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Adaptive Structural Modification and diversity of Hill-Stream Fish of Milak River, Mokokchung, Nagaland, Northeast India

Pukhrambam Rajesh Singh*, and Bendang Ao

Department of Zoology, Nagaland University, Lumami, Nagaland, India

ABSTRACT

The present study is conducted to make an inventory of fish diversity, and to study the adaptive structural modification, and key environmental parameters such as air temperature, water temperature, pH, dissolved oxygen, total alkalinity, total dissolved solids, and free carbon dioxide of the Milak River for two years (February 2021 to January 2023). The genera such as Balitora, Garra, Glyptothorax, Paracanthocobitis, and Schistura exhibited notable adaptive structural modifications to their environment. At the same time, species like Garra and Glyptothorax showed thoracic structural modifications, and Garra and Paracanthocobitis bore suctorial discs for adhesion. This river provides a conducive habitat for aquatic organisms and can be one of the repositories for ornamental fish resources because 36 out of 38 recorded fish can be considered ornamental fish. Evenness index and Simpson's dominance index showed their maximum value at site I (0.95) and II (0.046) respectively.

Keywords: *Adaptative modification, Diversity, Garra, Milak river and Glyptothorax.*

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Corresponding Author: *Pukhrambam Rajesh Singh*

E-mail Address: *prajesh@nagalanduniversity.ac.in*

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INTRODUCTION

The Northeast of India, a portion of the Eastern Himalaya, is considered the most important biodiversity hotspot on the planet (1,2); however, it has not yet been explored properly (3,4). The High Himalayan Mountain range arose due to the drifting and collision of the two plates, Indian and Eurasian plates, and the cold and wet climatic conditions due to high altitude and high rate of rainfall are believed to have been responsible for the new species and evolution of organisms living in the region. The region's geomorphology and climatic conditions have made the northeast region among the globe's biggest repositories of freshwater fish resources. Beels (floodplain lakes) are important and unique breeding and nursery grounds of many native ichthyofaunal species. This region is also influenced by the southeast monsoon from May to September and western disturbances during winter (5). Ecologically, the topography and watersheds of this region give rise to many torrential hillstreams (HS), which in turn confluence large rivers and finally join the Ganga-Brahmaputra-Barak-Chindwin drainage system (6) and play a crucial role in conserving biodiversity as a habitat for all the aquatic organisms (7).

The geographical area of Nagaland is 16,579 km^2 and the geographical coordinate of the state lies between 93° 20'E and 95° 15' E longitude and 25° 60' N and 27° 40' N latitude. The geomorphology comprises peculiar tropical regions, both cold and warm water bodies, with muddy, hard-rocky substrata. The state has diverse natural topography, such as hill logs and mountains, dense forests, big rivers, hill streams lakes, passes etc. Eleven drainage systems drain from Nagaland into the eastern Himalaya side or into the Indo-Burma side.

A literature review reveals that many workers have studied fish diversity in the northeast states. Dey and Barat (8) reported a total of 426 fish from the Eastern Himalayan region. From the northeastern region, Vishwanath (9) reported 318 species of fish under 36 families and 113 genera (229 from Brahmaputra drainage, 103 from Chindwin, and 27 from Kaladan), and Goswami *et al*., (10) recorded 422 species of fish which include 133 genera and 38 families, and the Cyprinidae was the main family and represented by 154 species. Gurumayum *et al.,* (11) recorded 259 ichthyofaunal species from Arunachal Pradesh. *Pseudolaguvia vespa* (12), a new catfish, was reported from Tsucha River, Mokokchung, Nagaland. *Pethia dikhuensis*, a new Cyprinid species, was discovered by Praveenraj *et al*., (13) from the Dikhu River, Mokokchung, Nagaland. Currently, enlisted fish in Nagaland state is 216 species of fish which include 10 orders, 29 families, and 87 genera (14).

