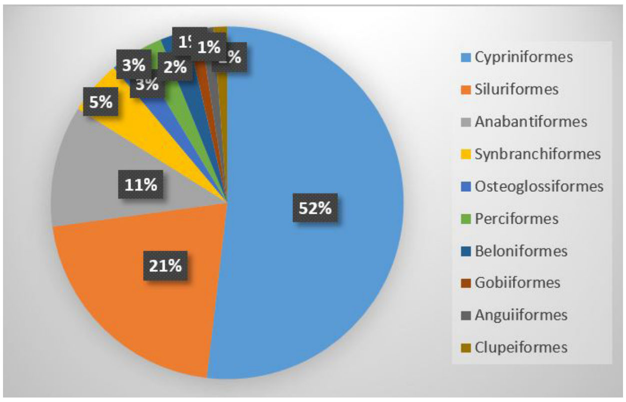

Fig. 2. Composition of fish under different orders (A), families (B), common groups (C), IUCN categories (D), and on the basis of availability (E) in Diyung River.

Eleven common groups of fishes were recorded during this study where Minnows and barbs (30.49 %) were found to be the most prominent group in the Diyung River followed by catfishes (20.73 %), carps (13.41 %), perch (9.76 %),

Table II. List of Fishes in Diyung River, Assam.

Order/ Family	Species (Common name)	Vernacular name	IUCN 2021	Availa-bility	Group name
Cypriniformes Cyprinidae	1. *Tor tor* (Deep bodied mahseer)	Nah yung	DD	VR	Carp
	2. *Tor putitora* (Golden mahseer)	Nah suur	EN	TYS	Carp
	3. *Neolissochilus hexagonolepis* (Copper mahseer)	Nah msang	NT	R	Carp
	4. *Neolissochilus hexastichus* (McClleland Boker)	Nah msang	NT	VR	Carp
	5. *Garra annandalei* (Annandale garra)	Nah loh	LC	TYL	Minnow and barbs
	6. *Garra gotyla gotyla* (Nilgiris garra)	Nah loh	LC	TYL	Minnow and barbs
	7. *Garra nasuta* (Khasi garra)	Nah loh	LC	TYL	Minnow and barbs
	8. *Garra lamta* (Lamta garra)	Nah loh	LC	TYL	Minnow and barbs
	9. *Garra lissorhynchus* (Khasi garra)	Nah loh	LC	TYL	Minnow and barbs
	10. *Opsarius bendelisis* (Hamilton's barila)	Nah hajeng	LC	TYL	Minnow and barbs
	11. *Opsarius ngawa*	Nah hajeng	NE	R	Minnow and barbs
	12. *Opsarius barna* (Barna baril)	Nah hajeng	LC	TYL	Minnow and barbs
	13. *Opsarius tileo* (Tileo baril)	Puthi	LC	R	Minnow and barbs
	14. *Barilius barila* (Bared trout)	Nah hajeng	LC	TYL	Minnow and barbs
	15. *Pethia ticto* (Two spot barb)	Puthi	LC	TYL	Minnow and barbs
	16. *Pethia conchonius* (Rosy barb)	Puthi	LC	TYL	Minnow and barbs
	17. *Puntius sophore* (Soft fin swamp barb)	Puthimah	LC	TYL	Minnow and barbs
	18. *Systomus sarana* (Olive barb)	Puthi	LC	R	Minnow and barbs
	19. *Devario devario* (Bengal danio)	Nah hajengs	LC	R	Minnow and barbs
	20. *Devario aequipinnatus* (Giant danio)	Nah hajeng	LC	TYL	Minnow and barbs
	21. *Danio dangila* (Moustached danio)	Nah belang	LC	TYL	Minnow and barbs
	22. *Salmostoma bacaila* (Large rose belly minow)		LC	TYL	Minnow and barbs
	23. *Chagunius chagunio* (Chenguni)	Nah gung gashaodzi	LC	TYL	Minnow and barbs
	24. *Osteobrama cunma* (Cunma)	-	LC	R	Minnow and barbs
	25. *Tariqilabeo latius* (Stone roller)	-	LC	TYL	Carps
	26. *Labeo bata* (Bata)	Nah bon	LC	TYS	Carps
	27. *Labeo dyocheilus* (Brahmaputra labeo)	Nah wah	LC	TYS	Carps
	28. *Labeo pangusia* (Pangusia labeo)	-	NT	TYS	Carps
	29. *Bangana dero* (Kalaban)	-	LC	TYS	Carps
	30. *Cirrhinus reba* (Reba carp)	-	LC	TYS	Carps
	31. *Cirrhinus mrigala* (Mrigal carp)	-	LC	TYL	Carps
	32. *Cabdio morar* (Morar)	-	LC	TYS	Minnow and barbs
	33. *Amblypharyngodon mola* (Mola carplet)	-	LC	TYL	Minnow and barbs
Psilorhynchidae	34. *Psilorhynchus homaloptera* (Torrent stone carp)	Nahlohkhibru	LC	TYS	Minnow and barbs
	35. *Psilorhynchus balitora* (Balitora minnow)	Nahlohkhibru	LC	TYL	Minnow and barbs
	36. *Psilorhynchus nahlongthai*	-	NE	VR	Minnow and barbs
Botiidae	37. *Botia rostrata* (Gangetic loach)	Nah hola	VU	R	Loach
	38. *Botia dario* (Bengal loach)	Nah hola	LC	VR	Loach
Nemacheilidae	39. *Paracanthocobitis botia* (Mottled zipper loach)	Nah rani	LC	TYL	Loach
	40. *Schistura fasciata*	Nah londre	NE	TYL	Loach
	41. *Schistura* sp.	-		VR	Loach

