



**Functional Diversity of Fish Species in
Panaha River, Gulmi District, Nepal**

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**Dissertation submitted in partial fulfillment of the requirements for the
degree of Master of Science in Zoology with special paper Fish Biology
and Aquaculture**

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Declaration

I hereby declare that the work presented in this dissertation “Functional Diversity of Fish Species in Panaha River, Gulmi District, Nepal” has been done by myself, and has not been submitted elsewhere for the award of any degree. All sources of information have been specifically acknowledged by reference to the author(s) or institution(s).



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Bishnu Panthi

Abstract

Functional diversity reflects functional characteristics and their responses to environmental changes. For the study, four season's data was taken in the Panaha River of Gulmi District, from April 2023 to January 2024. This research involved the analysis of functional diversity and detailed exploration of the interconnection between functional traits and environmental conditions. To determine potential variations among environmental conditions a one-way ANOVA was done. Species and environmental variables were analyzed through multivariate analysis, canonical correspondence analysis (CCA) and intra- traits relationships were evaluated using principal component analysis (PCA). The research shows a diverse aquatic ecosystem hosting 19 fish species from 4 different Orders and 6 Families, with a total of 836 individuals collected fish. Seasonal variations showed the highest species diversity in summer. *Schizothorax plagiostomus* (20.93%) and *Garra rupecula* (19.62%) were the most dominant species. Cypriniformes (74%) appear as the dominant order and Cyprinidae (53%) being the most species rich family. Comparative analysis on functional traits among the species shows *Mastacembelus armatus* as the largest species, while *Schistura* species was the smallest in measurement. Body shapes, position in water, caudal fin types, and mouth orientations appear diverse among the fishes. Canonical Correspondence Analysis (CCA) show the EC, velocity, temperature, width are highly associated and influence factors for change in fish functional traits. PCA provide interrelationships among morphological traits, indicating strong positive correlations among certain traits and negative correlations with some others. This study provides the essential information for maintaining healthy aquatic ecosystems and biodiversity in the region. Knowledge on functional diversity play key role for identifying particular important species, evaluating ecosystem health and increase conservation efforts.

शोध सार

कार्यात्मक विविधताले कार्यात्मक विशेषताहरू र वातावरणीय परिवर्तनहरूमा तिनीहरूको प्रतिक्रियाहरू प्रतिबिम्बित गर्दछन् । यस शोधकार्यको लागि २०८० सालको वैशाखदेखी पुषसम्म गुल्मी जिल्लामा पर्ने पनाहा खोलामा ४ मौसममा माछाका नमुनाहरू र पानीको भौतिक रासायनिक प्यारामिटर मापकहरूको संकलन गरियो । यस सोधकार्यले कार्यात्मक विविधताको परिमाणिकरण र छनोट गरिएका कार्यात्मक विशेषताहरू र वातावरणीय अवस्थाहरू विचको अन्तर्सम्बन्ध विस्तृत अन्वेषण समावेश गर्दछ । प्रजाति र वातावरणीय चरहरूलाई **Multivariate analysis** मा **Canonical Correspondence Analysis (CCA)** मार्फत विश्लेषण गरियो । अन्तर विशेषताहरूको सम्बन्ध मूल्याङ्कन **Principal Component Analysis (PCA)** मार्फत गरियो । यो अनुसन्धानले जम्मा ८३६ समातिएका माछाहरूमा १९ प्रकारका माछाहरू फरक रहेको देखायो । जसमा ४ फरक **Orders** र ५ **Families** रहेका माछाहरू पाइयो । मौसमि भिन्नताहरूमा गृष्म ऋतुमा उच्चतम प्रजातिका माछाहरू पाइयो । *Schizothorax plagiostomus* (२०.९३%) र *Garra rupecula* (१९.६२%) सबैभन्दा धेरै प्रजातिका माछाहरूमा देखिए । **Cypriniformes** (९.७४%) प्रमुख अर्डरको रूपमा देखा प्यो र **Cyprinidae** (९५.३%) परिवारमा सबैभन्दा धेरै प्रजातिको माछाहरू देखियो । प्रजातिहरू विचको कार्यात्मक विशेषताहरूको तुलनात्मक विश्लेषणले *Mastacembelus armatus* सबैभन्दा ठूलो र *Schistura species* सबैभन्दा सानो मापन देखायो । शारीरिक आकारहरू, बासस्थान प्राथमिकताहरू, पुच्छरको प्रकारहरू र मुखको बोटमा माछाहरू विच विविधता देखियो । प्रजाति र वातावरणीय चरहरूको सम्बन्ध देखाउँदा माछाको कार्यात्मक विशेषतामा परिवर्तको लागि ईसी, वेग, तापक्रम, चौडाइ अत्यधिक प्रभाव कारकहरू हुनसक्छन् भन्नी देखायो। शारिरिक विशेषताविच सम्बन्ध देखाउँदा कोहीसँग सकारात्मक सम्बन्ध र कोहीसँग नकारात्मक सम्बन्ध देखायो । यस अध्ययनले यस क्षेत्रमा स्वस्थ जलिय पारिस्थितिक प्रणाली र कार्यात्मक विविधताको ज्ञानले विशेष महत्वपूर्ण प्रजातिहरूको पहिचान गर्न, पारिस्थितिक प्रणालीको स्वस्थ मूल्याङ्कन गर्न र संरक्षण प्रयासहरू बढाउन मुख्य भूमिका खेल्दछ ।

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List of abbreviations

Abbreviated form	Details of the Abbreviations
ADB	Asian Development Bank
ADP	Agricultural Development Project
BD	Body Depth
BW	Body Weight
B width	Body Width
CCA	Canonical Correspondence Analysis
CFL	Caudal Fin Length
DFL	Dorsal Fin Length
ED	EY Diameter
FD	Functional Diversity
FL	Fork Length
LC	Least Concern
NT	Near Threatened
PCA	Principal Component Analysis
SL	Standard Length
TL	Total Length
VDC	Village Development Committee
VU	Vulnerable

1. Introduction

1.1 Background

Fish are a diverse group of animals that inhabit various aquatic environments. They are essential for maintaining the balance of ecosystems and providing crucial nutrients for the human population (Levêque, 2018). Their capacity for distribution covers a wide range of ecological niches, reflecting their unique adaptations (Nguyen, 2015). Fish play an crucial role for human communities and global biodiversity, serving as essential food security, cultural value, and ecological balance (Martina Meinam et al., 2023).

The climate of Nepal encompasses three types of fish, including extremely cold fish in the Himalayan region, cold-water fish in the central hilly region, and hot-water fish in the Terai region (Mishra & Baniya, 2016). With more than 6,000 small rivers and three main river basins Koshi, Gandaki, and Karnali along with their tributaries, streams, lakes, ponds, reservoirs, and wetlands, Nepal serves as a major hotspot for aquatic biodiversity (Sharma 2008) and offers an ideal freshwater aquatic environment for the survival of aquatic animals and plants, including freshwater fish and aquatic life (ADB, 2018).

Early researchers, such as Hamilton (1822), provided the first significant references to the fishes of Nepal in "An Account of the Fishes Found in the Ganga and Its Tributaries." Other national and international researchers have also made early premier efforts to uncover th7 species. Shrestha (2001) reported 182 fish species. In 2013, that number was increased to 228. Rajbanshi (2005) reported 187 species. Shrestha latest update in 2019 shows there are now 252 fish species in Nepal. Recently in his book "Ichthyology of Nepal" documented 236 native species and 16 exotic fish species in different river of Nepal. Ichthyofaunal diversity of Nepal (ADP, 2014) and later Early researchers mainly focused on taxonomic classification and community structure analyses. Although these methods have yielded insightful information about the distribution and composition of fish species, they frequently fail to capture the functional elements of biodiversity (Mouillot et al., 2014).

Recent years have observed the development of new techniques for measuring diversity that more precisely reflect various aspects of species' roles within ecosystems and, consequently, assemblage functional structure (Mason et al., 2012). This approach is acknowledged as a more accurate approximation than traditional diversity indices for evaluating the dynamics of species assemblages (Lefcheck & Duffy, 2015). Functional

diversity refers to a variety of characteristics, actions, and ecological functions that support the general composition and operation of aquatic environments (Mason et al., 2012). This includes habitat preference, eating patterns, and reproductive techniques, among other functional features that affect how different species interact with one another and react to environmental changes. According to Díaz and Cabido (2001) functional diversity (FD), characterized as the range of ecological responsibilities and related characteristics within a biological community, has gained popularity as a critical indicator for comprehending ecosystem dynamics. A growing body of research points to FD as a crucial component of ecosystem (Granado-Lorencio et al., 2021). Several methods have been proposed to describe a community's functional diversity, but the best ones are up for debate.

To measure each aspect of FD in a community with species distributed in multidimensional functional spaces, three indicators have been constructed: functional richness, functional evenness, and functional divergence (Mason et al., 2012). Functional richness represents the quantity of functional space occupied by the community. Ecologists typically view them as sign of potentially exploited or underutilized niche area, means of preventing invasions (Mason et al., 2005). The number of species existing naturally has a positive correlation with functional richness (the more species present, the bigger the functional space occupied when species features are relatively randomly distributed). Functional richness may be different if there is two communities have same number of species. low Functional richness reduces ecosystem production, suggesting that certain potentially useful resources are underutilized due to fewer species inhabiting a given niche (Goswami et al., 2017). Functional evenness describes the evenness of abundance distribution in a functional trait space. Functional evenness indices quantify whether mean species traits are distributed regularly within the occupied trait space, that is, with equal distances between nearest neighbors and equal abundances. Functional evenness indicators are typically used to show if resources are being used too little or too much, which affects productivity, dependability, and invasion vulnerability (Mason et al., 2005). The derivation of this index group takes species abundances into account. Lastly, FD indices quantify the variation in the functions of the species and the location of their clusters in trait space; a high FD results from species and/or abundances being grouped together at the boundaries of the traits' space. According to Mason et al. (2005), FD indices may be used to show the degree of resource divergence and competition, but they

can also show the preponderance of extreme species. FD uses species abundances in its computation, much like functional evenness does.

The characteristics, feeding ecology, reproductive techniques, and habitat preference that may influence how a species behaves within a community is another facet of functional diversity (Baptista et al., 2021). Fish feeding ecology is one component of their functional diversity. Fish use a variety of feeding techniques, including filter feeding and scavenging, in addition to their herbivorous, omnivorous, and carnivorous diets (Villéger et al., 2017). Fish species interactions in tropical environments are essential for controlling food webs and energy flow in ecosystems. For instance, the existence of piscivorous fish may regulate the quantity of tiny fish species, affecting the community's overall structure (Horn & Ferry-Graham, 2006). The functional variety of fish species is also significantly influenced by the diversity of their reproductive methods. For example, some species have short generation periods and high fecundity, while others have low fecundity and provide their offspring greater parental care. Population dynamics and resilience to environmental change are influenced by variables found in life histories, such as age at maturity, reproductive output, and spawning behavior (DeMartini & Sikkel, 2006). Fish species' varied preferences for habitats contribute to functional diversity. Various species have evolved to flourish under certain environmental circumstances, such as water flow, substrate type, and temperature. Certain fish participate in ecosystem engineering practices, such as constructing nests or altering the substrate, which can have a domino effect on other species as well as the physical structure of the environment (Teresa & Casatti, 2012) .

