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HILL STREAM ICHTHYOFAUNAL DIVERSITY OF BAKSA DISTRICT ALONG THE INTERNATIONAL BORDER BETWEEN INDIA AND BHUTAN: ECONOMIC IMPORTANCE AND ANTHROPOGENIC THREATS

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

North-Eastern states are leaders in the diversity of indigenous species of economically important fish. Hill streams of this region inhabit ichthyofauna of broad importance. However, increased anthropogenic activity possess deleterious consequence. The goal of the study conducted from January 2021 to July 2022 was to document and report the ichthyofaunal diversity of the hill streams in the Baksa district of Assam, India, its economic importance as well as potential threats associated with it. A total of 3182 fishes classified into 39 species, 13 families, and 5 orders were documented. Cypriniformes is the dominant order (71.24%), followed by Perciformes (17.76%), Siluriformes (5.97%), Symbranchiformes (3.65%), and Beloniformes (1.38%). These hill streams inhabit endangered, vulnerable, near-threatened, lower-risk-near-threatened species (IUCN, CAMP, and ICAR). Diversity indices indicate that these streams are rich in evenly distributed ichthyofauna. However, the recent spike in riparian deforestation, illegal fishing, and tourism-related plastic garbage possess a serious threat to these hill-stream ecosystems and inhabiting fish fauna. The consequences of riparian deforestation are looming as a severe future issue. Conservation of this ecosystem has become an important call to take on.

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Keywords: Hill-stream biodiversity; North-East India; ichthyofauna.

1. INTRODUCTION

From microorganisms to larger species, the Earth is rich in diversity. Biodiversity is necessary for ecosystem balance and environmental neutrality [1]. Like other diversity, ichthyofaunal diversity also has its importance in its vicinity, considering that 25% of vertebrates are freshwater fishes [2,3] having commercial and nutritional importance [4]. Rivers and streams are important sources of fresh water and showcase high species richness in terms of biodiversity belonging to endangered ecosystems worldwide [5]. There are 1275 endangered fish species in the world and in Asia itself, 688 fishes are threatened [6].

India can be classified as a mega diversity hotspot with having 4 out of 36 hotspots around the world. Assam, one of India's seven north-eastern states shares parts of two hotspots namely the Himalaya and Indo-Burma region. The rich ichthyofaunal diversity of Assam is well-known. The freshwater ecosystem of this region is home to a diverse range of flora and fauna. This diversified area of India has long provided livelihood and has a significant economic impact [7,8]. This area's high species diversity has resulted in excellent ecosystem services, promoting the interrelationship between human well-being and biodiversity. Baksa district is a part of the eastern-Himalaya biodiversity hotspot. The majority of the hill streams in this district originate close to the international border between India and Bhutan and are rich in indigenous fish fauna.

Anthropogenic activities have had an impact practically on all aquatic habitats [9]. Hill-stream catchment land use is one of the most important stressors for stream ecosystems [10]. Riparian deforestation has a significant impact on hill streams such as (i) reducing wildlife habitat and corridors along with lowering stream water and habitat quality due to loss of woody debris, leaf litter, and dissolved organic carbon inputs [11]; (ii) absence of shade, which results in extremely high levels of photosynthetically active radiation [12], solar UV radiation [13], and temperature [14]; and (iii) minimum buffering against non - point source pollutants [15]. Landslides are one of the major factors that have a negative impact on the hill-stream ecosystem. Landslides are caused by a variety of circumstances, one of which is the loss of vegetation [16]. On the other hand plastic pollution, a threat to hill-stream biodiversity is a new subject of ecological research. Due to the growth of plastic waste in aquatic ecosystems, plastic ingestion by aquatic organisms has become an emerging hazard [17].

From January 2021 to July 2022, the study was conducted in an unexplored area along the international border between India and Bhutan in the Baksa district of Assam, India. A total of 12 hill streams with strong water currents were chosen for sampling. In this study, attempts were made to investigate the fish diversity of this unexplored region, and its economic value, and assess potential threats to these hill streams.

2. METHODOLOGY

The study was conducted on 12 locations in the Baksa district of Assam along the international border between India and Bhutan. Sampling Coordinates can be found in supplementary Table 1 and the geographic locations of these sampling sites are given in Fig. 1.

Fishing gear was used to capture fish, and fishermen were enlisted to assist in the process. Fishes were identified on the spot and released. Fishes which were not identifiable on the spot were preserved in 5%-10% aqueous formaldehyde solution and brought to the Department of Zoology, Cotton University, Guwahati and identified. For the identification of the specimen, Day, [18,19], Jayaram, [20], and Talwar & Jhingran, [21] were consulted and scientific names were validated using NCBI Taxonomy Browser [22] and Bangladesh Fisheries Information Share Home (https://bdfish.org/).

2.1 Statistical Analysis

The alpha (α) diversity indices were calculated by the Shannon-wiener diversity index (H′) [23,24], Simpson's diversity index (D) [25], Pielou's evenness index (J′) [26], Margalef species richness index (R), [27] and the effective number of species (ENS) [28] according to the site of collection. These are given by:

(a) Shannon-wiener diversity index (H′)

$$H' = -\sum Pi \ln Pi$$

$$Pi = \frac{n}{N}$$

Where n is the number of individuals of a single species, and N is the total number of fish collected from individual sites.

Effective number of species (ENS)

ENS =EXP (H′)

EXP is an exponential function.

(b) Simpson's diversity index(D)

$$D = 1 - \sum \frac{n(n-1)}{N(N-1)}$$

(c) Pielou's evenness index (J′)

$$J' = \frac{H'}{H\,max}$$

$$H\,max = \ln S$$

Where S is the number of species collected from each site.

(d) Margalef richness index (R)

$$R = \frac{(S-1)}{\ln N}$$

All the statistical calculations were conducted in MS Excel (version 2013).

3. RESULTS AND DISCUSSION

During the study period, a total number of 39 fish species belonging to 13 families, and 5 orders were recorded. Cypriniformes is the dominant order with 2267 (71.24 %), followed by Perciformes with 565 (17.76 %), Siluriformes with 190 (5.97 %), Symbranchiformes with 116 (3.65 %), and Beloniformes with 44 (1.38 %) individuals (Fig. 2). Family Cyprinidae of Cypriniformes order has the highest species richness with 20 species followed by Bagridae with 3 species out of 39 identified species(Fig. 3). *Danio rerio* is the most abundant species based on the number of individuals captured, followed by *Amblypharyngodon mola* (Table 1). Site-specific species number identified can be found in supplementary Fig. 1.