Table continued on next page..................

Order/ Family	Species (Common name)	Vernacular name	IUCN 2021	Availa-bility	Group name
Cobitidae	42. *Lepidocephalichthys guntea* (Guntea loach)	Nah rani	LC	TYS	Loach
Osteoglossiformes	43. *Notopterus synurus* (Bronze featherback)	-	LC	R	Featherback
Notopteridae	44. *Notopterus chitala* (Humped featherback)	Nah ma	NT	VR	Featherback
Anabantiformes	45. *Badis assamensis* (Assamese chameleon fish)	Nah daokha	DD	TYS	Minnow and barbs
Badidae	46. *Badis badis* (Dwarf chameleon fish)	Nah daokha	LC	TYS	Minnow and barbs
Channidae	47. *Channa marulius* (Giant snakehead)	Gozar	LC	VR	Snakehead
	48. *Channa gachua* (Dwarf snakehead)	Borga	LC	TYS	Snakehead
	49. *Channa punctata* (Spotted snakehead)	-	LC	TYS	Snakehead
	50. *Channa striata* (Striped snakehead)	-	LC	R	Snakehead
Anabantidae	51. *Anabas testudineus* (Climbing perch)	-	LC	R	Perch
Gobiiformes	52. *Glossogobius giuris* (Tank goby/bare eye goby)	-	LC	TYL	Mudskipper
Gobiidae	53. *Trichogaster fasciata* (Giant gourami)	-	LC	TYL	Perch
Osphronemidae	54. *Trichogaster lalius* (dwarf gourami)	-	LC	TYS	Perch
Perciformes	55. *Chanda nama* (Elongated glass parchlet fish)	-	LC	TYL	Perch
Ambassidae	56. *Parambassis ranga* (Indian glassy fish)	-	LC	TYS	Perch
Siluriformes	57. *Mystus cavasius* (Gangetic mystus)	-	LC	R	Catfish
Bagridae	58. *Mystus tengara* (Tengara catfish)	-	LC	R	Catfish
	59. *Mystus vittatus* (Striped dwarf catfish)	-	LC	TYS	Catfish
	60. *Rita rita* (Rita)	Nah gagol	LC	R	Catfish
Siluriformes	61. *Sperata aor* (Long-whiskered catfish)	Nah gree	LC	TYS	Catfish
Siluridae	62. *Olyra kempi* (Long tail catfish)	-	LC	R	Catfish
	63. *Wallago attu* (Helicopter catfish)	-	VU	R	Catfish
	64. *Ompok bimaculatus* (Butter catfish)	Nah blai	NT	R	Catfish
Sisoridae	65. *Glyptothorax trilineatus* (Three-lined catfish)	Nah phikhauri	LC	TYS	Catfish
	66. *Glyptothorax striatus*		NT	VR	Catfish
	67. *Bagarius bagarius* (Devil catfish)	Nah phi	NT	R	Catfish
	68. *Clupisoma garua* (Bachcha)	Nah shing	LC	R	Catfish
	69. *Gagata cenia* (Clawn catfishs)	-	LC	R	Catfish
Ailiidae	70. *Ailia coila* (Gangetic ailia)	-	NT	R	Catfish
Erethistidae	71. *Erethistes hara* (Kosi hara)	-	LC	VR	Catfish
Schilbeidae	72. *Eutropiichthys murius* (Indus garua)	-	LC	VR	Catfish