The water of Panaha River of river is generally clear, except during the rainy season. Geologically, the steep gradient upstream results in higher water velocity compared with the plain areas downstream. Upstream, the riverbed is dominated by large boulders and rocks, whereas downstream, cobble, pebble, gravel, and sand are the predominant components of the riverbed. The river is narrow and flows rapidly, creating canyons or gorges in certain places. It follows a meandering path, resembling a snake, as it flows from the northeast of the district to the southwest, enriching various locations such as Sirseni, Bajhketeri, Wagla, Bhanbhane, Dhurkot Nayagaun, Simaght and eventually confluence with the Childi River. This combined river is collectively named Chaldi Panaha River, and it ultimately joins the Badighat River near Parlami VDC.

1.2 Statement of problem

Fish diversity is experiencing a rapid decline, adversely affecting the morphological and physiological status of various species. This decline is due to multiple disturbances, including dam construction, water pollution resulting from chemical contamination, climatic changes, overfishing, illegal fishing, and the extraction of riverbed materials for construction (Sultana et al., 2022). These disturbances can alter the functional diversity of ecosystem by eliminating certain functional groups. Comprehensive research that measures functional diversity in a broad range of ecosystems, pinpoints the essential functional characteristics and ecological roles that support ecosystem functioning, how functional diversity reacts to different environmental stimuli, and investigates the effects of shifting functional diversity on ecosystem services and human well-being is essential. In order to maintain biodiversity and ecosystem functioning in face of environmental change, conservation initiatives, ecosystem management techniques, and policies that support these activities depend heavily on research of this kind.

1.3 Objectives

1.3.1 General objective

- To investigate the functional diversity of fish in Panaha River, Gulmi District, Nepal.

1.3.2 Specific objectives

- i. To explore the diversity of fish.
- ii. To analyze the distribution of fish species by order and family.
- iii. To explore the relationship between functional traits of fishes with environmental conditions.

1.4 Significance of the study

While many studies have been conducted on large fish species in the major larger rivers of Nepal, there is small and lack of investigations in smaller rivers and tributaries. Many researchers have mainly focused on the diversity of fishes among different ecosystems. Recently, research efforts had been centralized around the culture fishes for economic purpose. However, limited attention has been paid to the functional aspects of fish ecology, including how morphological traits, habitat preferences, and geographical locations vary among fish species. There is a lack of understanding regarding the ecological roles that fish play within their environment. This study served to explore the relationship between fish diversity, functional traits and relationship with the environmental variables. Furthermore, the research established baseline data on the species inhabiting this river, contributing valuable insights for the conservation of fish species.

1.5 Limitations of the study

While the study has provided valuable information on functional diversity of the Panaha River of Gulmi, district. The Functional traits examined were limited and other important traits such as feeding habits, reproductive strategies or physiological adaptations were not considered. Beside that some lacking of fishes to capture in non accessible areas, not collecting all the species that are present in the river. Moreover, accurately identification of collected *Schistura* species with an average BW 1.2 gm, TL 53.1 mm, FL 49.6 mm, SL 45.3 mm, HL 8.15 mm, SL 3.6 mm, ED 1.4 mm, were challenging. Despite that we classified this species as *Schistura* based on its color pattern, mouth orientation, and position in the water column. However, accurate identification was impeded by the intricate color patterns on its body and forked type of caudal fin were some challenges arise during the study carried out periods.

2. Literature Review

Alteration of ecosystem is the one of the major problems and growing concern to the biologist (Louis & Métallique, 1940). Rapid deterioration of water quality, overexploitation of the environmental and its habitat destruction and degradation (including the invasion of alien species and alternation of natural flow patterns of aquatic system, climatic change and over harvesting of fishes) significant decline in the species diversity and abundance of stream fishes (Shrestha, 2008; Vaughn, 2010). With high extinction rate there is less evidence of lessening towards the conservation efforts (Brooks et al. 2013). One way to improve conservation efforts is to study the relationship between their traits and environmental variables (Keck et al., 2014). Many researchers have adopted the concept of functional diversity approach for the study of what changes the variation among the species for the conservation prospective. The functional diversity relates to any characteristic at the individual level that might determine and impact how a species uses resources and interacts with other species, and it is often seen as a practical description of their potential niche (Gagic et al., 2015).

Numerous studies have examined the connection between fish functional characteristics and water factors, illuminating the intricate relationships between fish ecology and environmental conditions. Rubio-Gracia et al., (2020) describe body size, metabolism, morphology and their interrelationships influence intraspecific and interspecific variation in fish swimming performance through an study on eight freshwater species. Baptista et al. (2021) study suggest that environmental factors, particularly temperature and chlorophyll-a levels, were correlated with specific distributions of traits within fish communities. Acar and Kaymak (2023) highlights how both plastic responses to divergent selective and restricted gene flow due to habitat fragmentation can lead to morphological and ecological divergence in endemic fish populations, even at small spatial scales. Barlow (1961) review suggest that meristic variation can arise and become genetically reinforced thorough adaptive divergence between population. A. A. Pease et al. (2015) study the relationship between the functional traits of stream fish assemblages and both local environmental factors and find the significant associations between functional traits and environmental variables.

According to the research conducted by Mitra (2023) rising water temperature is linked to modifications in the time of spawning event and shifts in the reproductive habits of specific fish species and highlighted metabolic rates increase with higher water, affecting

the energy budget of fish species. This has implications for predicting how the fish population may respond to climate-induced temperature changes. Emmrich et al. (2014) also reported that the temperature is the common factor for the driven geographical patterns in body-size structure of European lake fish assemblages, mediated by both changes in taxonomic composition and intraspecific size.

Carrington (2021) found the result significantly different results, the deep and slow - water system. The deep sea had higher functional richness for habitat use and locomotion traits, lower functional dispersion for feeding and lower functional evenness for life history. Madgett et al. (2023) compared the functional diversity of fish assemblages in the vicinity of oil and gas pipelines compared to nearby natural reef and soft sediment habitats and found that, the pipeline and reef habitats shared a more similar functional composition and contained key functional groups required for the development and maintenance of healthy coral reef systems. Essential functional groupings are needed for the growth and upkeep of healthy coral reef systems. The habitat with the highest functional variety was the reef habitat, which was followed in order of importance by the soft sediment and pipeline habitats.

Ribeiro (2016) reported a strong correlation between functional traits and habitat structure. Compression index, relative depth, index of ventral fluttering, relative area of pectoral fin, pectoral fin aspect ratio, Relative composition and fitness coefficient are found strongly associated with stream habitats. Carpenter-Bundhoo et al.(2023) revealed that fish species exhibited distinct behaviors in response to varying flow regimes. for streamlined body shape were more prevalent in species inhabiting areas with higher flow velocities indicating the importance of flow dynamics as a selective pressure shaping fish morphology and behavior. Zhang (2020) found that anthropogenic factors such as pollution and habitat degradation were identified as key drivers of functional diversity changes. Santos (2020) found that variation in pH influenced the distribution patterns of acid-tolerant and acid-sensitive species. Zhang (2021) reported that species and functional richness varied significantly along environmental gradients where as functional evenness and divergence was weakly correlated with environmental variables. This study analyzed fish tropic traits and assessed changes in species richness and functional diversity. It identified vulnerable resident fish with specific characteristics. Fish assemblages showed low redundancy, possibly due to tropication. Increases in trait richness and dispersion indicate functional roles. Pease (2012) found that the functional diversity of assemblages increased with species richness along the gradient from upland to lower lands.

Swimming, habitat preference, and food resource utilization traits were linked to environmental variables at both the local (such as substrate type) and large-scale (such as forest cover) levels.

The functional diversity of fish has been observed to vary along environmental stress gradients. Vileger (2010) assessed multiple FD indices across 88 European lakes and found loss of thermal specialist species reduced functional richness while pollution favored morphological generalists. Using simulations of species loss, Schleuter (2010) predicted the highest decline in functional richness due to random extinction of specialized pelagic and benthic sucking fish in German streams. Declining functional diversity indicates diminished ecological functions and lower ecosystem resistance against further disturbance (Tilman, 2001). However, geographical differences exist in functional diversity relationships. Using a traits database of freshwater fish Pool (2010) predicted contrasting patterns of change in functional richness versus functional evenness in Canadian and European fish fauna in response to drivers such as climate change. The Context-dependency of diversity-function links needs to be investigated further (Cadotte, 2011). Overall, functional diversity reveals non-random community assembly processes and improves the understanding of ecosystem functioning.

3. Materials and Methods

3.1. Study Area

This study was conducted in the Panaha River of Gulmi district, situated approximately 28 km from Tamghas, the headquarters of Gulmi. Gulmi is one of the six districts of the Lumbini zone, located within 27°06'05" to 28°02'07" north latitude and 83°01'00" to 83°03'05" east longitude. The elevation of the district ranges from 610 m to 3,050 m. The climate in this area is influenced by the southeastern monsoon wind, leading to three main types of climatic conditions: cool temperate climate, temperate climate, and subtropical climate. The major rivers in the Gulmi district include Badigad, Chaldi, Daram, Hugdi, Kaligandaki, Nisti, and Ridi (Chhetri et al., 2020).

The Panaha River originates from the Marbung Madhane hill in the Mahabharat Range, situated at 28°13'03.15"N latitude and 83°05'.07"E longitude, with an elevation of 1783 m above sea level. It is a perennial and torrential river, measuring an estimated 41 km in length. The riverbanks support diverse vegetation, including simal, chilaune, katush, rhododendron and uttis trees, along with ferns and (*Eupatorium cannabinum*). In some areas, there are small groves of pine trees and patches of grass known as khar which, when dried form are used to make roofs for houses and serve as long-term fodder for cattle.