Shannon-wiener index (H′) score ranges from 3.40 to 3.11 (Table 2). The range of H′ indicates that the water in these streams is not polluted and the habitats have not been altered [29,30]. Values of the effective number of species (ENS) which measures true diversity [28], has a range of 29.89 to 27.73 (Table 2) and Simpson diversity index (D) ranges from 0.96 to 0.94 (Table 2). From the effective number of species (ENS) as tabulated along with Simpson diversity index (D), it can be inferred that the diversity of these hill streams are significantly high. Both Shannon's and Simpson's indexes are highly correlated with each other (Figs. 4 A & B). From the Margalef index (>5.00) (Fig. 5, Table 2) it can be inferred that all the collecting sites have high species richness. The Pielou's evenness index (J′) varied from 0.94 to 0.88, (Table 2, Fig. 6) indicating a balanced relationship between species and their richness. A higher evenness index value indicates low species diversity dominance in a specific location [31]. The range of J′ of the current study reveals uniformity in the distribution of individuals among species at all sampling points. From Figs. 7 (A & B) it can be stated that species richness and evenness have negligible correlation.

In Table 1, species that have been identified along with their habitats, economic value, IUCN (https://www.iucnredlist.org/) status, C.A.M.P. (Conservation Assessment and Management Plan) status [32] and ICAR-National Bureau of Fish Genetic Resources (ICAR-NBFGR) [6] status are shown. *Heteropneustes fossilis*, *Labeo pungusia*, *Mystus tengara*, *Mystus bleekeri*, and *Anabus testudineus* have high market value. Out of 39 fish species *Parambassis ranga*, *Chanda nama*, *Trichogaster fasciata*, *Trichogaster labiosa*, *Badis badis*, *Nandus nandus*, *Pethia phutunio*, *Garra gotyla*, *Rasbora rasbora*, *Pethia gelius*, *Pethia ticto*, *Puntius terio*, *Chagunius chagunio*, *Puntius chola*, *Danio rerio*, *Puntius sophore*, *Rasbora daniconius*, *Pethia conchonius*, *Danio dangila*, *Devario aequipinnatus*, *Esomus danricus*, *Amblypharyngodon mola*, *Psilorhynchus balitora*, *Acanthocobitis botia*, *Mystus vittatus*, *Mystus bleekeri*, *Mystus tengara*, *Mastacembelus armatus*, and *Xenentodon cancila* are widely used as ornamental fish all over the world (Table 1). According to IUCN, *Labeo pangusia* is categorised as a 'near threatened' (NT) species and the rest of the other species found in this study are considered as 'least concern' (LC) species (Table 1). However, according to C.A.M.P. *Channa punctata*, *Trichogaster fasciata*, *Glossogobius giuris*, *Labeo pangusia*, *Pethia phutunio*, *Pethia ticto*, *Puntius terio*, *Labeo bata*, *Danio rerio*, *Puntius sophore*, *Rasbora daniconius*, *Devario aequipinnatus* and *Xenentodon cancila* are listed as 'low risk near threatened' (LRnt) at national level, on the other hand *Anabus testudineus*, *Garra gotyla*, *Labeo dyocheilus*, *Systomus sarana*, *Pethia conchonius*, *Mystus vittatus*, and *Heteropneustes fossilis* are considered as 'vulnerable' (VU) at national level [32] (Table 1). According to ICAR-NBFGR *Badis badis*, *Labeo panguisa*, *Garra gotyla*, *Heteropneustes fossilis*, *Puntius chola*, and *Systomus sarana* are classified under 'vulnerable' (VU) category and *Chagunius chagunio* is classified under 'endangered' (EN) category in India [6] (Table 1).

It was also observed that the hill streams were inhabited not only by hill stream-specific fishes, but also by fishes that are prevalent in the plain region such as *Trichogaster fasciata, Trichogaster labiosa, Badis badis, Nandus nandus, Glossogobius giuris, Anabus testudineus, Pethia phutunio, Systomus sarana, Pethia gelius, Pethia ticto, Puntius terio, Labeo bata, Puntius chola, Puntius sophore, Pethia conchonius, Mystus bleekeri, Heteropneustes fossilis,* and *Xenentodon cancila* (Table 1). High water current is not ideal for these fish from a phenotypic standpoint; however, their occurrence was confirmed during the study period. Their existence might be owing to seasonal flooding that inundates the immediate region and neighbouring ponds. Because of their high market value, some of these fish are cultured in these ponds and eventually end up in streams due to floods. It's also probable that their presence in the hill-streams seems to be due to migration.

Hill-stream fishes such as *Parambasis ranga, Chanda nama, Channa punctata, Channa gachua, Labeo pangusia, Garra gotyla, Labeo dyocheilus, Rasbora rasbora, Chagunius chagunio, Danio rerio, Rasbora daniconius, Danio dangila, Devario aequipinnatus, Esomus danricus, Amblypharyngodon mola, Psilorhynchus balitora, Acanthocobitis botia, Mystus vittatus, Mystus tengara, Macrognathus aral,* and *Mastacembelus armatus* were recorded during the study (Table 1).