	73. *Eutropiichthys vacha* (Batchwa vacha)	-	LC	VR	Catfish
Amblycepitidae	74. *Amblyceps apangi* (Indian torrent catfish)	-	LC	TYL	Catfish
Beloniformes	75. *Xenentodon cancila* (Needlefish)	Nah gongela	LC	R	Gar
Belonidae	76. *Strongylura leura* (Banded needlefish)		NE	TYL	Gar
Synbranchiformes	77. *Mastacembelus armatus* (Tire-track spiny eel)	Nah dang	LC	R	Eel
Mastacembelidae	78. *Macrognathus aral* (One-stripe spiny eel)	Nah dang	LC	TYS	Eel
	79. *Macrognathus aculeatus* (Lesser spiny eel)	Nah dang	LC	R	Eel
Synbranhidae	80. *Monopterus cuchia* (Gangetic mud eel)	Nam nah	LC	R	Eel
Anguilliformes Anguilidae	81. *Anguilla bengalensis* (India mottlet eel)	Nah ner	NT	R	Eel
Clupeiformes Clupeidae	82. *Gudusia chapra* (Indian river Shad)		LC	VR	

VR, very rare; R, rare; TYS, Throughout the year in small amounts; TYL, Throughout the year in large amounts; NT, Near threatened; EN, Endangered; VU, Vulnerable; NE, Not evaluated; DD, Data deficient; LC, Least concern.

Table III. Fish diversity indices for different sampling stations in Diyung River.

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Taxa_S	19	35	44	52	45	40	45	48
Individuals	198	496	872	1252	682	524	752	1108
Shannon_H	2.784	3.334	3.587	3.742	3.585	3.52	3.666	3.738
Evenness_e^H/S	0.8519	0.801	0.821	0.869	0.801	0.844	0.869	0.874
Margalef	3.404	5.478	6.351	7.15	6.743	6.229	6.644	6.704

loach (7.32 %), eels (6.10 %) and snakehead (4.88%). The contribution of feather backs, gars, clupeids, and mudskipper was 2.44%, 2.44%, 1.44%, and 1.44%, respectively (Fig. 2C). According to the Red List of Freshwater Fishes published by IUCN (2021) more than half of the existing fish species (76.54 %) of this river were found to be in the least concern (LC) category, while 11.11 % of fish species were recorded as near threatened (NT), only 2.44 % as data deficient (DD), 2.44% as vulnerable, 1.23% endangered (EN) and 6.13% not evaluated (NE) (Fig. 2D). Very rare (VR) fish made up 13.5% of the total fish composition in Diyung River, and rare (R) fish made up roughly 30.86% of the available species. Furthermore, approximately one-third of the entire fish population (32.10%) was available in large quantities throughout the year (TYL), while only 23.46% of fish were present in small quantities throughout the year (TYS) (Fig. 2E).