Hill streams (HS) are aquatic bodies representing a lotic water ecosystem characterized by strong water currents, low temperature, high oxygen level, high transparency, boulders, pebbles, and gravel bottom, as well as seasonal variations in amount of flow (15). HS fish are small, short, and thick with a vast diversity of adaptive structural modifications, color patterns, unique mouths, and modes of locomotion. Their adaptive structural modifications are permanent, heritable, and manifested mainly in the integuments of the ventral side, mouth, and fins, which help in clinging to the rocky bottom of swift-flowing water. The adaptive structures are used as keys to describe new species in the HS fish. HS drains from the hills and confluences with the large rivers in the valley and forms the channel of migratory fishes between the HS and the plain rivers. Some workers, like Abhinit and Dandadhar (16), Gogoi et al. (17), and Panja et al. (18), worked on the diversity of HS fish and their economic importance in the region. Harmful fishing methods practiced by some fishermen of the region include electrocution, explosion, poisoning, and overexploitation. These destructive fishing methods destroy not only the habitat, but also other aquatic organisms thereby affect the entire ecosystem. Such degradation leads to loss of fish stock, loss of biodiversity, reduced aesthetic value, and loss of tourism. Though many workers have tried to study the fish of the state, a largely untouched area exists in the state, and therefore, this study was carried out to assess the fish diversity and adaptive structural modification of HS fish of Milak River (MR), Mokokchung district, Nagaland.

MATERIALS AND METHODS

Study area

Mokokchung is located between 26.32 '19219.3293 N Latitude and 94.50'302 48.4663 E Longitude. It has numerous HS, both perennial and non-perennial. Notable rivers flowing in the district are Milak, Dikhu, Tsurang or Desai, Tsumok, and Menung. The MR originates at the heart of Mokokchung town, and numerous drainage systems join this river after it begins its course. After covering a distance of 67 km, this river confluences the mighty Brahmaputra River in Assam. The catchment area of the MR spans approximately 845 square km, as reported by Temjen in 2018 (19). The present study was carried out in 3 sites of MR: Site 1 (94° 30' 56" E, 26° 22' 04" N, 646 msl),
Site 2 (94° 29' 09" E, 26° 26' 45" N, 362 msl), and Site 3 (94° 33' 17" E, 26° 32' 233 msl) (Fig. 1) for 2 years, between February 2021 to January 2023. Site 1, Site 2, and Site 3 are located upstream, midstream, and downstream, respectively. Sampling sites were chosen based on accessibility, altitude, physical habitat, and a similar gap of 10-15 km between the sites.

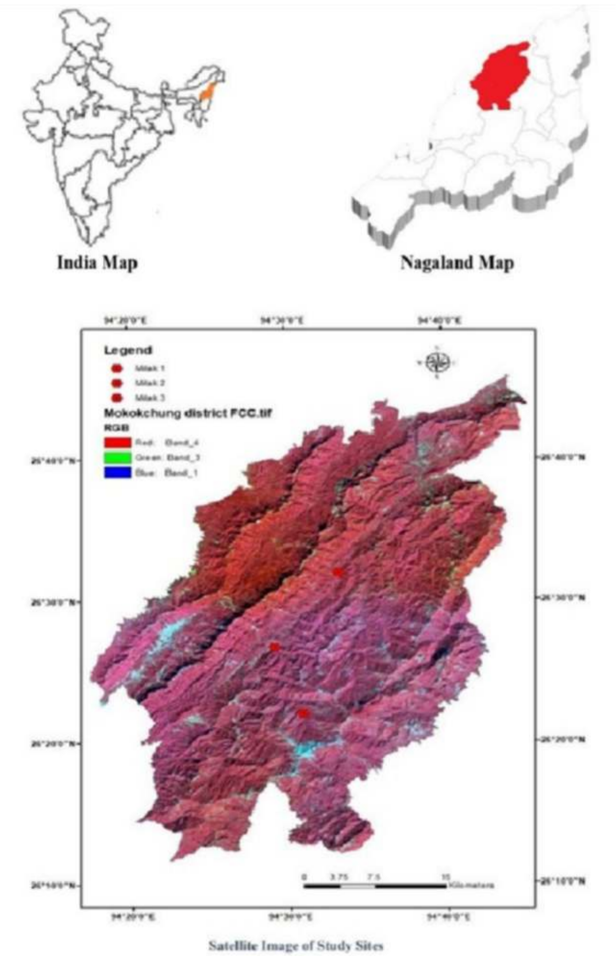

Fig: 1. Study Area Map

Sample collection and identification Procedures

Environmental Parameters (EP)