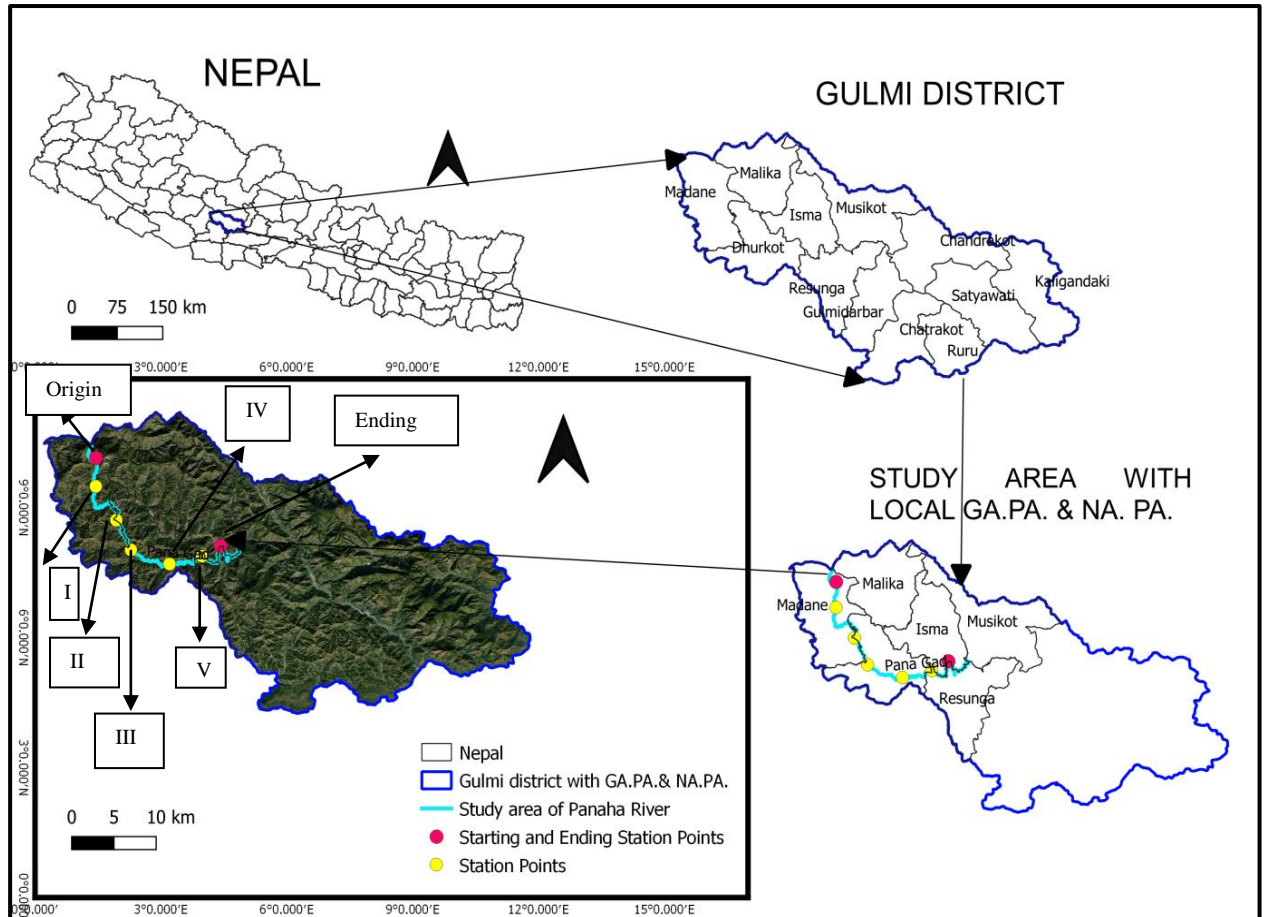


Figure 1. Study area of the Panaha River in Gulmi District

3.2. Selection of the sampling site

Before selecting the sample site, a preliminary survey was conducted with local fishermen. To achieve the objective of the study, five sampling sites were chosen considering factors such as human disturbance and settlement area, agriculture fields, forest coverage and confluences with other tributaries.

Station I (Sirsani)

Station I was located in Sirsani village at coordinates $28^{\circ}10'34.47''\text{N}$ latitude, $83^{\circ}04'57.71''\text{E}$ longitude, with an elevation of 1330 m. This station is characterized by large agricultural land and human settlements, extending up to 6 km from its origin.

Station II (Lahata)

Station II was situated at Lahata, it lies at $28^{\circ}7'01.11''\text{N}$ latitude $83^{\circ}07'22.27''\text{E}$ longitude, with an elevation of 1181 m and covering a distance of 8km form the first station. This station is characterized by a larger forested area.

Station II (Bhanbhane)

Station III is situated in **Bhanbhane** village with coordinates of 28⁰7'01.11"N latitude 83⁰07'22.27"E longitude, and an elevation of 1088 m. This station covers the 7 km distance from the second station and covers significant upper agriculture area. It marks the confluence of small tributaries of the Okharane River.

Station IV (Nadee)

Station IV is located at **Nadee**, with coordinates of 28⁰5'40'.5"N latitude 83⁰10'15.49"E longitude and an elevation of 976 m. This station covers a distance of 7 km from station III and this station is characterized by an expansive forested area.

Station V (Simaghat)

Station V is located at **Simaghat** at 28⁰06'25'.02"N, latitude 83⁰12'35.38"E, longitude with elevation of 908 m. This station is extending 8 km from station IV and 5 km from the confluence of rivers at Chaldi Rivers. This station faces more disturbances due to sand and stone mining along the river belt compared to the other stations.

3.3. Study Period

The fieldwork was conducted in four seasons (Spring, Summer, Autumn, Winter) between April 2023 to January 2024. Sampling was carried out at regular intervals during each season in April, June, September and January to collect the seasonal fish and environmental conditions.

3.4. Sample collection

The fish was collected with the assistance of fisherman. Sampling was done from upstream to the downstream of the river, spanning from 7 am to 11 am and from 2 pm to 5 pm excluding the winter season while sampling was done from 11 am to 4 pm. Cast net, with mesh size (1*1 cm) were used to collect fish samples. Cast net was thrown at intervals of around 10-20 meters away, each throw takes 2-3 minutes to recover. The gill net (1.5 *1.5 cm) mesh size was placed in different area of the sampling site and recovered after 1 to 2 hours interval of time or in the morning 11-11:30 am next day, if it was fixed in late evening. Fish that were not captured by cast and gill nets were captured by diversion of river channel "Dwalo thonne", using Bhurali jal for small fishes, and using bamboo trap. The bamboo trap was placed at the narrowest area of the running water, placing the wide mouth in the upward direction.

3.5. Preservation and identification of specimens

The collected fish samples were photographed, counted and recorded after the collection. The collected samples were labeled with vernacular name with help of fisherman and site. For biometric analysis fish samples were stored in appropriate bottles with a 10% formalin solution. After the biometric measurement fish sample were deposited in the Museum of Central Department of Zoology. The identification of collected fish samples were done by using fishbase.org and with the help of standard identification keys developed by Shrestha (2019), Talwar and Jhingran (1991).

3.6. Measurement of Functional Traits

Functional traits such as standard length, total length, fork length, head length, snout length, eye diameter, caudal fin length, pectoral fin length, dorsal fin length, body width, and body depth were measured for understanding how fish respond to their environment. These traits play a vital role in various aspects of a fish's life then other functional traits, including locomotion, feeding, and habitat utilization as describe by (Baptista et al., 2021; Ford & Roberts, 2019; A. A. Pease et al., 2015; Walsh et al., 2022). Additionally, traits like caudal fin types, mouth orientation, position in the water column, and body shape are also recorded which are also important indicators how fish interact with their surroundings. Digital weighing balances were used for measuring body weight and digital vernier calipers for morphological trait measurements. The fish were dried using blotting paper before weighing. Among total individuals fish collected, some were collected in higher number and some were collected lower in numbers. For functional traits measurements, species with higher abundance were measured using at least five individuals, covering different size within the species. On the other hand, species with lower abundance were measured by a minimum of two individuals from each station where they were found across all seasons.

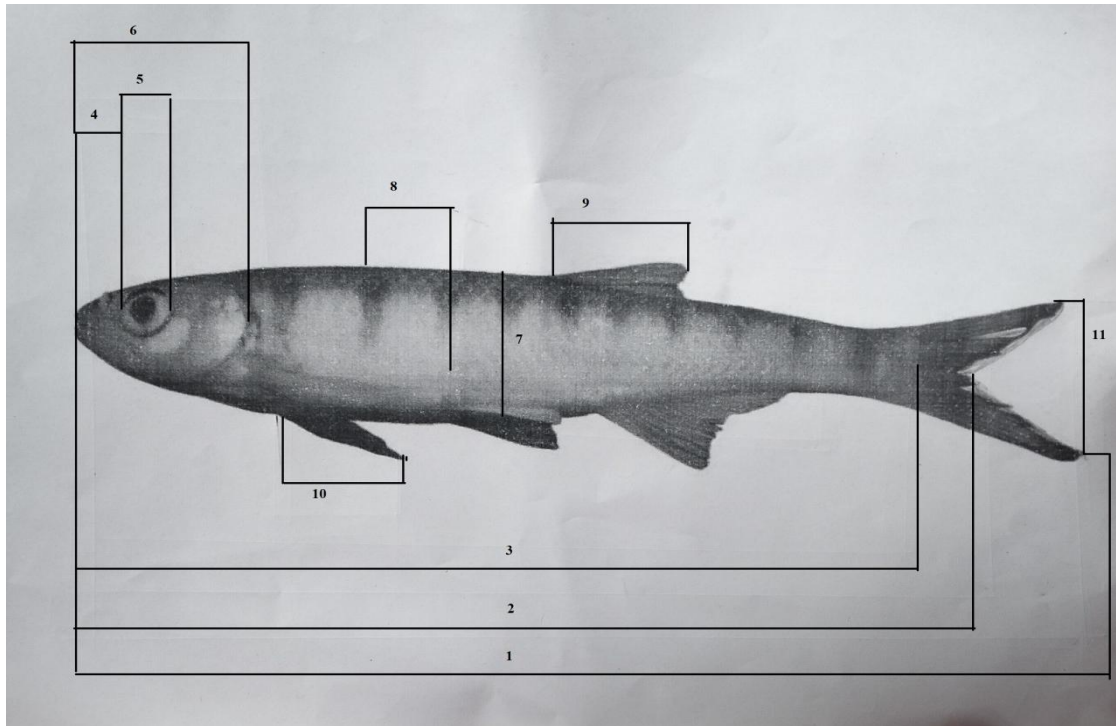


Figure 2. Measurement of Functional trait

Where,

1. Total length, 2. Fork length, 3. Standard length, 4. Snout length, 5. Eye diameter
6. Head length, 7. Body width, 8. Body depth, 9. Dorsal fin length, 10. Pectoral fin length
11. Caudal fin length

3.7. Physicochemical parameters

Various physicochemical parameters related to water quality were measured, following the standard protocols in each sampling site. The parameters were measured in sampling site during data collection. Physicochemical parameters include the calculation of pH, temperature, CO₂, hardness, TDS and EC.

a) Temperature

A calibrated digital thermometer was used to measure the water temperature. The thermometer was dipped in the water at least 4 inches below the surface. After some time, when reading reached a stable temperature, the reading was noted in degree Celsius.

b) pH

The pH was measured with the help of a digital calibrated pH meter (Model HI 98106 (Champ®)). The pH meter electrode was submerged and when reading reached stable after some time, and the pH value was noted.

c) Free carbon dioxide CO₂

For calculation of free carbon dioxide, 100 ml of water was taken in a conical flask. A few drops of phenolphthalein were added. The occurrence of pink color after the addition of phenolphthalein indicates the absence of free CO₂. The colorless solution indicates the presence of free CO₂. The solution was then titrated against the 0.05 solution of NaOH which was filled in burette. The end point is indicated by the solution's color changing from colorless to pink. This process was repeated three times and the average value was recorded. The free CO₂ in given sample is calculated by following formula.

$$\text{Free CO}_2 = (\text{ml} * \text{N of NaOH} * 1000 * 44) / V$$

Where, V=Volume of the water sample in milliliters.

d) Dissolved oxygen (DO)

The dissolved oxygen concentration was determined using the data obtained from the digital pen-type intelligent dissolved oxygen analyzer model (D.O Meter-DO9100). The Do meter provides instantaneous readings in percentage later percentages were converted into the in milligrams per liter (mg/L).

e) Total dissolved solute (TDS) and electrical conductivity (EC)

The TDS and EC of the water sample were calculated using the digital TDS and EC Sensors. This digital sensors connected to a microcontroller were immersed in water sample, and readings were recorded instantaneously. The digital TDS sensor provides readings in parts per million (ppm), whereas the EC sensor provides measurements in micro siemens per centimeter (μS/cm).

f) Hardness

For the determination of water hardness, 100 ml of a water sample was placed in a conical flask. Subsequently, 1 ml of hardness buffer was added to the solution, followed by the addition of 1 ml of sodium sulfide and a pinch of ferrochrome black-T indicator to the same solution. The solution turned wine red in color. The burette was filled with standard EDTA, and the mixture was titrated slowly with continuous stirring until the reddish tinge disappeared from the solution. Under normal conditions, the color of the solution at the endpoint was blue. The volume of EDTA used was then recorded.