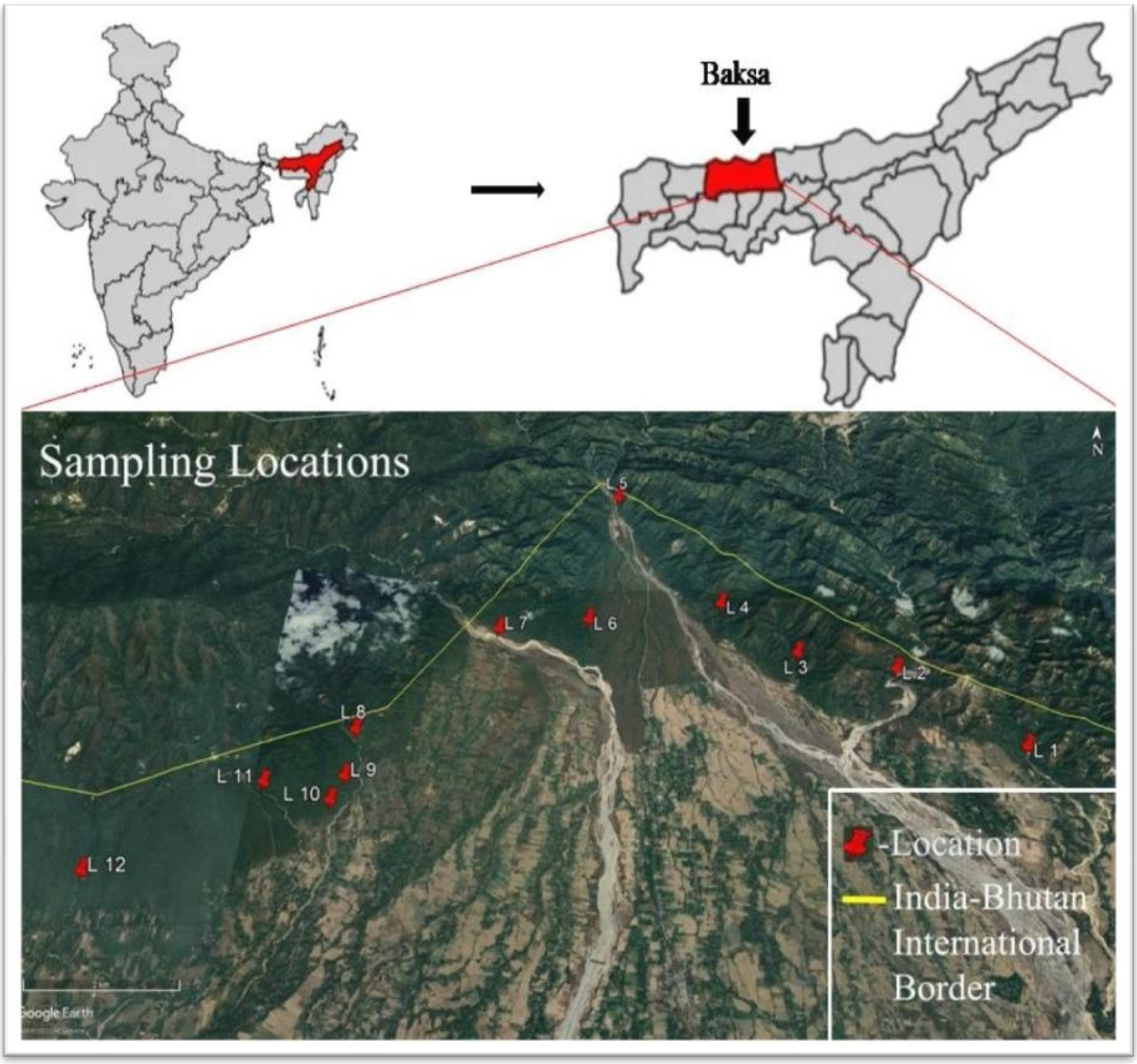


Fig. 1. Study area map and sampling site location

Table 1. Fish fauna of hill streams of Baksa district, their habitat, economic importance, status, number of species collected, and percentage

Order	Family	Species	Habitat	Economic importance	IUCN status	NBFGR	CAMP	Total fish collected	%
Perciformes	Ambassidae	*Parambassis ranga*	*R, L, WL*	*Or*	*LC*	-	*ne*	*85*	*2.67*
		Chanda nama	*R, L, WL*	*Or*	*LC*	-	*ne*	*116*	*3.65*
	Channidae	*Channa punctata*	*R, L, WL*	*Fd*	*LC*	-	*LRnt/N*	*16*	*0.50*
		Channa gachua	*R, L, WL*	*Fd*	*LC*	-	*ne*	*20*	*0.63*
	Osphronemidae	*Trichogaster fasciata*	*R, L, WL*	*Fd, Or*	*LC*	-	*LRnt/N*	*45*	*1.41*
		Trichogaster labiosa	R, L, WL	*Fd, Or*	*LC*	-	*ne*	*13*	*0.41*
	Nandidae	*Badis badis*	*R, Str*	*Or*	*LC*	*VU*	*ne*	*56*	*1.76*
		Nandus nandus	*R, Str*	*Or*	*LC*	-	*LRnt*	*63*	*1.98*
	Gobidae	*Glossogobius giuris*	*R, L, WL*	*Fd*	*LC*	-	*LRnt/N*	*75*	*2.36*
	Anabantidae	*Anabas testudineus*	*R, L, WL*	*Fd*	*LC*	-	*VU/N*	*76*	*1.39*
Cypriniformes	Cyprinidae	*Labeo pangusia*	*R, L, Str*	*Fd*	*NT*	*VU*	*LRnt/N*	*12*	*0.38*
		Pethia phutunio	*R, Str, L, WL*	*Or*	*LC*	-	*LRlc/N*	*143*	*4.49*
		Garra gotyla	*R, Str*	*Fd,Or*	*LC*	*VU*	*VU/N*	*61*	*1.92*
		Labeo dyocheilus	*R, L*	*Fd*	*LC*	-	*VU/N*	*67*	*2.11*
		Rasbora rasbora	*R, Str*	*Or*	*LC*	-	*ne*	*51*	*1.60*
		Systomus sarana	*R, Str, WL*	*Fd*	*LC*	*VU*	*VU/N*	*77*	*2.42*
		Pethia gelius	*R, Str*	*Or*	*LC*	-	*ne*	*20*	*0.63*
		Pethia ticto	*R, Str, L, WL*	*Or*	*LC*	-	*LRnt/N*	*22*	*0.69*
		Puntius terio	*R, Str, WL*	*Or*	*LC*	-	*LRnt/N*	*30*	*0.94*
		Chagunius chagunio	*R, Str*	*Fd, Or*	*LC*	*EN*	*ne*	*21*	*0.66*
		Labeo bata	*R, L, P*	*Fd*	*LC*	-	*LRnt/N*	*116*	*3.65*
		Puntius chola	*R, Str, L*	*Or*	*LC*	*VU*	*VU*	*81*	*2.55*
		Danio rerio	*R, Str*	*Or*	*LC*	-	*LRnt/N*	*377*	*11.85*
		Puntius sophore	*R, Str, L, WL*	*Or*	*LC*	-	*LRnt/N*	*126*	*3.96*
		Rasbora daniconius	*R, Str*	*Or*	*LC*	-	*LRnt/N*	*52*	*1.63*
		Pethia conchonius	*R, Str*	*Or*	*LC*	-	*VU/N*	*91*	*2.86*
		Danio dangila	*R, Str*	*Or*	*LC*	*VU*	*ne*	*113*	*3.55*
		Devario aequipinnatus	*R, Str*	*Or*	*LC*	-	*LRnt/N*	*217*	*6.82*
		Esomus danricus	*R, Str*	*Or*	*LC*	-	*LRlc/N*	*161*	*5.06*
		Amblypharyngodon mola	*R, Str*	*Fd, Or*	*LC*	-	*LRlc/N*	*233*	*7.32*
	Psilorhynchidae	*Psilorhynchus balitora*	*R, Str*	*Or*	*LC*	-	-	*88*	*2.77*