The samples were collected from the sites in the morning between 6.30 to 8.30 am every month. Dissolved Oxygen (DO), Free Carbon dioxide (FCO_2), and Total alkalinity (TA) were estimated *in situ* through titration methods following the standard guidelines of APHA (20). A Mercury thermometer was used to measure the air temperature (AT ^{0}C) and water temperature (WT ^{0}C). pH, electrical conductivity (EC), and total diossolved solids (TDS) were estimated by µ pH meter (Systronic 361), Conductivity meter (Systronic 306) and TDS/ Conductivity meter (Systronic MK-509) respectively. The results of EP are given in Table 1.

Fish sampling

Gill net, scoop net, cast net, and indigenous fishing traps were used to collect fish species. The sampling, with the help of local fishermen, was done within a radius of 1 km from each site. During the study period, local fish markets and various landing centers associated with the MR were constantly monitored for the presence of species not recorded earlier. Common fish specimens were segregated and photographed on the spot before fixing. The other specimens were fixed in 5% formaldehyde and were brought to the laboratory of the Zoology Department, Nagaland University for identification. The collected fish specimens were taxonomically identified following the identification keys of Jhingran and Talwar (21), Jayaram (22), Vishwanath (23), and Darshan et al., (24). Identified fish were authenticated using online facilities such as www.calacademy.org. The present scientific name of the fish was followed based on Eschmeyer's Catalog of Fishes (25) and the latest conservation status was assigned following the IUCN Red List of Threatened Species (26).

Data analysis

$$\text{Relative Abundance (RA)} = \frac{N \times 100}{T}$$

Where, N=No. of individuals of a species. T= total no. of all the species (27).

Species diversity in the sites was determined by the Shannon-Wiener diversity index (28), Simpsons dominance index (D) (29). Simpson diversity index [1-D] is measured by subtracting the value of D from 1.

Evenness of the Fish population was determined by E_H (Shannon's equitability). Species richness = The total no. of species documented in the present study.

RESULT

Environmental Parameters

The mean AT and WT ranged from 12.5±0.5 to 30.0±1.0 ^{0}C and 11.83±0.50 to 25.0±1.00 ^{0}C respectively. Similarly, the mean DO value ranged from 6.2±0.2 to 9.73±0.61 mg/L. The mean TA value ranged from 55.3±1.53 to 65.3±1.53 mg/L. The mean FCO_2 value ranged from 4.68±0.72 to 7.74±0.71 mg/L. The mean pH value ranged from 6.8±0.00 to 8.4±0.20. The mean EC value ranged from 104±2.0 to 139.33±3.06 µS/cm and the mean TDS recorded ranged from 54.66±0.58 to 78.0±2.0 mg/L (Table 1).

Table 1: Monthly mean variations Environmental parameters (mean±SD)