The total hardness was calculated using the following formula:

Total Hardness (mg/l) = $((V \times 1000) / \text{Sample volume})$

Where, V is the volume (in ml) of the EDTA titrant.

g) Depth

The bottom substrate of the river was clearly seen by the eye that's why the depth of river was measured using a long bamboo. The bamboo was submerged in the water, and upon reaching the riverbed, it was carefully pulled back. The length of the rod that made contact with the river bottom was then measured. Repeating the above step in several points across the width of river to get a representative depth of different area of the depth measuring site. At last all the recorded reading were averaged and divided by the total number of measurements taken. Final reading was noted.

h) Width

For calculating the river width, a measuring tape was used at each sampling site. The measuring tape was extended across the river, and the distance between the two points where tape touched the opposite banks was measured.

3.8. Data analysis

To overview the central tendency and variability of data, mean and standard deviation was calculated for each species functional traits measurement. To determination of the appropriate statistical test on the results of normality assessments, conducted the Shapiro-walk test. To examine potential variation over space and time a one-way analysis of variance (ANOVA) was used for temperature, pH, dissolved oxygen, hardness, and water velocity. To determine which means were significantly different at the 0.05 level of probability, a Posthoc Tukey HSD test was used (Spjøtvoll & Stoline, 1973). Samples by species and environmental variables were analyzed through a multivariate analysis in R-software (Oksanen, 2015). The direct multivariate ordination method (Legendre & Legendre, 1998) based on a linear response of traits to environmental gradients was applied. To test the intra-traits relationship within functional traits, Principal Component Analysis (PCA) was performed in past software.

4. Results

4.1 Diversity of fish

A study in Panaha River revealed the presence of a diverse aquatic ecosystem, hosting a total 19 different fish species. These species were taxonomically distributed across 4 Orders (Cypriniformes, Anabantiformes, Siluriformes and Synbranchiformes) and 6 families (Cyprinidae, Nemacheilidae, Channidae, Sisoridae, Mastacembelidae and Amblycipitidae). Among them 14 species are least concern (LC), 3 species are Vulnerable (VU) and 1 species is near threatened (NT) according to the Global Red List Categories (<https://www.iucnredlist.org/>) (Table 1).

Table 1. Fish Diversity of Panaha River with Order, family, local name and IUCN status

Sn	Order	Family	Name of Species	Local Name	IUCN status
1	Cypriniformes	Cyprinidae	<i>Schizothorax plagiostomus</i> (Heckel, 1838)	Asla	VU
2			<i>Garra gotyla</i> (Gray, 1830)	Buduna	LC
3			<i>Garra annandalei</i> (Hora, 1921)	Buduna	LC
4			<i>Garra lissorhynchus</i> (McClelland, 1842)	Buduna	LC
5			<i>Garra rupecula</i> (McClelland, 1839)	Buduna	LC
6			<i>Barilius bendelisis</i> (Hamilton, 1807)	Faketa	LC
7			<i>Barilius vagra</i> (Hamilton, 1822)	Faketa	LC
8			<i>Barilius barila</i> (Hamilton, 1822)	Faketa	LC
9			<i>Neolissochilus hexagonolepis</i> (McClelland, 1839)	Katale	NT
10			<i>Naziritor chelynoides</i> (McClelland, 1839)	karanga	VU
11			<i>Schistura rupecula</i> (McClelland, 1838)	Gadela	LC

12			<i>Schistura multifasciata</i> (Day,1878)	Gadela	LC
13		Nemacheilidae	<i>Schistura fasciata</i> (Lokeshwor and Vishwanath, 2011)	Gadela	LC
14			<i>Schistura</i> species	Gadela	
15			<i>Channa punctata</i> (Bloch,1793)	Charanga	LC
16	Anabantiformes	Channidae	<i>Channa orientalis</i> (Bloch and Schneider,1801)	Charanga	VU
17		Sisoridae	<i>Pseudecheneis eddsi</i> (H.H. Ng, 2006)	Kabre	LC
18	Siluriformes	Amblycipitidae	<i>Amblyceps mangois</i> (Hamilton,1822)	Lama junge	LC
19	Synbranchiformes	Mastacembelidae	<i>Mastacembelus armatus</i> (Lacepede,1800)	Bam	LC

4.1.2 Distribution and Frequency Occurrence of fish.

The present study conducted in the Panaha River, resulting in the collection of a different fish species. A total 836 individual fish, belonging to different species were collected from five different stations along the river. The data reveals that station I yielded 10 species (n=85 individuals), station II host 13 species (n=178 individuals), station III host 10 species (n=206 individuals), Station IV included 13 species (n=175 individuals), and station V host 12 species (n= 192 individuals). Furthermore, the study also examined the seasonal variations in fish diversity, with 14 species (n= 236 individuals) collected during spring, 18 species (n=236 individuals) during summer, 15 species (n=199 individuals) during autumn, and 9 species (n=99 individuals). Among the collected species, the species *Schizothorax plagiostamus* emerged as the dominant, constituting 20.93% of the total catch, followed by *Garra rupecula* at 19.62%. Notably, the species *Mastacembelus armatus*, *Pseudocheneis eddis* and *Channa punctata* exhibited the lowest frequency, each accounting for only 0.24% of the total individuals sampled, as shown in (Table 2).

Table 2. Distributional and frequency occurrence of fish

Sn	Name of Species	Station 1				Station2				Station 3				Station 4				Station 5				Total	Fre %
		S p	Su	A u	W i	Sp	S u	Au	W i	Sp	Su	A u	W i	Sp	Su	A u	W i	Sp	Su	A u	W i		
1	<i>Schizothora x plagiostomus</i>	8	9	7	3	7	27	11	4	9	16	9	3	16	8	9	2	9	8	9	1	175	20.93
2	<i>Garra gotyla</i>	-	-	-	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	3	0.37
3	<i>Garra annandalei</i>	2	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	0.59
4	<i>Garra lissorhynchus</i>	1				2	1	-	-	-	-	-	-	1	-	-	-	-	-	1	-	6	0.72
5	<i>Garra rupecula</i>	5	12	5	2	15	7	6	3	16	11	12	6	10	16	8	6	9	6	7	2	164	19.62
6	<i>Barilius vagra</i>	-	-	-	-	-	-	-	-	1	1	2	-	1	2	1	-	7	13	4	-	32	3.83
7	<i>Barilius barila</i>	-	-	-	-	-	-	-	-	1	2	1	-	1	3	1	1	1	3	3	2	19	2.27
8	<i>Barilius bendelisis</i>	-	1	-	-	3	10	6	1	9	5	1	2	3	1	4	3	5	2	4	2	62	7.43
9	<i>Neolissochilus hexagonolepis</i>	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	8	1	-	11	1.31
10	<i>Naziritor chelynoides</i>	-	1	-	-	2	7	3	1	4	15	2	3	4	12	9	15	14	16	12	7	127	15.19
11	<i>Schistura species</i>	-	-	-	-	5	3	2	3	-	-	-	-	-	-	-	-	-	-	-	-	13	1.55

12	<i>Schistura rupecula</i>	1	3	1	-	6	4	5	2	6	9	6	2	2	1	-	-	5	4	7	1	65	7.78
13	<i>Schistura multifasciata</i>	6	4	2	1	2	4	2	3	8	7	12	3	5	3	4	5	2	2	2	1	78	9.33
14	<i>Schistura fasciata</i>	4	2	1	1	1	5	3	4	4	9	2	1	6	3	4	1	3	2	3	1	60	7.18
15	<i>Channa punctata</i>	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0.24
16	<i>Channa orientalis</i>	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	3	-	-	-	4	0.47
17	<i>Pseudecheneis eddsi</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	2	0.24
18	<i>Amblyceps mangois</i>	-	-	-	-	-	-	-	-	3	1	2	-	-	-	-	-	-	-	-	-	6	0.71
19	<i>Mastacembelus armatus</i>	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0.24
Total		27	34	17	7	44	72	40	22	61	76	49	20	49	53	40	33	55	67	53	17	836	100

4.1.3 Order and Family wise distribution

The results show that the order Cypriniformes was the dominant order, constituting 74% followed by Siluriformes 11%, Anabantiformes 10%, and Synbranchiformes 5% indicated in figure 3. While the Cyprinidae family contained the most species, contributing to 53% of the total species diversity, followed by Nemacheilidae 21%, Channidae 11% and Sisoridae, Amblycipitiade and Mastacemblidae each contributing 5% of the species diversity.