Order	Family	Species	Habitat	Economic importance	IUCN status	NBFGR	CAMP	Total fish collected	%
	Balitoridae	*Acanthocobitis botia*	*R, Str*	*Or*	*LC*	-	*LRnt*	*108*	*3.39*
Siluriformes	Bagridae	*Mystus vittatus*	*R, Str*	*Fd, Or*	*LC*	-	*VU/N*	*35*	*1.10*
		Mystus bleekeri	*R, L, WL*	*Fd, Or*	*LC*	-	*VU*	*28*	*0.88*
		Mystus tengara	*R, Str*	*Fd, Or*	*LC*	-	*ne*	*121*	*3.80*
	Heteropneustidae	*Heteropneustes fossilis*	*R, L, WL*	*Fd*	*LC*	*VU*	*VU/N*	*6*	*0.19*
Symbranchiformes	Mastacembelidae	*Macrognathus aral*	*R, L, WL*	*Fd*	*LC*	-	*LRnt*	*24*	*0.75*
		Mastacembelus armatus	*R, L, WL*	*Fd, Or*	*LC*	-	*ne*	*92*	*2.89*
Beloniformes	Belonidae	*Xenentodon cancila*	*R, Str*	*Or*	*LC*	-	*LRnt/N*	*44*	*1.38*

Abbreviations: R: river, L: lake, WL: wetland, Str: stream, Or: ornamental fish, Fd: food LC: least concern; NT: near threatened EN: endangered, VU: vulnerable, LRnt: low-risk near threaten, LRnt/N: low-risk near threatened in nature, LRlc: low risk least concern, VU/N: vulnerable in nature, ne: not evaluated

Table 2. Statistical indices according to the sampling location

INDICES	L-1	L-2	L-3	L-4	L-5	L-6	L-7	L-8	L-9	L-10	L-11	L-12
Shannon-wiener index (H’)	3.40	3.23	3.29	3.30	3.14	3.11	3.30	3.20	3.21	3.12	3.32	3.15
Simpson diversity index (D)	0.96	0.96	0.96	0.96	0.94	0.95	0.96	0.95	0.95	0.94	0.96	0.95
Pielou's evenness index (J')	0.93	0.92	0.92	0.92	0.88	0.89	0.91	0.90	0.91	0.88	0.94	0.89
Effective number of species(ENS)	29.89	25.32	26.82	27.23	23.20	22.33	26.99	24.64	24.85	22.65	27.73	23.39
Margalef species richness index (R)	6.50	5.96	6.42	6.48	6.05	5.83	6.33	6.20	6.14	6.13	5.74	5.97

Abbreviations: L- Location

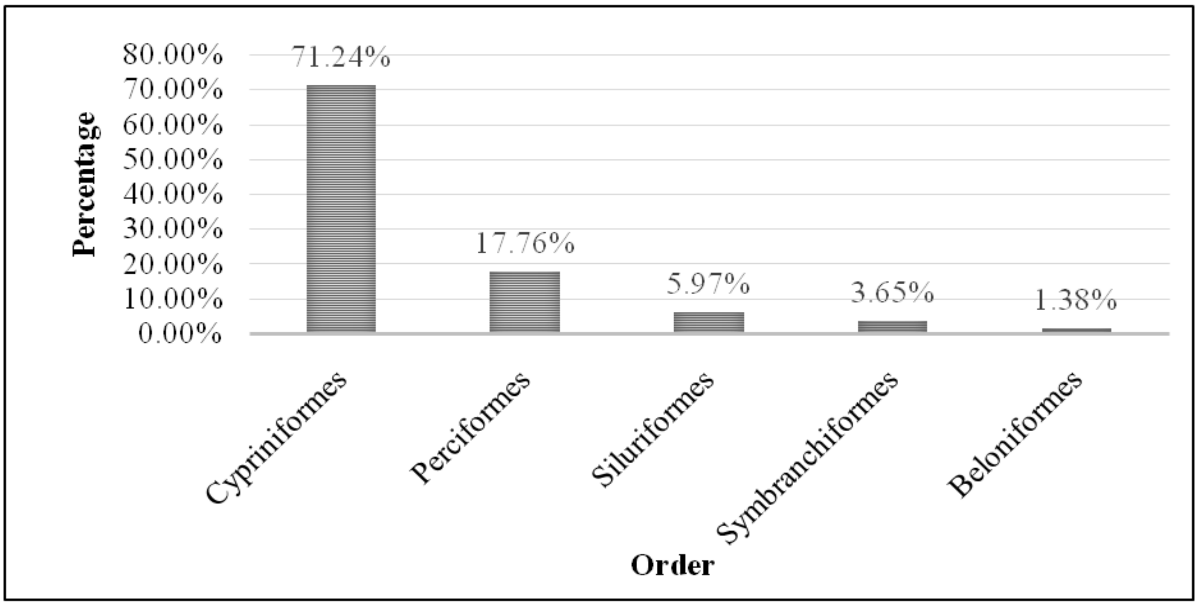


Fig. 2. Percentage of different orders of the fishes found during the study period. In this figure, the horizontal axis represents different orders of the fishes which are found during our study and the vertical axis represents the percentage. Cypriniformes is the dominant order with 2267 (71.24 %), followed by Perciformes with 565(17.76 %), Siluriformes with 190 (5.97 %), Symbranchiformes with 116 (3.65 %), and Beloniformes with 44 (1.38 %) individuals of the total fishes found during the study period