The Spatio-temporal variation of diversity indices among the selected sampling sites of the River Diyung is shown in (Tables III and IV). The value of the Shannon-Weiner diversity index calculated based on fish assemblage for eight sampling stations of the river ranged between 2.78 to 3.74. As far as the diversity indices are concerned Dehangi Bazar Point (S4) and Diyungmukh confluence zone (S8) exhibited the highest H′ value (3.742 and 3.738, respectively) while Syamagram (S1), the least (2.784). The Margalef richness index (D) value showed variation with highest being recorded from Station 4 (7.15) and lowest from Station 1 (3.404). However, the evenness index was highest in station 8 (0.8749) and lowest in station 5 (0.8011). The highest value of D and H′ were observed during the post-monsoon season were as evenness values during pre-monsoon seasons.

The hierarchical cluster analysis technique was used to find the similarity in species abundance and composition. The cluster analysis categorized the fish species into two distinct groups (Fig. 3). Group 1 comprised sites S6, S7, and S8 representing the lower stretches of the river. Thirteen fish species (*Opsarius bendelisis, Pethia ticto, P. conchonius, Puntius sophore, Devario devario, Salmostoma bacaila, Cirrhinus reba, Paracanthocobitis botia, Channa gachua, C. punctata, Osteobrama cunma, Labeo bata* and *Mastacembelus armatus*) were recorded in group 1. Group 2 comprised stations S1, S2, S3, S4 and S5, all of which were located in the middle and upper stream. Eleven species (*Tor putitora*, *Garra gotyla*, *G. nasuta, barilius barila, Devario aequipinnatus, Danio dangila, Tariqilabeo latius, Labeo dyocheilus, Psilorhynchus homaloptera, P. balitora* and *Schistura fasciata*) were found in cluster 2. The species showing more than 1% relative abundance is only shown here.

Table IV. Fish diversity indices for different seasons in Diyung River.

	Monsoon	Post monsoon	Pre monsoon	Winter
Taxa_S	69	78	62	54
Dominance_D	0.021	0.017	0.025	0.036
Simpson_1-D	0.979	0.982	0.975	0.963
Shannon_H	4.042	4.176	3.909	3.623
Evenness_e^H/S	0.824	0.834	0.804	0.693
Margalef	9.405	9.963	8.536	7.828

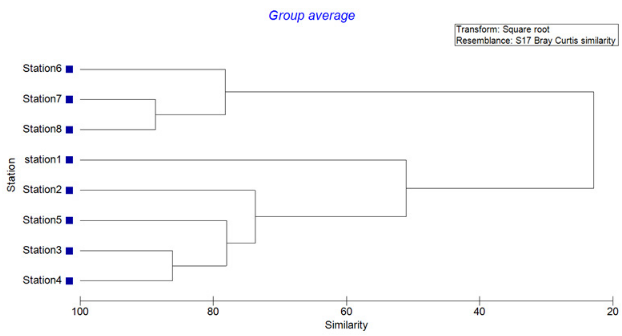

Fig. 3. Dendrogram clustering of Bray- Curtis similarity index.

Environmental parameters influence on riverine fish diversity

A multivariate method- canonical correspondence analysis (CCA) was used to establish the relationship between fish abundance and environmental parameters.