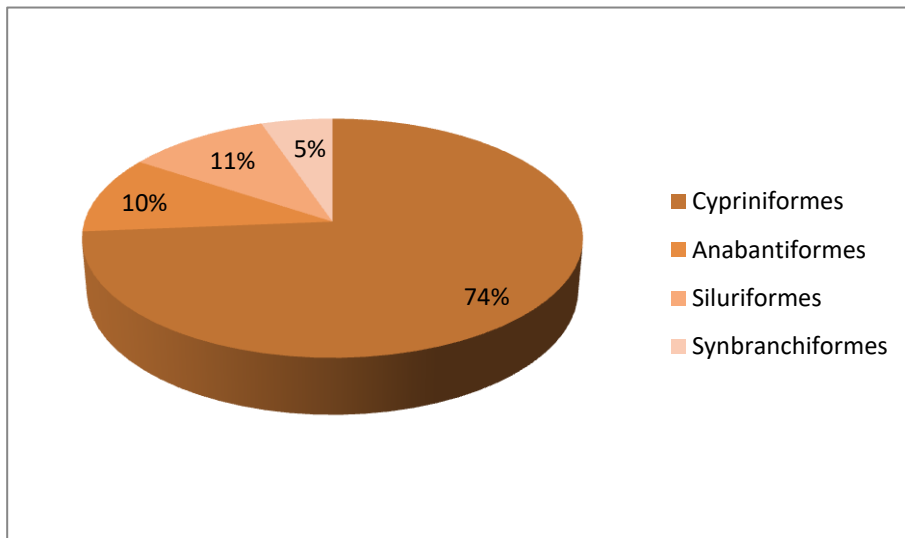


Figure 3. Order wise fish distribution

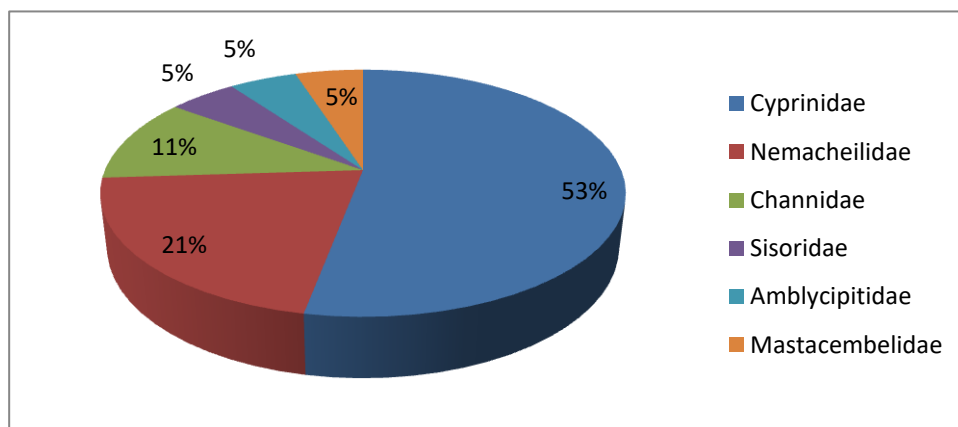


Figure 4. Family wise fish distribution

4.2 Functional Traits

In a comparative analysis of functional traits among 19 fish species, *Mastacembelus armatus* stands out as the largest species, displaying maximum body weight (25 gm), total length (221 mm), and standard length (214 mm), followed closely by *Neolissochilus hexagonolepis* (112 gm), (104 mm) and (86.1 mm) respectively. Conversely, *Schistura* species present the smallest measurements for body weight (1.2 gm), total length (53 mm), and standard length (49.6 mm). Head length reveals variations, with *Neolissochilus hexagonolepis* possessing the longest head (21.8 mm) after *Mastacembelus armatus* (34.8 mm) while *Schistura* exhibits the shorter (8.15 mm). Body depth shows (20.7 mm), (15.8 mm) variation and width (12.33 mm), (12.35 mm) shows similar patterns, with *Neolissochilus hexagonolepis* and *Mastacembelus armatus* displaying the greatest measurements, while *Schistura multifasciata* exhibits the smallest body depth (5.67 mm) and *Schistura species* with smallest body width (5.66 mm). Snout length, a functional trait linked to prey capture methods, is longest in *Mastacembelus armatus* (12.12 mm) followed by *Pseudecheneis eddis* (9.43 mm) and shortest in *Schistura species* (3.6 mm). Eye diameter follows a similar trend, with *Neolissochilus hexagonolepis* (6.07 mm) having the largest eyes and *Amblyceps mangois* with the smallest (0.66 mm). Dorsal fin functional traits exhibit substantial variation across species, *Garra species* display with the largest dorsal fin length and *Channa species* displaying the smallest. Caudal fin length is longest in *Neolissochilus hexagonolepis* (18.3 mm).

Table 3. Average and standard deviation measurement of functional traits

s.n	Name of species	BW(gm)	TL(mm)	FL(mm)	SL(mm)	HL(mm)	SL(mm)	EY(mm)	DFL(mm)	PFL(mm)	CFL(mm)	BD(mm)	B width(mm)
1	<i>Schizothorax plagiostomus</i>	3.9± 3.06	68.3±13.58	62.4±11.47	55.7±10.91	13.4±2.29	5.3±1.23	2.86±0.43	10.3±3.36	9.14±4.8	10.9±3.94	10.8±2.40	9.18±3.95
2	<i>Schistura rupecula</i>	2.4±0.4	59.3±4.32	57.4±4.32	50.7±3.09	11.4±1.45	5.07±0.49	1.68±0.17	8.6±1.68	8.5±0.82	8.6±1.5	7.29±7.29	7.33±8.09
3	<i>Schistura multifasciata</i>	1.9±0.25	56.4±2.51	55±2.66	48.1±6.06	10.4±0.6	4.78±0.2	1.71±0.23	8.88±0.58	8.04±0.78	7.06±1.34	5.67±0.76	6.09±0.60
4	<i>Schistura fasciata</i>	1.9±0.74	57.3±8.67	55.3±8.25	49±8.45	11.7±3.47	4.73±0.96	1.76±0.34	8.27±2.79	8.04±1.26	8.32±2.4	6.65±1.17	6.28±0.9
5	<i>Amblyceps mangois</i>	6.6±4.47	97.1±26.26	94.1±25.85	85.2±19.51	15.1±3.79	4.55±1.9	0.66±0.15	7.11±3.04	9.02±2.67	11.1±6.84	10.7±2.3	8.08±1.94
6	<i>Mastacembelus armatus</i>	25±11.22	221±41.71	0	214±4.55	34.8±7.41	12.2±2.02	3.03±0.25	7.9±3.60	12.95±5.02	7.53±0.2	15.8±2.12	12.35±1.12
7	<i>Garra rupecula</i>	6.2±2.76	78.2±12.16	73.4±12.19	66.5±11.94	15±1.94	7.43±1.11	2.53±0.50	13±4.50	12±3.43	11.2±3.05	12.2±2.22	10.62±2.11
8	<i>Garra gotyla</i>	5.7±3.66	72.3±14.75	66±14.22	59.4±13.78	13.8±2	7.24±1.5	2.04±0.44	15.2±4.8	10.96±3.6	12.9±1.07	12.7±4	11.05±2.68
9	<i>Garra annandalei</i>	3.1±1.06	60.4±6.06	55.7±5.78	50.5±5.8	12±1	6.1±0.45	1.9±0.15	9.33±1.22	9.39±1.27	10.6±0.62	9.13±0.9	8.33±1.02
10	<i>Garra lissorhynchus</i>	4.1±3.09	68±5.60	64±6.4	59.3±5.87	13±0.34	6.97±0.36	2.84±0.08	11.4±0.35	10.3±0.08	9±0.95	11±1.23	9.87±0.81
11	<i>Barilius barila</i>	2.7±0.31	71.9±3.69	63.8±5.26	58.7±2.2	12.6±0.85	3.84±0.36	3.36±0.20	8.41±2.63	10.51±0.5	12±1.53	9.6±0.27	6.51±0.35
12	<i>Schistura</i> species	1.2±0.5	53.1±5.94	49.6±5.03	45.3±4.94	8.15±1.78	3.6±0.8	1.4±0.34	6.82±0.98	5.84±0.82	7.82±2.05	5.91±1.4	5.66±1.33
13	<i>Pseudechenesis eddsi</i>	6.7±1.6	96.9±7.09	86.2±3.13	81.7±6.05	14±1.05	9.43±0.4	1.58±0.09	15.2±2	20.02±1.86	15.2±1.05	12.1±2.79	11.36±2.15
14	<i>Channa orientalis</i>	7.9±2.49	86.1±8.82	0	73.4±7.05	21.2±2.52	5.23±1.27	2.98±0.76	5.22±0.32	14.86±0.37	12.7±2.05	12.8±2.05	11.66±1.69

16	<i>Neolissochilus hexagonolepis</i>	12±7.29	104±14.82	94.6±13.12	86.1±10.91	21.8±3.09	7.46±1.22	6.07±3.01	21.3±6.51	29.43±6.85	18.3±5.01	20.7±2.23	12.33±1.99
17	<i>Naziritor chelynoides</i>	3.9±1.4	63.1±9.31	59.2±7.8	53.9±8.00	14.1±1.87	4.74±0.8	3.4±0.48	11.1±2.46	9.81±1.93	10.91±2.48	11.6±1.8	7.52±1.6
18	<i>Barilius vagra</i>	2.9±0.27	69.6±2.43	62.3±2.09	56.7±1.69	13±0.39	4.2±0.09	3.41±0.27	9.06±0.57	9.9±0.36	12.4±1.08	9.95±0.23	6.82±6.35
19	<i>Channa punctata</i>	7±2.65	83.2±10.25	-	70.7±7.36	20.3±2.88	4.7±1.21	2.91±1.05	5±0.99	14.1±0.56	12.5±2.52	12.3±2.52	10.47±1.90

4.2.1 Functional traits diversity composition

The following first figure 5 shows the different caudal fin types present in the species studied. The majority of species (98.33%) possess a forked types of caudal fin shapes, while very small proportions have rounded (0.72%), emarginated (0.72%) , or paddle-like caudal fin (0.23%). Figure 6 represents the mouth orientation of the species examined. Nearly half (48%) have an inferior or downward- facing mouth orientation followed by sub-terminal (38%), anterior (13%) and terminal (1%) mouth positions. Figure 7 shows the types of body shapes observed among the fish species examined. The majority (50.9%) of the species exhibit a compressed and elongated body shape, followed by cylindrical (25.84%) and sub- cylindrical (21.34%) shapes. Smaller proportion shows elongated sub-cylindrical (0.72%), serpentine (0.24%), cylindrical and flattened (0.24%), and cylindrical with a rounded abdomen (0.72%). Figure 8 describe the position of the fish species in the water column, with (51%) occupying the pelagic zone and (49%) being benthic or bottom dwelling.