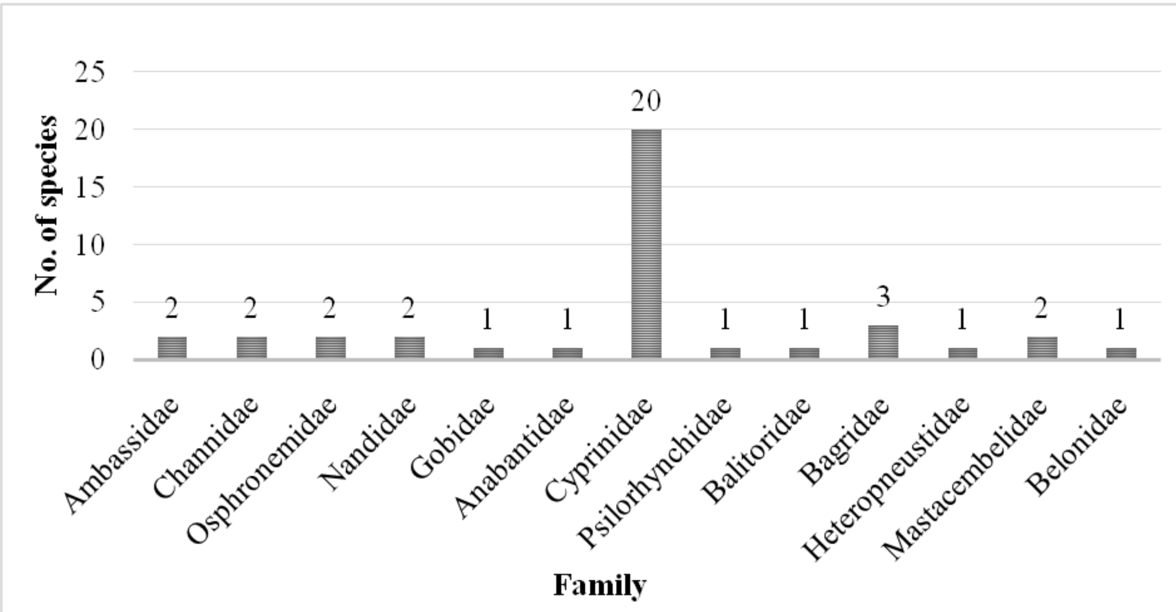
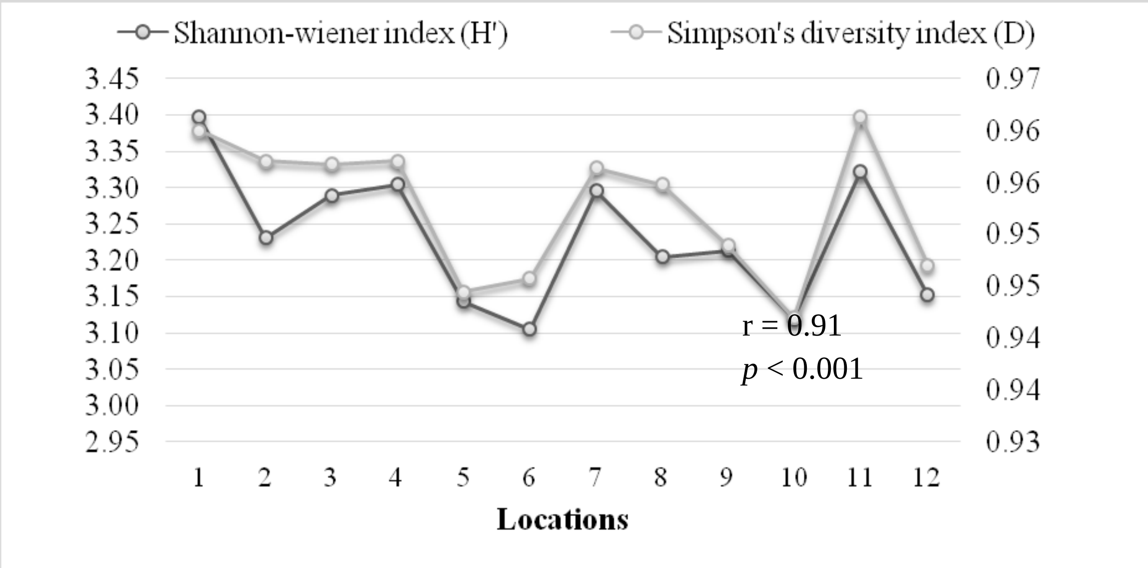


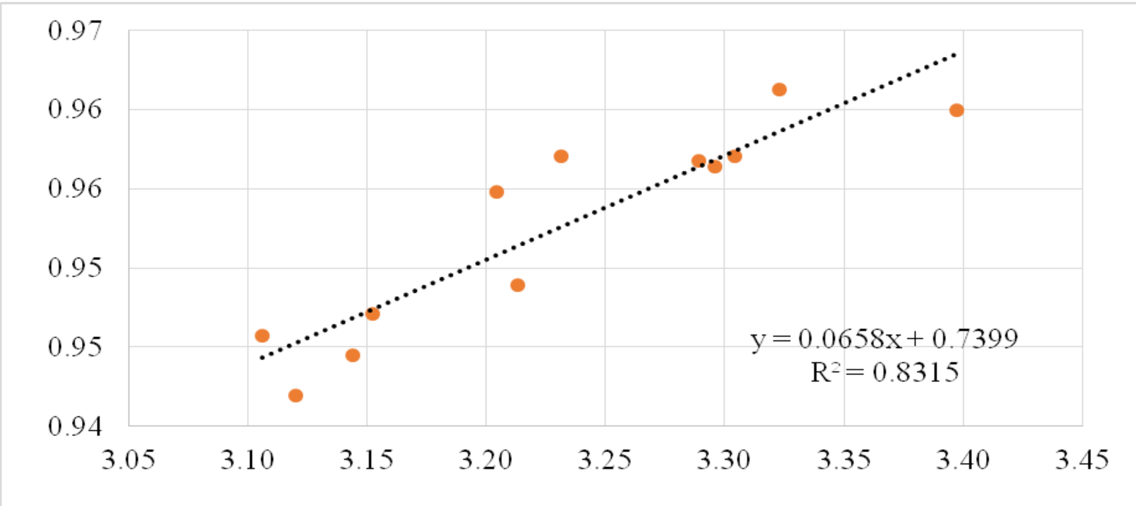
Fig. 3. Number of species of fishes belongs to different families. In this figure, the horizontal axis represents different families of the fishes which are found during our study and the vertical axis represents number of species. Cyprinidae is the most abundant family with a total species count of 20 followed by Bagridae with 3 species. Ambassidae, Channidae, Osphronemidae, Nandidae and Mastacembelidae each consist of 2 species. Gobidae, Anabantidae, Psilorhynchidae, Balitoridae, Heteropneustidae and Belonidae each consist of single species from the total fish species found during the study period