MONTH	AT ºC	WT ºC	DO (mg/L)	TA (mg/L)	FCO_2 (mg/L)	pH	EC (µS/cm)	TDS (mg/L)
FEBRUARY	15.66±0.58	14.0±0	8.53±0.25	59.3±1.53	4.8±0.93	7.46±0.12	112.4±3.86	57.6±1.53
MARCH	20.16±1.04	18.5±0.5	7.73±0.61	60.3±3.06	5.57±0.63	7.20±0.17	117.0±2.65	64.6±2.08
APRIL	22.66±0.58	20.3±0.58	7.20±0.2	62.6±2.08	5.94±0.59	7.20±0.2	117.3±3.06	69.0±1
MAY	26.83±0.76	23.0±1	6.66±0.15	63.0±2.0	6.63±2.15	7.46±0.23	121.3±2.49	68.3±1.15
JUN	27.33±0.58	23.3±0.58	**6.20±0.2**	57.3±1.53	**7.74±0.71**	6.8±0.1	131.7±3.37	72.0±1.73
JULY	28.50±0.5	24.3±0.58	6.26±0.15	**55.3±1.53**	6.13±0.46	**6.8±0**	**139.3±3.06**	**78.0±2.0**
AUGUST	**30.00±1.0**	**25.0±1**	6.63±0.15	60.3±1.53	5.78±0.32	6.93±0.23	125.3±1.53	68.3±1.15
SEPTEMBER	26.50±0.5	22.0±1	7.86±0.06	59.6±2.08	5.78±0.32	7.3±0.2	105.0±1.73	60.3±1.15
OCTOBER	21.83±0.29	19.3±1.15	8.26±0.23	62.0±1.0	6.18±1.21	7.23±0.21	110.3±2.52	62.3±0.58
NOVEMBER	15.8±0.72	15.0±1	8.40±0.23	56.6±2.08	5.53±0.75	7.83±0.06	108.6±0.58	61.3±0.58
DECEMBER	14.00±0	12.6±0.58	8.80±0.8	56.6±2.08	5.06±0.23	8.13±0.23	**104.0±2.0**	59.0±1.15
JANUARY	**12.50±0.5**	**11.8±0.5**	**9.73±0.61**	**65.3±1.53**	**4.68±0.72**	**8.4±0.20**	109.6±1.53	**54.6±0.58**

Fish diversity

Altogether, 1026 fish were collected out of which 38 species of fish which include 28 genera, 13 families and 5 orders have been enlisted (Table 2). With respect to order, Cypriniformes with 22 species (67.66% of the total catch) showed the highest diversity followed by Siluriformes with 8 species (20.92 %), Anabantiformes with 4 species (8.66%), Synbranchiformes with 3 species (2.03 %) and Beloniformes with 1 species each (0.58 %). Among the families, Cyprinidae with 15 species (47.22 % of the total species recorded) showed the most diversity, followed by Nemachielidae (16.46%), Bagridae (10.32%), Amblycidae (6.62%), Badidae (5.16%), Channidae (3.5 %), Sisoridae (2.44 %), Cobitidae (2.14 %), Mastacembelidae (2.03 %), Siluridae (1.55 %), Balitoridae (2.45%), Belonidae (0.58 %) and Botidae (0.58 %).