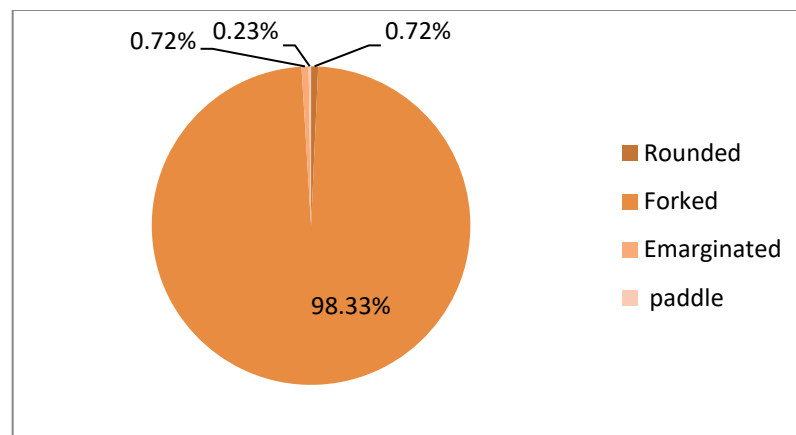


Figure 5. Distribution of fish on types of Caudal Fins

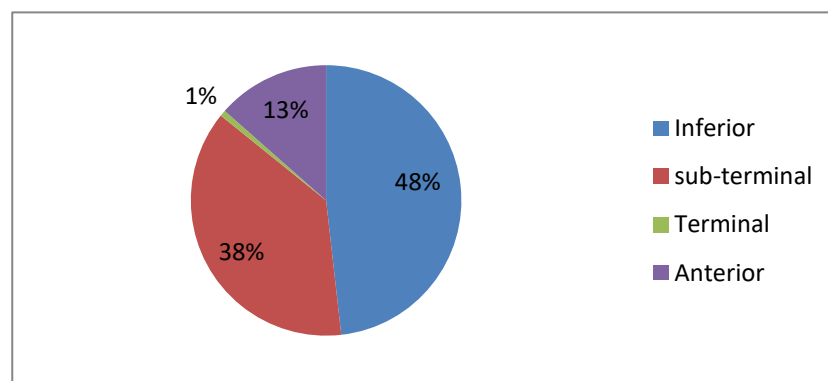


Figure 6. Distribution of fish on types of mouth orientation

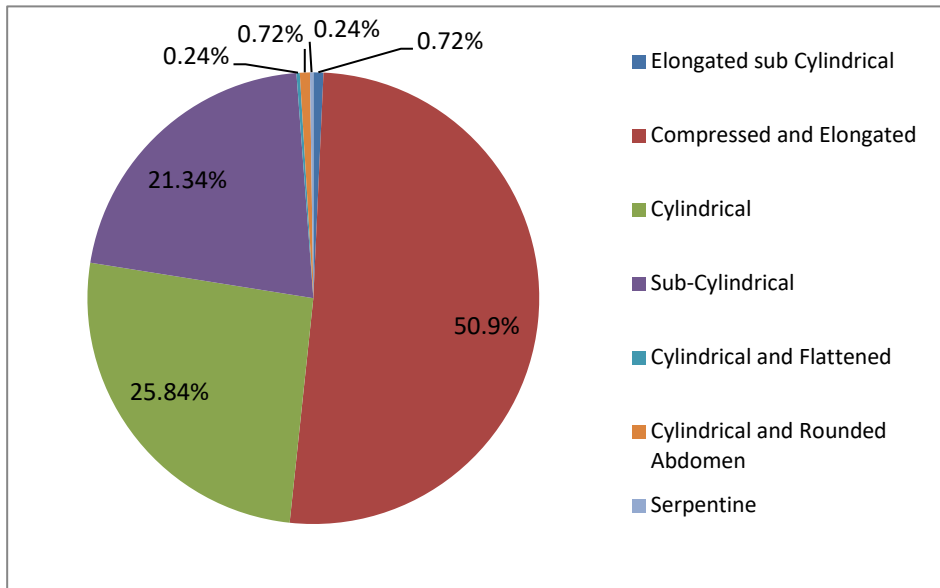


Figure 7. Distribution of fish on types of body shape

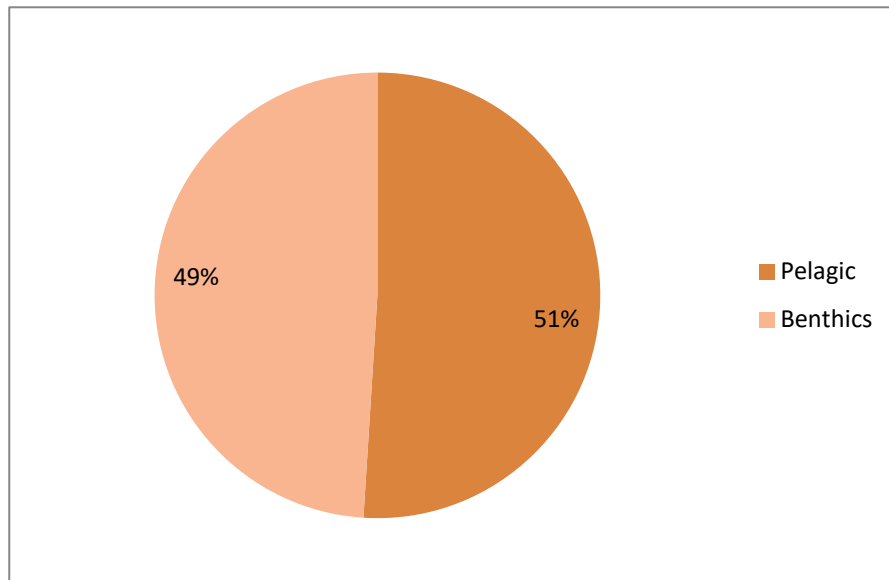


Figure 8. Distribution of fish on position in water Column

4.3. Environmental variables vs Functional traits

The results obtained after the canonical correspondence analysis are plotted in figure 9. The first (CCA1) and second (CCA2) axis of the CCA accounted for 55% and 28%, respectively. The axis length and eigen value acquired from DCA suggested that the uni-model of canonical correspondence analysis (CCA) was more applicable. The CCA plot indicates the relationship between traits and environmental variables. The traits such as body weight, standard length and total length are strong association related to water depth and total hardness, while weak negatively association was showed related to width, water temperature, free carbon-dioxide and water velocity. Similarly, snout length, pectoral fin length, caudal fin length and eye diameter are also highly association related to width, water temperature, free carbon-dioxide and water velocity but are negatively related to water depth and total hardness. On the other hand, dorsal fin length showed no any relation with environmental variables but showed a negative relation with pH, and EC.

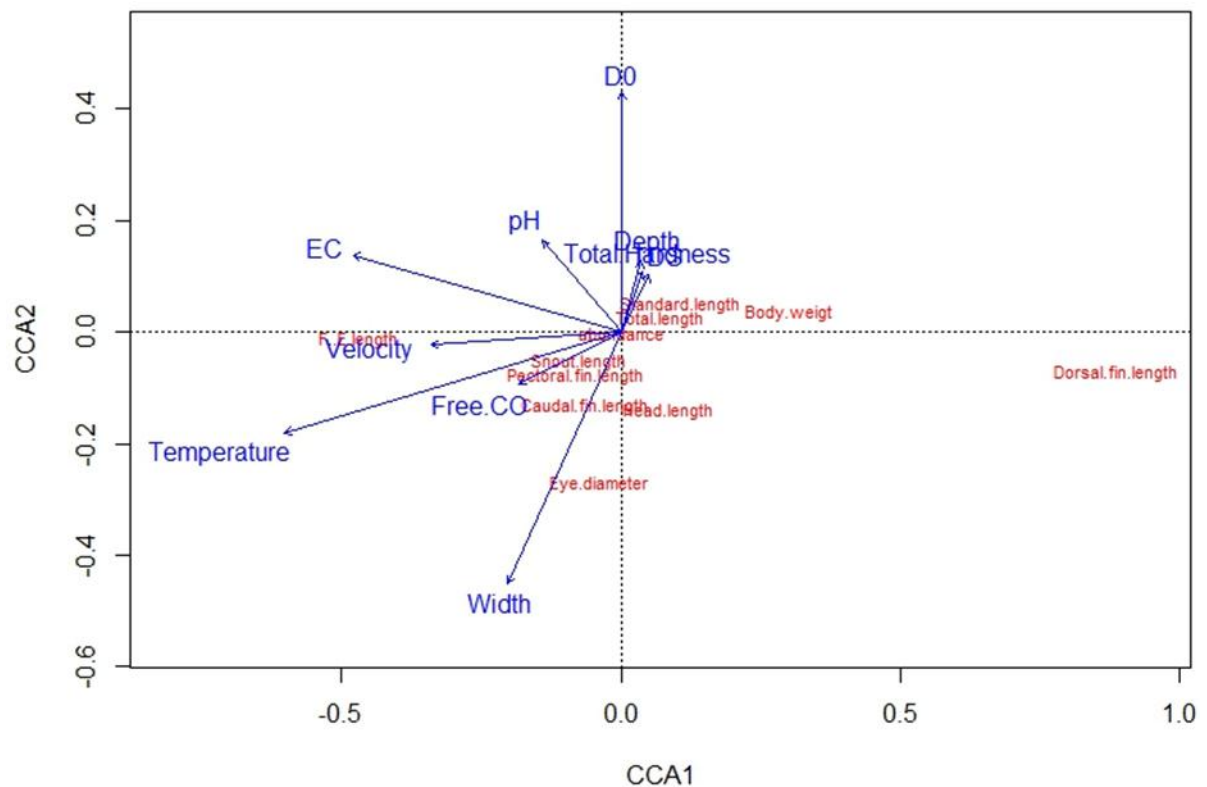


Figure 9. The relationship between functional traits and water parameters

4.3.1 Correlation in between selected traits

The results of Principal Component Analysis (PCA) provide valuable insights into the interrelationships among various morphological traits of the studied fishes. Notably, body depth, head length, body width, dorsal fin length, and body weight exhibited a strong positive correlation. Additionally, caudal fin length, standard length, and forked length also demonstrated a strong positive association. Conversely, a notable weak relationship was observed between the set of morphological traits encompassing body depth, head length, body width, dorsal fin length, total length, and body weight when compared to caudal fin length, standard length, and forked length. Furthermore, a negative relationship emerged between eye diameter and various morphological traits, indicating a distinct pattern of association. The observed negative correlation suggests that changes in eye diameter tend to be inversely related to alterations in other morphological characteristics

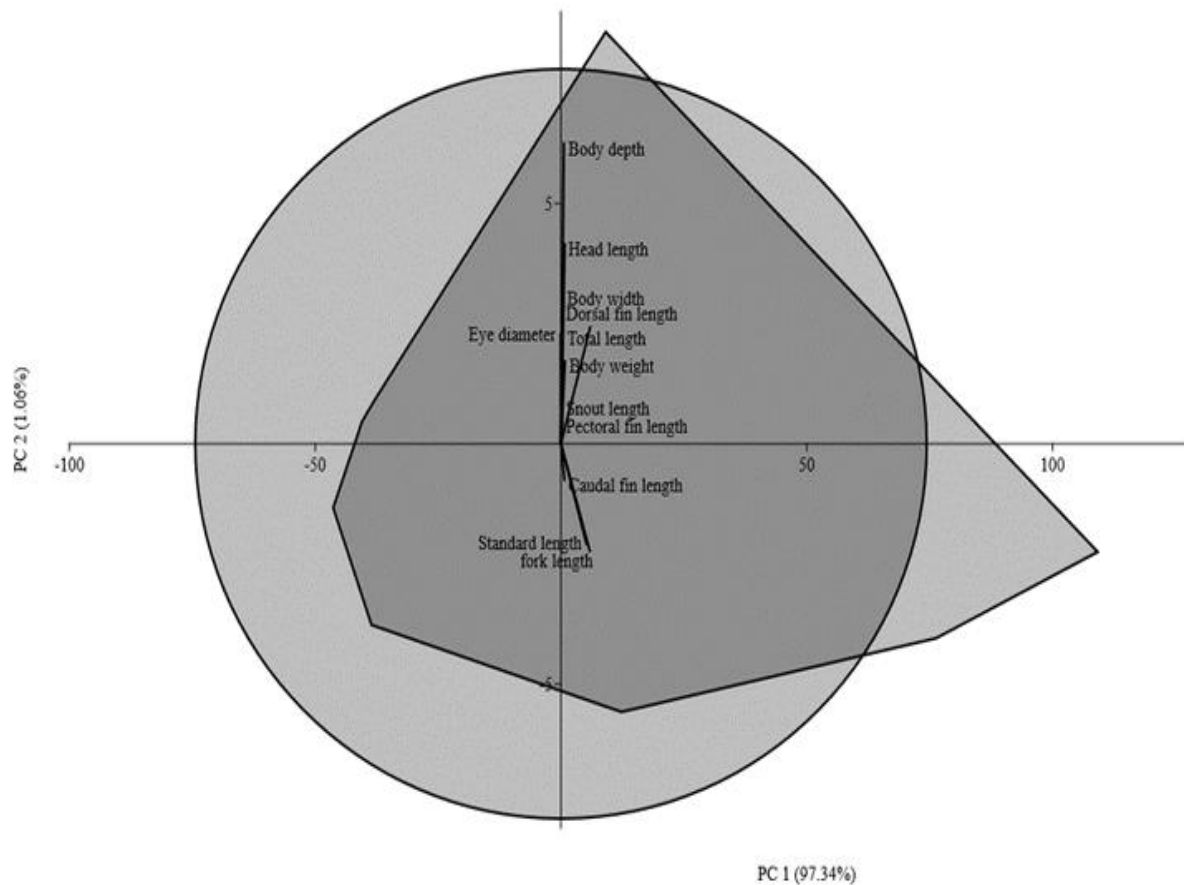


Figure 10. Correlation between selected functional traits

5. Discussion

5.1. Fish Status

A research study conducted in the Panaha river shows a rich aquatic ecosystem, hosting a total of 19 different fish species from 4 different Orders and 6 Families out of total 836 collected fish individuals from all five sites. The majority of the species were classified as Least Concern (LC) according to the IUCN report, with a few species falling under Vulnerable (VU) and Near Threatened (NT) categories. The number of species collected varied across the seasons, with the highest species diversity observed in summer. *Schizothorax plagiostamus* emerged as the most dominant species, followed closely by *Garra rupecula*, while other species exhibited lower frequencies. Cypriniformes emerged as the dominant order, with Cyprinidae being the most species- rich family. Moreover, the Cypriniformes and Cyprinidae were identified as the dominating order and family by Sharma and Shrestha (2001), Edds (1993), Gautam et al.(2016), Thapa (2018) who mentioned that order Cypriniformes was dominant in terms of both species composition as well as individuals captured in different rivers of Nepal.