3.1 Economic Importance as Ornamental Fish

In this study, out of 39 fish species found, 29 are considered to be ornamental fish (Table 1) and have the potential to export. Domestication and captive breeding will add economic value. Although, Hill stream fishes are considered high-risk ornamental fishes due to their fewer survival chances in captivity but in a research conducted by Kumar et al. [33] reported that many hill-stream ornamental fishes can be domesticated and can be reared for trade. Domestication and captive breeding will bring ornamental fish culture as a suitable scope for the north-eastern states of India because of its rich ichthyofaunal diversity. It will also reduce the wild catch of these fishes as 85% of ornamental fishes exported from India are caught in the wild hilly regions of north-east India [34]. Educating and training local farmers and developing ornamental fish-oriented trade will add more value to the economy.



(A)



(B)

Fig. 4. (A) Shannon-wiener and Simpson's diversity index of fish along the collection site. The association between Shannon and Simpson's index was tested using Pearson correlation test, and the correlation coefficient (r) is 0.91. The *p* value is < 0.0001 and significant. (B) Scattered plot of Shannon-wiener and Simpson's diversity index shows strong correlation with R^2 value of 0.8315

3.2 Exotic Fishes

The invasion of exotic fish into the native ecosystem is considered a serious threat to freshwater biodiversity all around the globe [35,36]. Freshwater ecosystems are considered one of the most vulnerable ecosystems to invasive species [36,37]. *Trichogaster labiosa* which was found in the current study is treated as exotic ornamental fish in India. We have recorded during the study that exotic fishes like *Cyprinus carpio, Hypophthalmicthys molitrix, Ctenopharyngodon idella,* and *Puntius gonionotus* are also found in the study sites. These fishes are cultured in both commercial fisheries and household ponds by the people living nearby to the hill streams; however, no huge amount of export was recorded from these regions so far. The majority of residents around the sampling regions maintained household ponds known as "*pukhuri*" for domestic use in addition to gratifying the need for agricultural water necessities to conquer the water crisis in the non-rainy season. Furthermore, those ponds are simultaneously utilized to raise a variety of exotic species to satisfy domestic desire. During the monsoon, floods impact commercial fisheries and domestic ponds, and a huge number of fish enter into rivers and streams that have a direct connection to these hill streams. This is also supported by the findings of this study that exotic fishes were discovered in the lower stream points, but were absent in the upstream points. This kind of invasion results in a loss of taxonomic diversity [38].

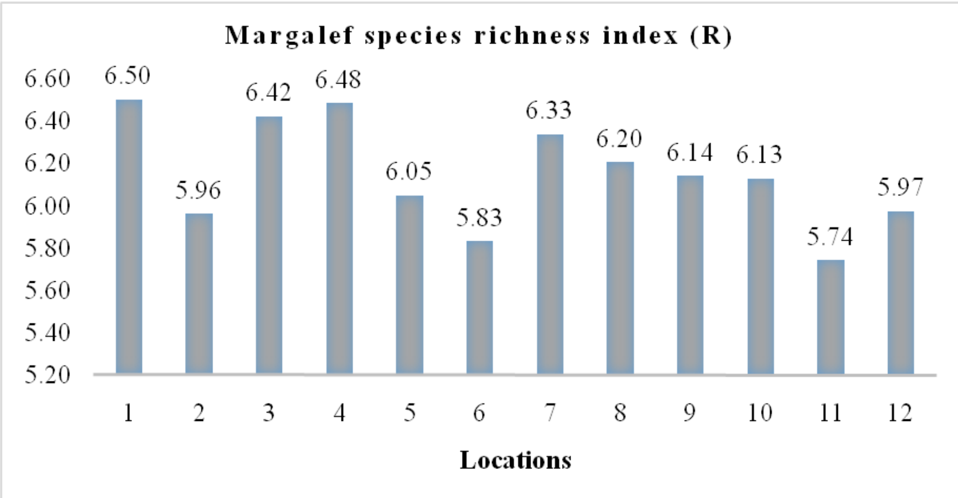


Fig. 5. Location wise Margalef species richness index (R). The range of R indicates that all cites are rich in species as R > 5.0