Table 2: Fish distribution, IUCN status, frequency, and RA

Order	Family	Scientific Name	IUCN Status	Frequency	RA %	S I	S II	S III
Beloniformes	Belonidae	*Xenentodon cancila* (Hamilton 1822)	LC	6	0.58	-	-	+
Anabantiformes	Badidae	*Badis badis* (Hamilton 1822)	NE	53	5.16	+	+	+
	Channidae	*Channa puntatus* (Hamilton 1822)	LC	9	0.87	+	+	+
		Channa quinquefasciata (Praveenraj, Uma, Knight, Moulitharan, Balasubramanian, Bineesh & Bleher 2018.)	EN	15	1.46	+	+	+
		Channa stewatii (Playfair 1867)	LC	12	1.17	+	+	+
Synbranchiformes	Mastacembelidae	*Mastacembelus armetus* (Lacepede 1800)	LC	9	0.87	+	+	+
		Macrognathus aral (Bloch & Schneider 1801)	LC	6	0.58	-	+	+
		Macrognathus pancalus (Hamilton,1822)	LC	6	0.58	-	+	+
Siluriformes	Amblycidae	*Amblyceps apangi* (Nath & Dey 1989)	LC	68	6.62	+	+	+
	Bagridae	*Mystus cario* (Hamilton, 1822)	NE	17	1.65	+	+	+
		Mystus cavasius (Hamilton, 1822)	LC	22	2.14	+	+	+
		Olyra longicaudata (Chaudhuri 1912)	LC	67	6.53	+	+	+
	Siluridae	*Ompok bimaculatus* (Bloch 1794)	NT	10	0.97	+	+	+
		Pterocryptis indica (Dutta, Barman &Jayaram 1987)	DD	6	0.58	-	-	+
	Sisoridae	*Exostoma labiatum* (McClelland 1842)	LC	8	0.77	-	-	+
		Glyptothorax maceriatus (Ng &Lalramliana 2012)	NE	17	1.65	+	+	+
Cypriniformes	Cyprinidae	*Bangana dero* (Hamilton, 1822)	LC	18	1.75	+	+	+
		Danio assamila (Kullander 2015)	NE	41	3.99	+	+	+
		Devario assamensis (Barman 1984)	Vu	47	4.58	+	+	+
		Devario aequipinnatus (McClelland 1839)	LC	90	8.77	+	+	+
		Devario coxi (Kullander 2017)	NE	10	0.97	+	+	+
		Garra gotyla (Hora 1921)	LC	36	3.50	+	+	+
		Garra lissorhynchus (McClelland 1842)	LC	36	3.50	+	+	+
		Garra naganensis (Hora 1921)	NE	47	3.58	+	+	+
		Neolissochilus hexagonolepis (McClelland 1842)	NT	30	2.92	+	+	+
		Opsarius bendelesis (Hamilton 1822)	LC	47	4.58	+	+	+
		Opsarius barna (Hamilton 1822)	LC	27	2.63	+	+	+
		Puntius sophore (Hamilton, 1822)	LC	8	0.77	+	+	+
		Schizothorax richardsonii (Gray, 1832)	Vu	9	0.87	+	+	+
		Securicula gora (Hamilton, 1822)	LC	8	0.78	+	-	+
		Tor tor (Hamilton, 1822)	NT	31	3.02	+	+	+
	Nemachielidae	*Paracanthocobitis botia* (Hamilton, 1822)	LC	23	2.24	+	+	+
		Psilorhynchus balitora (Hamilton 1822)	LC	82	7.99	+	+	+
		Schistura fasciata (Lokeshwor & Vishwanath 2011)	NE	37	3.6	+	+	+
		Schistura naganensis (Menon 1987)	Vu	27	2.63	+	+	+
	Balitoridae	*Balitora brucei* (Gray, 1830)	NT	13	1.26	+	+	+
	Botidae	*Botia rostrata* (Gunther, 1868)	Vu	6	0.58	-	+	+
	Cobitidae	*Lepidocephalichthys guntea* (Hamilton, 1822)	LC	22	2.14	+	+	+

S- Site, LC- Least concern, DD - Data Deficient, EN - Endangered, Vu - Vulnerable, NT- Near Threatened, NE – Not Evaluated, + recorded, - Not recorded.

Relative abundance

The RA of all the recorded fish is shown in Table 2. The most dominant species with the highest RA (8.77%) was *D. aequipinnatus*, followed by *P. baliptora* with 7.99%, *A. apangi* with 6.62%, *O. longicaudata* with 6.53%, *B. badis* with 5.16%, *D. assamensis* with 4.58% and *O. bendelesis* with 4.58 %. The RA of the remaining fish was less than 4%. Among the recorded species, 21 fish species (59.46 %) were of LC, 7 species (21.64 %) were NEv, 4 species (8.67 %) were Vu, 4 species (8.18 %) were NT, 1 species (1.46 %) was EN and 1 species (0.58 %) was in the DD category.