5.2. Functional traits

In a comparative analysis of functional traits among 19 fish species, significant inter-specific variation in functional traits was observed. Some species displayed maximum variation while some exhibited minimum variation. This result aligns with the findings from previous studies (Acar & Kaymak, 2023; Paunikar & Panwar, 2021) who found that there is inter and intra specific variation among the different fish. De Barros and Colleagues (2019) outlined that such variations stem from the intricate interplay between the characteristics of their habitats, such as current velocity, water depth, water chemistry, and substrate type, and the dynamics within the community, including food availability, presence of predators, and competition for resources. These environmental factors shape the evolution of fish morphology and behavior, highlighting the intricate adaptation of these species to their respective ecological niches. This major size difference might be attribute to faster growth rates, increased longevity and their genetic characteristics (Goodrich & Clark, 2023). Head size correlates with the feeding apparatus and diet, suggesting a diverse range of feeding strategies (Watson & Balon, 1984). Larger eyes, as seen in some species, contribute to increased vision for feeding and movement in multiple habitats and also help in predator detection in fishes (Evans, 2004; Svanbäck &

Johansson, 2019). Dorsal fin functional traits exhibit substantial variation across species. The dorsal help in providing stability to fish during rolling and helps them make sudden turns and effective swimming (Standen & Lauders, 2007).

5.2.1. Functional traits diversity composition

From the examination of functional traits diversity including body shapes, position in the water column, types of caudal fin, and mouth orientations of the collected fish samples, shows the variation among the fish. The majority of the fish species exhibit a compressed and elongated body form. Rubio- Gracia et al. (2020) observed that streamlined body shapes are advantageous for effective swimming and maneuverability such that *Barilius* sps, *Schizothorax* sps, *Neolissochilus* sps and *Naziritor* sps were effectively swimming on Panaha River. Webb (1984) noted that cylindrical and sub cylindrical body forms are often found in benthic or sedentary species, providing enhanced stability on or near the substrate such that *Schistura* sps., *Amblyceps* sps., *Garra* sps, *Psudechenosis* and *Channa* sps were dominantly found in benthic habitat. Regarding the position in the water column, the distribution of species occupying mid-water and benthic regions shows the diversity of ecological niches and feeding strategies, as described by (van der Sleen & Albert, 2022). Regarding types of mouth orientations, sub-terminal and terminal mouth positions are more common in mid-water or surface - feeding species, as reported by (Wainwright & Richard, 1995). The inferior mouth orientation may be specialized for feeding on sessile organisms attached to substrates.

5.3. Environmental variables vs Functional traits

The connections between fish traits and environmental conditions are shaped by diverse ecological factors and the adaptive strategies of fish to their habitats (Lin et al., 2021). In this case of body weight, standard length, and total length show that highly association with water depth and total hardness suggest that deeper waters offer more resources for fish growth, including minerals and nutrients (Vijayan et al., 2016). Conversely, negative relationships with width, water temperature, free carbon oxide, and water velocity indicate that in narrower, warmer, and faster flowing environments, fish may prioritize streamlined shapes and efficient swimming over larger body sizes (Zhong et al., 2019). For traits like snout length, pectoral fin length, caudal fin length, and eye diameter, positive relationships with wider water bodies, moderate temperatures, and slower velocity suggest adaption for enhanced feeding efficiency and mobility (Evans, 2004; Roos et al., 2011). Conversely, negative associations with water depth and total hardness

imply streamlined adaption for deeper waters and softer environments. Dorsal fin length show no clear relationship with general environmental variables but exhibits a negative association with pH and electrical conductivity (EC), suggesting a preference for habitats with lower acidity and conductivity. As result describe that EC, temperature, velocity and width were highly influence water variable to change the fish functional traits. Emmrich et al. (2014), De Barros and Collegaues (2019) also describe that temperature, velocity are factor shape the functional traits of fish.

5.4. Correlation in between selected functional traits

The strong positive relation observed among body traits , such as body depth, head length, dorsal fin width, dorsal fin length, and body weight, indicates that these traits collectively contribute to the overall body structure, reflecting adaptations for efficient swimming, buoyancy control and foraging as noted by (Watson & Balon 1984) and (Zhong et al. 2019). Some other studies Yadav and Paul (2023); Onyekwelu et al. (2021); Singh et al. (2022) on morphometric traits shows the positive correlation among different traits, highlighting the interconnectedness of various morphological features in fish. The negative relationship between eye diameter and various morphological traits implies a different pattern of association. This inverse correlation might be related to visual activities and the ecological requirements of the species, where changes in eye diameter are inversely related to alterations in other morphological characteristics, reflecting and adaptive compromise in response to specific environmental. Siraj et al. (2017) also describe that in relation to percentage of head length, eye diameter was observed to be least correlated compared to other traits. To proper management and growth and development of fish it is necessary for estimation of through the study of morphmetric traits which are correlated each other (Qazi et al., 2023).

6. Conclusions and recommendations

6.1. Conclusions

A study in panaha River revealed the presence of a diverse aquatic ecosystem, hosting a total 19 different fish species. These species were taxonomically distributed across 4 Orders and 6 Families. The order Cypriniformes and the Cyprinidae were the dominant taxonomic groups. The Most abundant species was *Schizothorax plagiostomus* (20.93%), followed by *Garra repecula* (19.62%). The species with the lowest frequency were *Mastacembelus armatus* (0.24%), *pseudochenesis eddis* (0.24%), and *Channa punctat* (0.24%), followed by *Garra gotyla* with a frequency of (0.37%). The comparative analysis of functional traits among the 19 fish species provided valuable information about their ecological preferences. The different patterns observed in body size, head length, body depth and fin characteristic provides the interspecific strategies employed by these fish in response to their habitat. The observed body shapes, habitat preferences, caudal fin morphologies and mouth orientations appear to be well-aligned with the diversity of ecological niches and functional roles present in the fish communities studied. The variation likely represents adaptations to different feeding strategies, swimming modes, and microhabitat preferences, reflecting the remarkable evolutionary radiation of fishes into a wide range of aquatic environments. Canonical Correspondence Analysis (CCA) show the EC, velocity, temperature, width are highly associated and influence factors for change in fish functional traits.

6.2. Recommendations

- ❖ Species which are classified as Vulnerable (VU) and Near Threatened (NT) by IUCN and found in different station should be given proper attention for their conservation strategies.
- ❖ Species which are found only in specific sampling station. Their conservation is also equally essential.

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8. Photographs



Photo 1. *Schizothorax plagiostomus* (Heckel, 1838)



Photo 2. *Garra gotyla* (Gray, 1830)



Photo 3. *Garra annandalei* (Hora, 1921)



Photo 4. *Garra lissorhynchus* (McClelland, 1842)



Photo 5. *Garra rupecula* (McClelland, 1839)



Photo 6. *Barilius bendelisis* (Hamilton, 1807)



Photo 7. *Barilius vagra* (Hamilton,1822)



Photo 8. *Barilius barila* (Hamilton,1822)



Photo 9. *Neolissochilus hexagonolepis* (McClelland, 1839)



Photo 10. *Naziritor chelynoides* (McClelland, 1839)



Photo 11. *Schistura rupecula* (McClelland, 1838)



Photo 12. *Schistura multifasciata* (Day, 1878)



Photo 13. *Schistura fasciata* (Lokeshwor and Vishwanath,2011)



Photo 14. *Schistura* species



Photo 15. *Channa punctata* (Bloch, 1793)



Photo 16. *Channa orientalis* (Bloch and Schneide,1801)



Photo 17. *Pseudecheneis eddsi* (H.H. Ng, 2006)



Photo 18. *Amblyceps mangois* (Hamilton, 1822)



Photo 19. *Mastacembelus armatus* (Lacepede, 1800)

Appendices

Appendix I

Table 1. Water Parameter across the season and station

Seasons	Water Parameters										
	St	pH	D0 (mg/L)	TDS (PPM)	EC (mS/cm)	Tem (°C)	Hrd (mg/L)	CO2 (mg/L)	Velo (m/s)	Depth (m)	Width (m)
Sp	s1	8.6	7.23	112	230	28	8.8	4.9	0.93	2	11.8
Sp	s2	8.4	8.52	63	144	25	6.7	4.2	1.21	4.5	5
Sp	s3	9	7.5	72	190	27	8.5	4.1	1.05	3.2	6.3
Sp	s4	8.5	8.32	52	150	26.2	7.9	4.3	1.12	2.1	10.1
Sp	s5	8.8	7.4	196	375	28.2	6.5	3.12	0.79	1.92	12.7
Su	s1	7.9	8.85	127.5	204	25.7	7.9	4.1	1.23	4.78	17.5
Su	s2	8.1	7.13	96.5	200	23	7.5	3.9	1.45	4	10.4
Su	s3	8.4	8.34	87.5	142	25.4	8.3	3.6	1.59	5.34	9.8
Su	s4	7.9	7.13	86.3	208	24.6	8.5	4.1	1.56	6.32	14
Su	s5	8.2	7.12	101.3	176	25.2	9.1	4.32	1.32	4.3	14.3
Au	s1	8.1	8.7	93.8	197	17.4	8.6	3.9	1.1	3.54	12.1
Au	s2	8.2	9.6	111.3	201	15.2	9.1	4.2	1.32	3.12	8.6
Au	s3	8.2	8.75	83.9	156	16	8.35	3.85	1.21	3.34	7.7
Au	s4	8.1	8.62	112.4	240	15.8	8.35	3.89	1.35	3.12	9.12
Au	s5	7.9	8.3	97.4	192	16.2	7.21	3.97	1.24	3.2	10.2
wi	s1	7.9	8.1	103.4	124	6	8.5	4.1	1.01	2.1	12.4
wi	s2	8.3	8.4	95	156	6.5	8.2	3.7	1.09	4.6	6
wi	s3	8.5	7.78	104.1	207	6	7.9	3.2	1.13	4.2	6.9
wi	s4	8.4	8.3	134.8	256	6.6	8.12	4.2	1.16	3.1	9.8
wi	s5	8.9	7.2	105	208	5.9	8.2	4.01	1.12	3.75	12.3