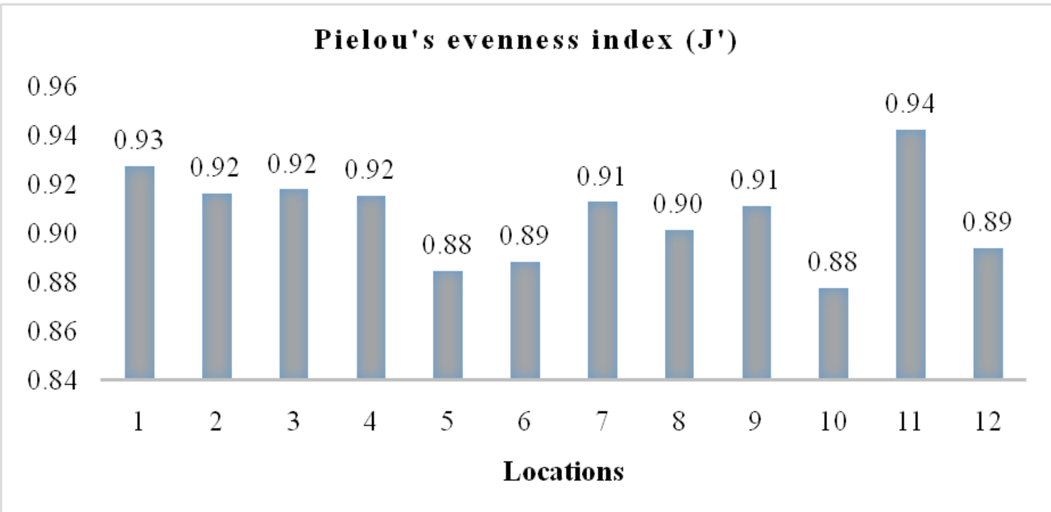
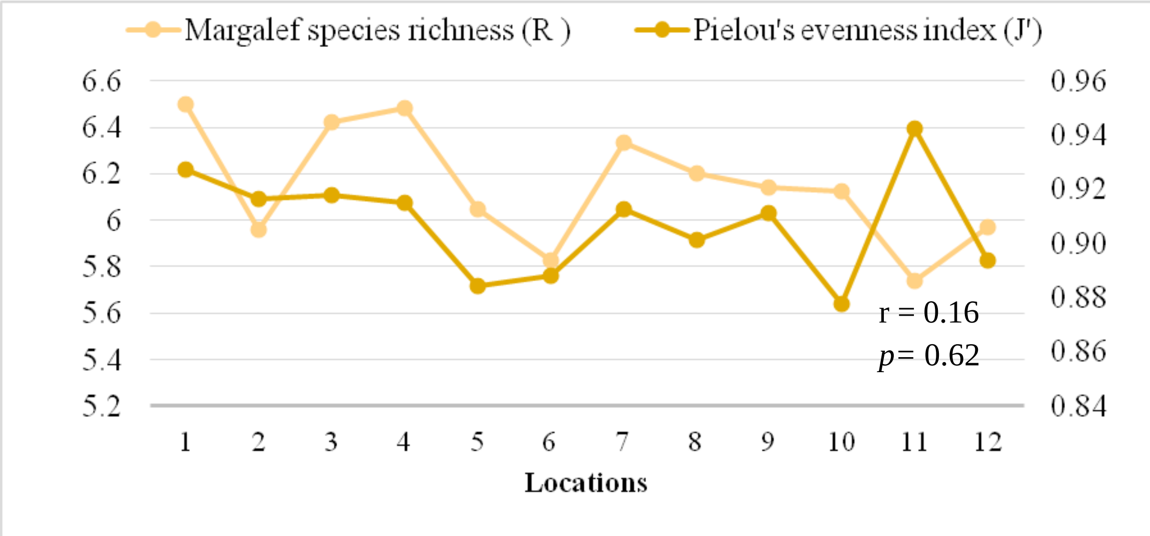
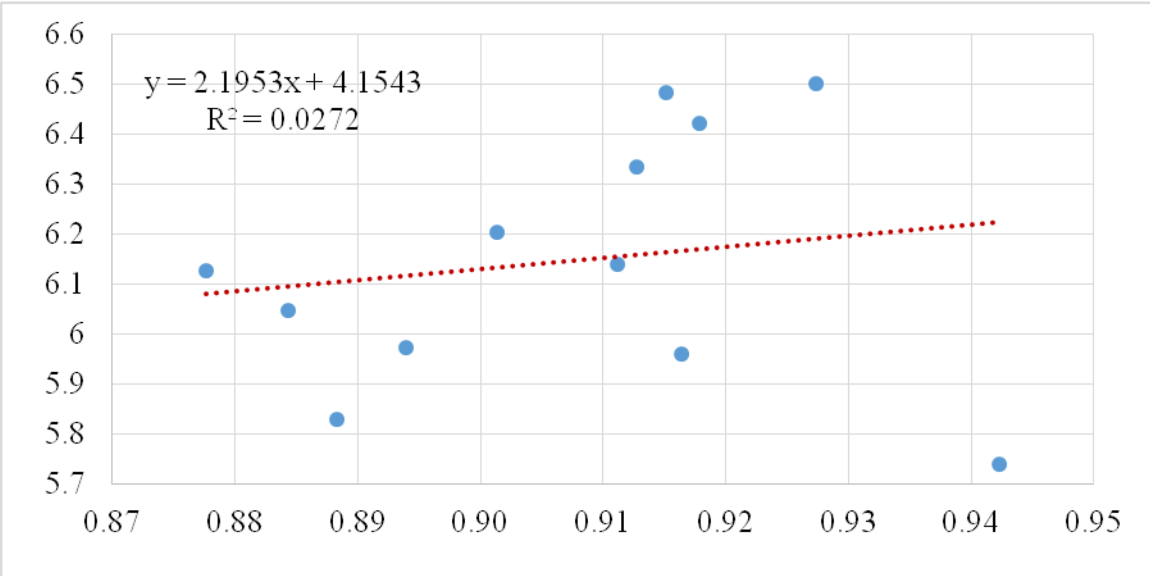


Fig. 6. Location wise Pielou's evenness index (J). The range of J indicates that all the studied cites have evenly distributed fish diversity



(A)



(B)

Fig. 7. (A) Species richness and Pielou's evenness index of fish along the collection site. The association between Species richness and Pielou's index was tested using Pearson correlation test, and the correlation coefficient (r) is 0.16. The *p* value is 0.62 and not significant. (B) Scattered plot of Species richness and Pielou's evenness index shows negligible correlation with R^2 value of 0.0272

3.3 Anthropogenic Impact on Hill Streams

During the investigation, significant human activities were observed in and around the study locations such as illicit fishing and the establishment of picnic areas. Anthropogenic activity possess a greater threat to diversity, impacting the ecosystem of these streams in the process. The development of the picnic as well as tourist spots have resulted in a rise in plastic waste, which is harming the natural environment of these streams. Human-driven activities have excessive pressure on rivers and it affects water quality [39] which has a direct impact on ichthyofauna. The anthropogenic activity exceedingly prompted the freshwater biodiversity and because of that, the balance in the environment is disturbed which ultimately results in the loss of aquatic ecosystem functioning [40].

The stream ecosystems and organismal diversity that exist in the streams are regulated by the riparian forest [41]. The good ecological condition of streams depends on forest cover in such a way that small-scale riparian deforestation in and around streams results in habitat degradation [42] and change in riparian forest structure can change the taxonomic diversity along with aquatic ecosystem functioning [41,43]. Due to the increasing human population, the demand for wood has also increased tremendously. Increasing riparian deforestation around the sampling location was noted during the study. Due to changes in riparian forest structure along the study area, the impact of earthquake-induced landslide is comparatively high on hill-stream ecosystems and it seems to have increased in the last few years. Study sites have (Himalayan region) high seismic activity due to the continuous movement of the Indian continental plate towards the Eurasian continental plate [44]. Due to this movement of these two lithosphere plates, geo-morphologically, Assam belongs to an earthquake-prone region (zone V) of high seismic activity [45]. Due to earthquake-induced landslides, the maximum amount of damage is suffered by the hill-stream ecosystem in the form of loss in aquatic space and in extreme cases, small streams will be completely blocked or vanished.