A total of 9 environmental parameters were used. Fish assemblage in relation to environmental parameters of Diyung river is plotted in axis 1 and axis 2 by CCA analysis with Eigenvalue calculated higher at Axis 1 (93.44%) and Axis 2 with (5.06%) (Fig. 4). The fish assemblage structure is dependent on the interaction of multiple ecological processes over changing the temporal and spatial scale (Poff, 1997). In our study, *Cirrhinus mrigala, Mastacembelus armatus, Xenentodon cancila, Glossogobius giuris, Channa punctata, Mystus vittatus, Pethia ticto,* and *Salmostoma bacaila* showed a positive relationship with depth, temperature, TDS and turbidity. *Tor putitora, Schistura fasciata, Paracanthocobitis botia, Devario devario, Garra lissorhynchus, G. gotyla, D. aequipinnatus, G. lissorhynchus, Opsarius bendelisis, Psilorhynchus homaloptera, P. balitora* and *Barilius barila* showed a positive relationship with dissolved oxygen (DO) and velocity. The other species like *Badis badis, B. assamensis, G. nasuta, Chagunius chagunio, Labeo dyocheilus, O. barna* and *O. ngawa* showed a positive relationship with pH. The species *Channa gachua, T. fasciata, B. dario, L. bata, Osteobrama cotio* and *P. conchonius* did not show any defined relationship with the above environmental parameter.

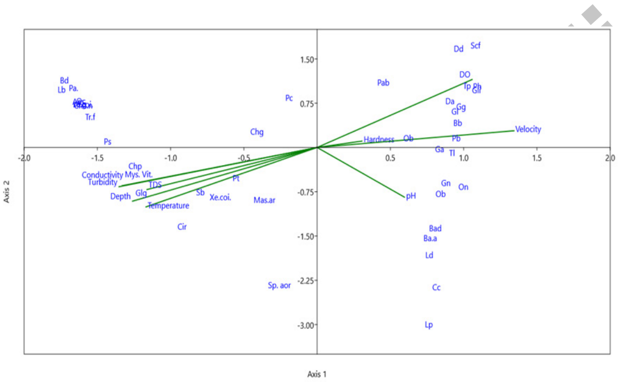

Fig. 4. Relationship between the fish assemblage of Diyung River with environmental parameters across sampling periods.

K-dominance curve

The cumulative dominance curve (K-dominance curve) is expressed as a percentage of abundance in a sample. On a logarithmic scale, the plot is displayed against the species rank 'K' By ranking the species in descending order of abundance, the dominance curve was plotted to evaluate the dominance of individual species between different sampling sites and seasons. Because of high species richness, which could be related to habitat variability (presence of deep pools, riffles, etc.) and less human influence, the Dehangi Bazar point (S-4) falls on the lower side of the spatial plot curve and expands further, and increases slowly forming an S-shaped curve (Fig. 5). In the temporal plot, the post-monsoon curve lies on the lower side extended further and rises slowly due to the high density of species, reaching 100% cumulative due to more species forming more or less an S-shaped curve (Fig. 6). The highest species abundance in the post-monsoon might be linked with higher aggregation of fish due to reduced water levels in the river which enhanced fish capturing.

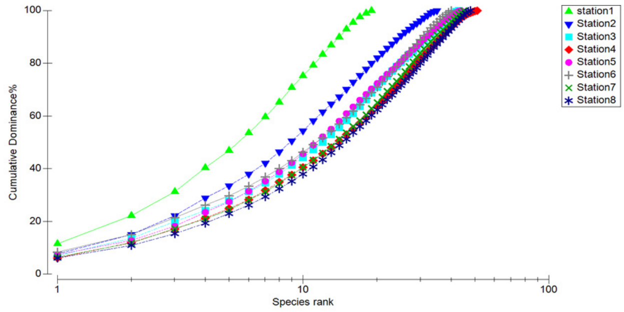

Fig. 5. Station wise K- dominance curve for species biomass.

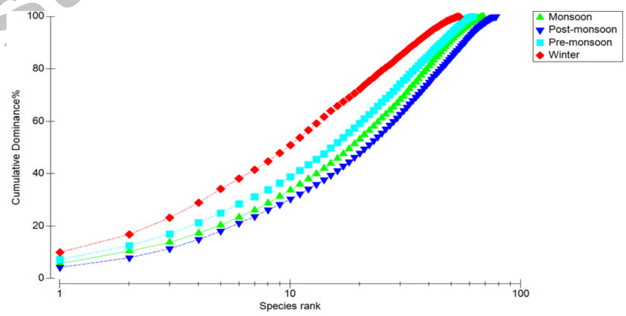

Fig. 6. Seasonal K- dominance curve for species biomass.