Diversity index

H ranges from 3.23 (site II) to 3.39 (site III). *H* of site I is 3.26. Higher *H* indicates a balance between species richness and the total number of individuals of every species. Species evenness measured by E_H varies from 0.92 (site II) to 0.95 (site I). The maximum E_H was recorded at Site I and the lowest E_H was at Site II. The D ranges from 0.038 (site III) to 0.046 (site II). The river's high diversity may stem from the absence of large predatory fishes and the normal EP of water. The habitat complexity of a hill stream encompasses turbulent current, underlying stratum, light, temperature, depth etc., within which aquatic organisms make their home. This ascertains the species richness and divergent of the aquatic organisms. The cumulative species richness, total catch, *H* of the three sites, D, 1-D, and E_H, showed relatively high values with 38 species, 1026 individuals, 3.33, 0.04, 0.96, and 0.92, respectively (Table 3).

Table 3: Diversity index of the study sites

Parameters	Sampling Sites			
	S I	S II	S III	Total
Species richness	31	34	38	38
Total catch	241	469	316	1026
Shannon-Weinner diversity index	3.26	3.23	3.39	3.33
Simpson dominance index (D)	0.040	0.046	0.038	0.04
Simpson diversity index (1-D)	0.96	0.95	0.96	0.96
Evenness index (E_H)	0.95	0.92	0.93	0.92

S=Site

Adaptive structural modification

Most HS fish are considered ornamental fish due to their dazzling colouration, small size, and unusual structures. Adaptive Structural modifications are manifested in the body shape, size, small eyes, mouth, adhesive apparatus, and fins (Fig. 2A-B).

Size and Shape: The genera such as Badis, Balitora, Botia, Garra, Mystus, Paracanthocobitis, Amblyceps, and Psilorhynchus were recorded as genera with short and thicker bodies with semicircular heads and small tubercles in the snout.

Eyes: The presence of tiny eyes that were pushed upward on the dorsal surface of the head was observed in genera like Xenentodon, Olyra, Macrognathus, Glyptothorax, Balitora and Garra.

Barbels: Short and stumpy, used for capturing prey in the torrential environment were seen in *A. apangi*, *O. longicaudata*, *B. brucei*, *G. gotyla* , *P. indica* and *S. fasciata*.

Mouth: The mouth was found on the lower surface of the head as seen in the genus like Balitora, Garra, Glyptothorax, Psilorhynchus, Olyra, and Schistura . In the genus Garra, the lower lip is modified into an oromandibular structure, while the upper lip is highly muscular which is fringes and overhangs the mouth. In the case of genera such as Paracanthocobitis and schistura, the lips are swollen, and the lower lip forms a ring-like sucker.

Fins: Fins were modified to perform some special functions like swimming, balance, and anchoring to the hard substratum of the swift current. The structure of the fins was as follows:

Paired fins: The genera like Garra, Opsarius, Balitora, Mystus, Paracanthocobitis, Psilorhynchus, etc showed the presence of large pectoral and pelvic fins placed at the latero-ventral side. In fishes like *G. maceriatus*, *S. fasciata*, the outermost rays of fins were adapted for adhesion.

Caudal fin and its peduncle: The genera Balitora, Glyptothorax, Olyra, and Opsarius possessed a narrow and muscular caudal peduncle.

Adhesive apparatus: The integuments of the thoracic region of some fish were modified to form an adhesive apparatus. The genus Glyptothorax bore numerous ridges on the ventral side of thoracic region, which help them to cling on to the rocks. In Garra, Paracanthocobitis, and schistura, the lower lips were adapted as a suctorial plate which functions like adhesive apparatus.