Development of tourism as well as picnic spots around the study area have economic benefits but also have the potential to influence the biodiversity of these hill streams considering vacationers and tourists are seen to apply plastic gadgets (polythene bags, Chips packets, meals wrappers, etc.) and throw them into the streams after use. Ingestion is the most serious concern posed by plastic pollution [46]. Plastic particles have the potential to damage fish intestines [47] and when fishes engulf an extra amount of plastic waste, it can block the intestine by accumulating in the gastrointestinal tract [17]. These anthropogenic activities have extended the danger to aquatic diversity and ultimately affected the ecosystem services of those streams. Especially, the development of picnic spots increased plastic waste which can be detrimental to the nature and composition of those streams.

4. CONCLUSION

Increased anthropogenic stress such as riparian deforestation, single-use plastic pollution, and excessive wild catch of ornamental fish has contributed to the decreasing aquatic wildlife and also has deteriorated water quality. The invasion of exotic fish into the ecosystem is also a foreseeable threat. We can conclude from the study that the investigated hill streams are rich in ichthyofaunal diversity and dispersed uniformly. The stream ecology and water quality are both in good shape. However, anthropogenic activity has recently increased, posing a potential threat to this environment. The wild catch of ornamental fish is one of the key difficulties that may be addressed by educating locals about ornamental fish culture and export. To reduce plastic pollution in these streams, quests can be shaped to prohibit the selling of plastic packets or unloading the contents of plastic packets into handmade paper bags there in the shop or at the entrance to these sites. A good disposal mechanism is also essential at certain tourist destinations to limit the number of plastic accessories in the hill streams. To safeguard this natural reservoir, the authority might implement measures to minimize or eliminate riparian deforestation.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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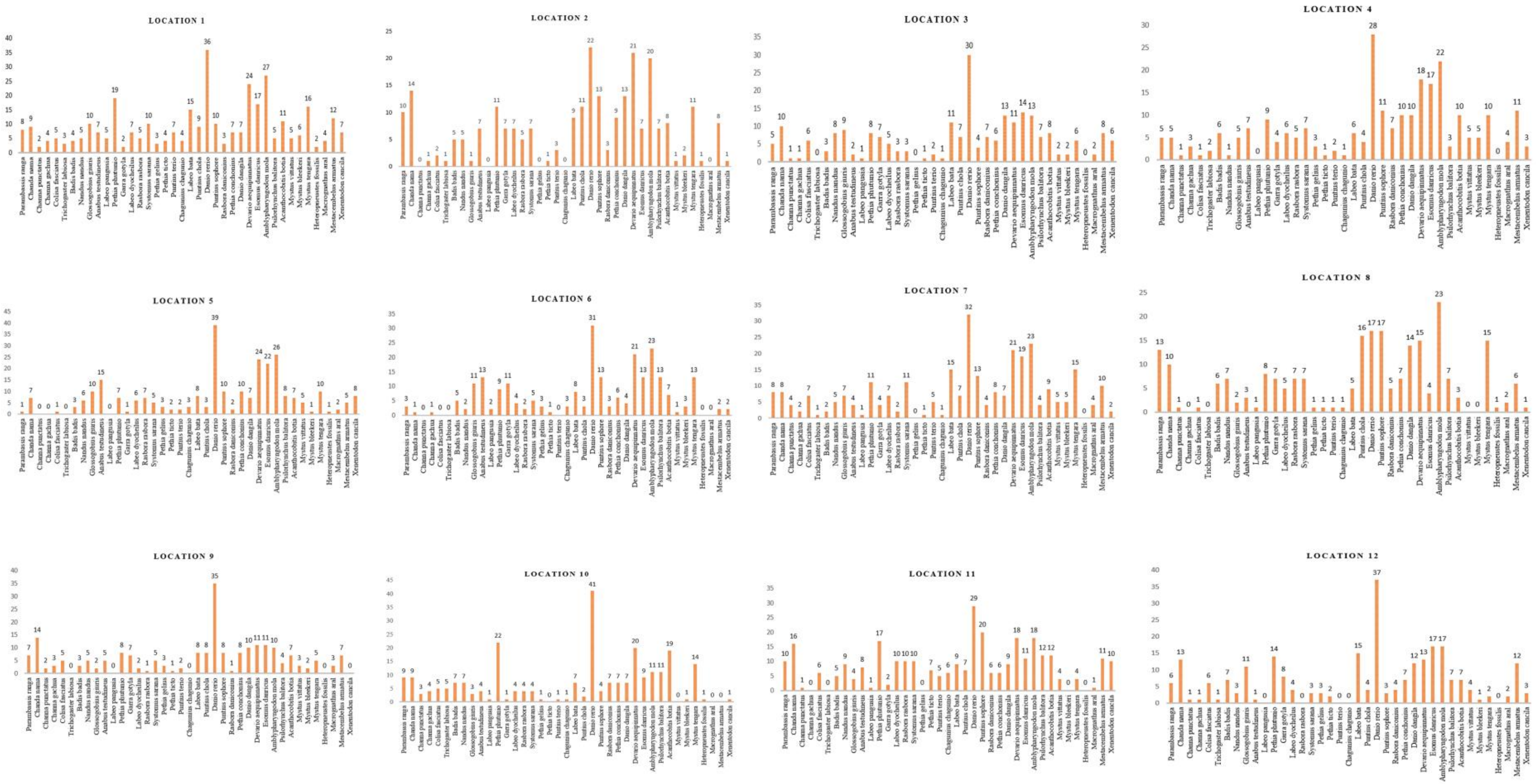

Supplementary Fig. 1. Number of individuals of each species collected from 12 collecting sites

Supplementary Table 1. Coordinates of the sampling locations

Location serial No.	Coordinates	
1.	26°47'28.23"N	91°28'13.80"E
2.	26°48'10.55"N	91°27'11.85"E
3.	26°48'19.00"N	91°26'17.69"E
4.	26°48'49.57"N	91°25'36.65"E
5.	(26°50'5.35"N	91°24'36.70"E
6.	26°48'37.35"N	91°24'19.74"E
7.	26°48'29.59"N	91°23'28.80"E
8.	26°47'26.17"N	91°22'17.21"E
9.	26°47'1.72"N	91°22'15.51"E
10.	26°46'49.32"N	91°22'10.24"E
11.	26°46'56.71"N	91°21'34.80"E
12.	26°46'11.47"N	91°20'15.53"E