DISCUSSION

Fish species diversity

The occurrence, diversity, distribution and habitat use of fish provides essential information on exploitation, conservation, and management measures. Fish are the most studied group of animals and the most accurate predictors of spatial trends (Abell *et al*., 2008). The fish species recorded in the present study in the Diyung river accounts for 37.5% of the total number of fish species in the Brahmaputra River basin (Bhattacharjya *et al*., 2003). In the current study, 81 fish species belonging to 52 genera, 24 families, and 10 orders were recorded from 8 different stretches of River Diyung. These findings are found in parallel with several studies on the fish biodiversity in different freshwater bodies of India, where they reported

Cypriniformes and Siluriformes as the most prevailing orders (Dey *et al*., 2021; Dey and Sarma, 2018; Medda and Dey, 2021; Baro, 2015). Among the families, Cyprinidae was found to be the major contributor to the overall fish diversity. A similar result of the dominance of Cyprinid fishes has been reported from other rivers of India like Sankosh River, (Baro *et al*., 2015), Khowai river (Mandol, 2015), the Brahmaputra river (Sarma *et al*., 2012; Baishya *et al*., 2016), the Ranganadi river (Koushik and Bordoloi, 2016).

The findings of the present clearly indicated almost similar number of specie recorded by Sarabjit (2016) in his baseline study in the Diyung river where he recorded 79 fish species. Compared with the previous study (Sarabjit, 2016) a fifteen species viz. *Puntius chola, Rasbora rasbora, Raiamas bola, Psilorhynchus arunachalensis, P. amphicephalus, P. nudithoracicus, Pangio pangia, Schistura chindwinica, S. macrocephalus, Glyptothorax botius, G. radiolus, G. telchitta, Nangra assamensis, Pseudecheneis sulcata, P. viriosa.* On the other hand, nineteen species viz. *Neolissochilus hexastichus, Amblyceps apangi, Mystus teengara, Danio dangila, Pethia ticto, Gudusia chapra, Garra lamta, Systomus sarana, Anabas testudineus, Monopterus cuchia, Trichogaster lalius, T. fasciata, Badis assamensis, Strongylura leura, Erethistes hara, Ailia coilia, Glyptothorax trilineatus, Wallago attu, Psilorhynchus nahongthai and P. homaloptera* are being recorded in the present study, which was not reported in the previous study. Compared with the earlier study (Sarabjit, 2016) twelve species under the threatened category, including seven near threatened, one endangered, and four vulnerable species. The status of seven NT species viz. *Chitala chitala, Anguilla bengalensis, Tor tor, Neolissochilus hexagonolepis, Glyptothorax striatus, Bagarius bagarius, Ompok bimaculatus*, is still found under the NT category except for *Tor tor* which present IUCN (2021), status is data deficient. Among the four vulnerable species viz. *Devario assamensis, Botia rostrata, Schistura chindwinica, and Schistura macrocephalus* were recorded in the previous study, but only one species i.e *Botia rostrata* was retrieved in the present study. The main causes of the differences occurring in the biodiversity among stations and seasons may be attributed to seasonal variation of nutrients affecting the coexistence of many fish species (Huh and Kitting, 1985), variations in atmospheric air currents and environmental conditions (Hossain *et al*., 2012), seasonal fish migrations (Ryer and Orth, 1987).