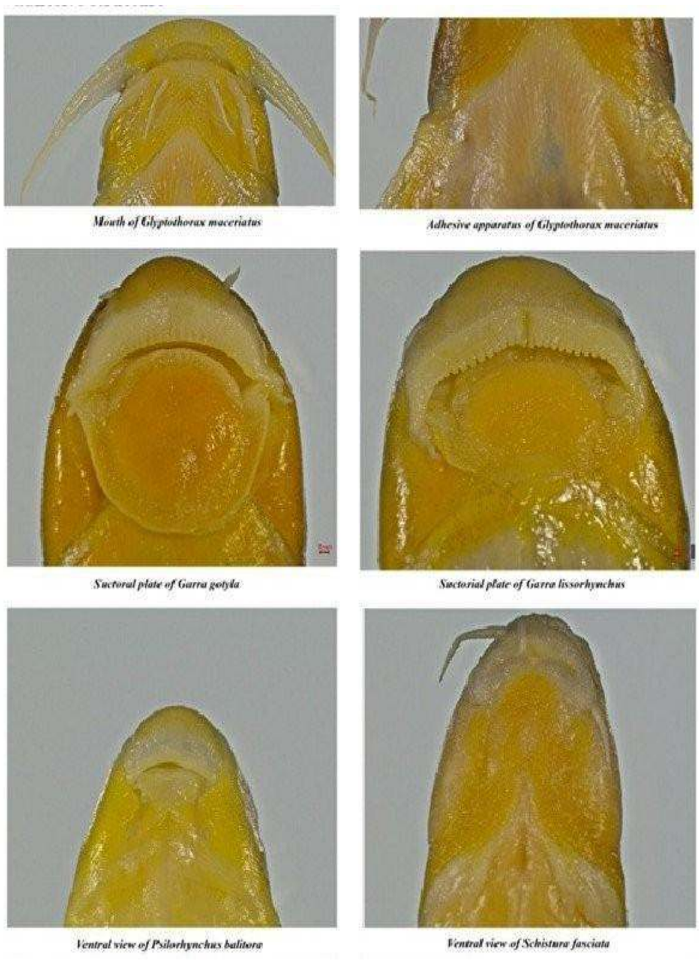

Fig 2 A: Modification in the snout, thoracic region, mouth, and presence of adhesive structure