The fish assemblage structure is dependent on the interaction of multiple ecological processes over changing the temporal and spatial scale (Poff, 1997). These factors act indigently and constrain the presence and distribution of fishes through a hierarchy of nested environmental filters. Fish abundance and distribution are the resultant of a multitude of stream variables and Physico chemical regimes of water such as water depth, water flow velocity, substrate, canopy and thermal regime, dissolved oxygen, transparency etc. (Raveendar *et al*., 2018). Environmental parameters like DO, pH, water depth, TDS, alkalinity, Conductivity, and Hardness were found to be positively correlated with the fish assemblage. This pattern has been observed in flood plain wetlands by Sarkar *et al*. (2020). Water flow is the dominant factor determining the distribution of aquatic life forms in a river and these organisms develop life-history mechanisms to sustain in response to altered flow regimes were observed by Akhi *et al*. (2020) which substantiate our findings with respect to *Garra lissorhynchus, G. gotyla, D. aequipinnatus, G. lissorhynchus Opsarius bendelisis, Psilorhynchus homaloptera, P. balitora* and *Barilius barila*. These species evolved morphologically and physiologically to adapt to these fast-flowing waters. Zang *et al*. (2019) found that chemical parameters water temperature, salinity, dissolved oxygen are the main factors in structuring fish assemblage. Morias *et al*. (2009) also recorded that water inflow is the most deciding factor in changing the biotic and abiotic regime with an important role in the distribution and abundance of ichthyoplankton. Polian *et al*. (2020) came to the decision in their study on the Amazon floodplain that water hydrology strongly influences the fish assemblage structure and distribution.

The cumulative dominance curve (K-dominance curve) is expressed as a percentage of abundance in a sample. On a logarithmic scale, the plot is displayed against the species rank K. By ranking the species in descending order of abundance, the dominance curve was plotted to evaluate the dominance of individual species between different sampling sites and seasons. Because of high species richness, which could be related to habitat variability (presence of deep pools, riffles, etc.) and less human influence, the Dehangi Bazar point (S-4) falls on the lower side of the spatial plot curve and expands further, and increases slowly forming an S-shaped curve. Habitat complexity structure the fish assemblage and leads to different ecological processes and spatial habitat complexity gives rise to various microhabitats and increases the fish diversity and abundance (Poff and Ward, 1990), and loss of habitat complexity results in biotic homogenization.

In the temporal plot, the post-monsoon curve lies on the lower side extended further and rises slowly due to the high density of species, reaching 100% cumulative due to more species forming more or less an S-shaped curve. The highest species abundance in the post-monsoon might be linked with higher aggregation of fish due to reduced water levels in the river which enhanced fish capturing. The river bed featured numerous deep pools exposed to fishing during post-monsoon. In the post-monsoon, the river water expands the horizon by inundating the adjoining areas and providing more space for fish to forage leading to declined abundance in the river. The seasonal changes can influence the fish aggregation and assemblage pattern (Kumar *et al*., 2020; Kautza and Sullivan, 2012; Akhi *et al*., 2020).

Freshwater ecosystems, mainly rivers are more susceptible to environmental degradation due to multiple stressors such as anthropogenic factors, climate change, invasive species, and many others (Johnson *et al*., 2019). Habitat modification of rivers in the form of weirs, barrages, and dams impact the fish history stages of fish and ecological processes by fragmentation. These vital ecosystems play a fundamental role by supporting numerous ecosystems services and providing critical habitats for a wide range of animals and birds. River Diyung which harbors rich ichthyofaunal diversity of both cold and warm water fish species imparting nutritional security and providing recreational fisheries even is not exempted from anthropogenic activities (sand and boulder mining, electrical fishing practice, river poisoning, overfishing, etc.) in recent years. Identifying and quantifying the impact of these multitudes of stressors led by human activities will give an insight into the scientific intervention in support of the conservation of aquatic resources.

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IRB approval and ethical statement

The use of experimental animal (fish) follows to the existing laws in India. Prior to the sample collection, care was taken to collect the specimens which was in accordance with the guidelines of the Institutional Animal Ethics Committee, College of Fisheries, Assam Agricultural University. The experimental protocol and end points were carried out according to the guidelines laid by the said committee.

Statement of conflict of interest

The authors have declared no conflict of interest.

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