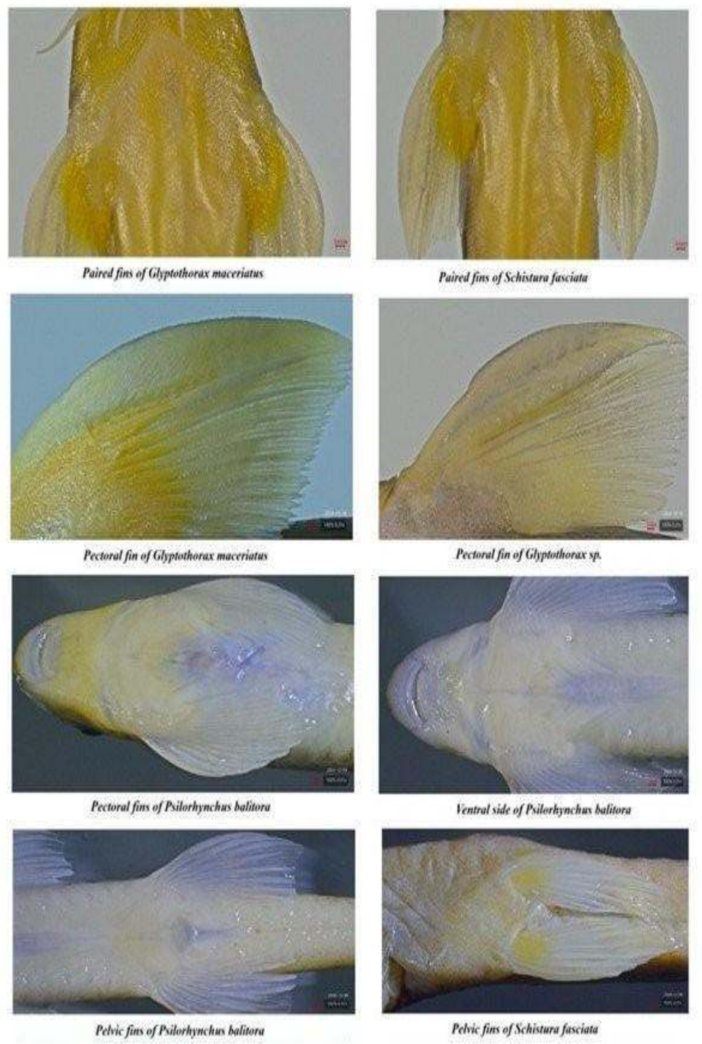

Fig 2 B: Modification in the fins and barbels

Discussion

The EP like WT, DO, FCO2, pH, TA, EC and TDS are closely related to the diversity and distribution of fish in the riverine ecosystem (31, 32). Fish diversity and distribution are also influenced by plankton and riparian vegetation which provide food and shelter for hatchlings and small fish species (33, 34). The present assessment is primarily related to the ichthyofaunal diversity and their adaptive structural modification of MR. The species richness of an aquatic ecosystem is directly related to the seasonal variation in the EP. In light of the diversity, adaptive modification, and conservation status of fish, the current study is the first one of its kind for the MR, Mokokchung district, Nagaland.In this river alone, 38 species of fish were recorded, which is 17.35% of Nagaland state's 216 total fish species (15). The highest species diversity and abundance was observed in the late monsoon season and post-monsoon while the lowest was found in the premonsoon season. A similar result was observed by other workers like Prasad et al. 2020 (35) and Chapagain et al. 2021 (36). Owing to the lack of literature on fish diversity from this river, it will not be possible to determine the rate of decline in biodiversity, hence this data would be extremely useful as baseline data for future reference. The EP and substrate compositions of the riverbeds are an essential part of a riverine ecosystem and influence the diversity, reproduction, growth, adaptation and survival of fish. A diverse microhabitat condition for the HS fish is created by the structure of the substratum which helps fish acquire adaptive structures.

On top of that, to prevent being washed away by the fast and tumultuous currents of hill streams, Fish have to attach themselves to the rocks and have to develop adaptive structural modification (10). Various environmental as well as physiological conditions are responsible for the development of adaptive structures. Besides that, Adaptive structural modifications have evolutionary significance and lead to both phenotypic and genotypic divergence in the fish (37). In the lotic ecosystem, Chapagain et al. (36) revealed that the upstream was characterized by bolder, riflles, shallow, and rapid current, whereas downstream was flat and flood plain on either side. In the HS, Fish communities exhibit a certain pattern of diversity, where upstream are less diverse with the species richness than downstream. In the current study too, corresponding results were seen. It may be due to being closer to big rivers or lakes where fish diversity is more and alteration in the habitat attributes across different sites. Diversity indices such as the *H*, Species richness, D, 1-D, and Species evenness show the varied nature of HS fish species. The application of diversity indices ameliorates the interpretation of the dataset, which is unique for each community or individual studied. Dominant and rare species greatly influence the *H* index, which is highly sensitive to even a small altercation in species' richness. Thus, the *H* index is mainly utilized to monitor the actual state of the environment. On the other hand, the D index displays more important to dominant species, evenness and is not influenced by rare species; therefore, it is mainly used to show the direction in which ecological diversity is heading positively.

Conclusion

Although the information given by the local fisherman and community that there has been a decline in the species richness of ichthyofauna in the last 2 decades, the total number of fish species and their structural adaptive modification documented in the present study have shown that MR still provides a conducive habitat for aquatic organisms and can be one of the repositories of hill stream fish resources. To improve the fish diversity in the river, cutting or disturbing the drainage basin, habitat destruction, and destructive fishing throughout the reproductive season are some of the challenges that require attention. Proper management of the riverine ecosystem of the MR and spread awareness of the importance of fisheries resources would also help in increasing the population of fish and the ecological integrity of the riverine ecosystem. Therefore, the prime need of the hour is the understanding of biodiversity, conservational value, and the adaptation of the existing HS ichthyofauna.

Completing interests

This research article has no conflict of interest.

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Ethics approval and consent to participate

The present study does not deal with laboratory animals. Therefore, this study does not require ethical approval.

However, we availed the approval from IAEC, NU. The approval no is "IAEC Approval No. NU/ZOO/IAEC/Meeting No 1/2020, Protocol No. 05".

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