Appendix II

Table 2. Average functional traits measurement of collected samples of station I

Name of species	BW (gm)	TL (mm)	FL (mm)	SL (mm)	HL (mm)	SL (mm)	EY (mm)	DFL (mm)	PFL (mm)	CFL (mm)	BD (mm)	B width (mm)
<i>Schizothorax plagiostomus</i>	4.15	70.35	64.34	56.6	12.72	5.29	2.48	12.7	11.14	13.7	10.94	8.08
<i>Schistura rupecula</i>	1.82	56.45	54.3	47.47	8.89	4.06	1.62	9.14	7.39	8.97	6.43	6.19
<i>Schistura multifasciata</i>	1.97	59.34	58.1	52.03	10.66	4.79	1.74	8.93	7.88	7.316	4.78	5.57
<i>Schistura fasciata</i>	1.96	60.17	58.34	54.98	16.73	5.14	1.93	8.86	7.95	5.34	6.11	6.3
<i>Garra rupecula</i>	9.45	90.04	86.24	80.5	16.91	8.62	3.33	18.79	17.58	9.56	14.98	12.97
<i>Channa punctata</i>	6.95	83.16	-	70.67	20.29	4.7	2.91	5	14.1	12.5	12.25	10.47
<i>Garra annandalei</i>	3.08	60.42	55.7	50.5	11.96	6.1	1.9	9.33	9.39	10.6	9.13	8.33

Table 3. Average functional traits measurement of collected samples of station II

Name of species	BW (gm)	TL (mm)	FL (mm)	SL (mm)	HL (mm)	SL (mm)	EY (mm)	DFL (mm)	PFL (mm)	CFL (mm)	BD (mm)	B width (mm)
<i>Garra gotyla</i>	5.69	72.34	66	59.41	13.8	7.24	2.04	15.23	11	12.9	12.7	11
<i>Garra lissorhynchus</i>	4.062	68.32	63.9	59.34	13.1	6.97	2.84	11.39	10	8.99	11.4	9.87
<i>Barilus bendelisis</i>	8.84	85.26	77.1	69.79	16.9	5.12	3.89	16.81	16	15.5	15.8	9.05
<i>Naziritor chelynoides</i>	4.44	72.25	64.3	57.94	15.7	5.47	3.79	12.08	11	14.3	11.6	8.17
<i>Barilus varga</i>	2.42	69.59	63	57.1	12.2	3.72	3.24	9.18	9.9	12.5	9.64	6.28
<i>Garra rupecula</i>	3.34	66.04	60.5	54.43	13.4	6.22	2.15	7.16	9.8	9.39	10	8.95
<i>Schizothorax plagiostomus</i>	9.15	90.72	81.4	73.43	17.4	7.37	3.59	14.5	16	15	14.7	16.2
<i>Mastacembelus armatus</i>	24.99	220.5	0	213.5	34.8	12.2	3.03	7.9	13	7	15.8	12.4
<i>Schistura rupecula</i>	2.23	59.06	57.9	50.87	10.7	5.11	1.82	9.63	8.6	8.19	6.54	7.04
<i>Schistura multifasciata</i>	2.13	53.33	51.9	38.32	9.64	4.52	1.66	8.76	8.8	8.13	6.39	6.67
<i>Schistura fasciata</i>	1.06	44.4	43.2	36.34	8.08	3.55	1.17	3.65	6.6	8.06	5.16	4.89

Table 4. Average functional traits measurement of collected samples of station III

Name of species	BW (gm)	TL (mm)	FL (mm)	SL (mm)	HL (mm)	SL (mm)	EY (mm)	DFL (mm)	PFL (mm)	CFL (mm)	BD (mm)	B width (mm)
<i>Schistura fasciata</i>	3.04	67.65	65.38	58.25	13.68	5.85	1.99	11.22	10.03	9.4	8.01	7.43
<i>Schistura multifasciata</i>	1.69	54.97	53.21	46.45	10.29	4.95	1.81	8.34	7.15	8.51	6.11	6.4
<i>Schistura rupecula</i>	2.67	58.2	55.56	50.15	12.93	5.3	2.06	9.38	8.36	8.05	7.7	7.32
<i>Schizothorax plagiostomus</i>	1.94	58.97	54.63	47.11	12.04	4.72	2.89	8.77	7.47	11.33	8.72	7.05
<i>Amblyceps mangois</i>	6.62	97.06	94.08	85.2	15.09	4.55	0.66	7.11	9.02	11.05	10.7	8.08
<i>Barilius bendelisis</i>	4.78	73.62	67.49	62.53	14.97	4.82	4.02	12.73	12.18	11.08	14.44	9.42
<i>Barilius vagra</i>	1.96	65.99	59.01	54.04	11.81	3.67	2.95	8.99	9.59	11.946	9.46	6.07
<i>Barilius barila</i>	2.7	74.5	67.6	60.7	13.48	4.06	3.41	10.34	11	13.81	9.86	6.84
<i>Naziritor chelynoides</i>	2.03	55.69	49.82	45.09	12.28	4.28	3.08	9.96	8.068	10.59	9.83	6.9
<i>Garra rupecula</i>	6.57	82.8	77.58	69.05	15.33	7.45	2.04	13.3	12.4	13.76	12.27	9.17

Table 5. Average functional traits measurement of collected samples of station IV

Name of species	BW (gm)	TL (mm)	FL (mm)	SL (mm)	HL (mm)	SL (mm)	EY (mm)	DFL (mm)	PFL (mm)	CFL (mm)	BD (mm)	B width (mm)
<i>Garra rupecula</i>	8.19	87.8	82.25	72.59	16.62	8.44	2.52	15.51	14.04	15.21	13.84	12.89
<i>Schizothorax plagiostomus</i>	2.59	64.48	58.01	54.9	13.19	4.96	2.75	10.21	9.21	9.57	10.43	7.79
<i>sistura species</i>	1.16	53.07	49.64	45.25	8.15	3.6	1.4	6.82	5.84	7.82	5.91	5.66
<i>Barilius bendelisis</i>	8.78	87.72	80.52	75.17	16.99	5.13	3.99	16.59	17.03	13.87	15.89	8.37
<i>Pseudecheneis eddsi</i>	6.7	96.89	86.24	81.7	14	9.43	1.58	15.15	20.02	15.2	12.11	11.36
<i>Schistura rupecula</i>	2.23	56.11	54.71	49.17	10.81	4.67	1.82	9.25	8.35	6.94	7.83	8.26
<i>Schistura multifasciata</i>	2.01	58.65	57.42	53.53	11.2	5.01	2	9.84	8.88	5.46	6.2	6.5
<i>Schistura fasciata</i>	1.52	54.08	52	46.98	9.48	3.89	1.94	8.54	7.51	7.09	7.67	6.36
<i>Barilius varga</i>	2.53	68.24	62.31	56.64	11.79	3.77	3.54	8.35	10.04	11.45	9.61	5.87
<i>Barilius barila</i>	3.04	73.37	66	59	12.4	4.04	3.53	5.41	10.07	11.02	9.7	6.56
<i>Naziritor chelynoides</i>	2.35	61.18	55.25	50.78	13.68	5.09	3.24	10.24	11.16	10.51	10.68	7.08

Table 6. Average functional traits measurement of collected samples of station IV

Name of species	BW (gm)	TL (mm)	FL (mm)	SL (mm)	HL (mm)	SL (mm)	EY (mm)	DFL (mm)	PFL (mm)	CFL (mm)	BD (mm)	B width (mm)
<i>Barilius bendelisis</i>	5.12	82.37	75.91	69.8	14.7	4.9	4.04	12.4	12.32	12.6	13	8.24
<i>Garra rupecula</i>	3.43	64.4	60.41	56.16	12.5	6.4	2.62	10.3	9.07	8.23	10	9.11
<i>Naziritor chelynooides</i>	2.28	60.08	54.62	50.06	13.4	4.5	3.41	11.5	9.56	10	9.97	7.06
<i>Schizothorax plagiostomus</i>	1.81	56.93	53.39	46.39	11.8	4.1	2.6	5.08	2.3	4.9	8.99	6.8
<i>Neolissochilus hexagonolepis</i>	11.76	104.4	94.58	86.13	21.8	7.5	6.07	21.3	29.43	18.3	20.7	12.33
<i>channa orientalis</i>	7.91	86.07	-	73.42	21.2	5.2	2.98	5.22	14.86	12.7	12.8	11.66
<i>Barilius varga</i>	2.55	71.94	63.79	57.98	12.6	3.9	3.53	9.75	10.46	14	9.12	7.2
<i>Barilus barila</i>	2.41	67.64	57.83	56.36	11.8	3.4	3.14	9.48	10.16	11.3	9.44	6.13
<i>Schistura rupecula</i>	2.85	66.74	64.78	55.71	11.4	5.1	1.68	5.61	9.7	11	7.99	7.86
<i>Schistura fasciata</i>	2.13	60.24	57.36	48.54	10.7	5.2	1.78	9.09	8.13	11.7	6.32	6.43
<i>Schistura multifasciata</i>	1.5	55.94	54.48	50.03	9.98	4.6	1.35	8.51	7.47	5.91	4.91	5.33

Table 12. Functional traits diversity composition in fish

Name of species	Types of Caudal fin	Types of Body shape	Types of Mouth Orientation	Position in water column
<i>Schizothorax plagiostomus</i>	Forked	Compressed and Elongated	sub-terminal	Mid water
<i>Schistura rupecula</i>	Forked	Cylindrical	Inferior	Benthic
<i>Schistura multifasciata</i>	Forked	Cylindrical	Inferior	Benthic
<i>Schistura fasciata</i>	Forked	Cylindrical	Inferior	Benthic
<i>Amblyceps mangois</i>	Emarginated	Cylindrical and Rounded Abdomen	Terminal	Benthic
<i>Mastacembelus armatus</i>	lyre or paddle	Serpentine	sub-terminal	Benthic
<i>Garra rupecula</i>	Forked	Sub-Cylindrical	Inferior	Benthic
<i>Garra gotyla</i>	Forked	Sub-Cylindrical	Inferior	Benthic
<i>Garra annandalei</i>	Forked	Sub-Cylindrical	Inferior	Benthic
<i>Garra lissorhynchus</i>	Forked	Sub-Cylindrical	Inferior	Benthic
<i>Barilius barila</i>	Forked	Compressed and Elongated	Anterior	Mid water
<i>Schistura species</i>	Forked	Cylindrical	Inferior	Benthic
<i>Pseudechenesis eddsi</i>	Forked	Cylindrical and Flattened	Inferior	Benthic
<i>Channa orientalis</i>	rounded	Elongated sub cylindrical	Inferior	Benthic
<i>Barilius bendelisis</i>	Forked	Compressed and Elongated	Anterior	Mid water
<i>Neolissochilus hexagonolepis</i>	Forked	Compressed and Elongated	sub-terminal	Mid water
<i>Naziritor chelynoides</i>	Forked	Compressed and Elongated	sub-terminal	Mid water
<i>Barilius vagra</i>	Forked	Compressed and Elongated	Anterior	Mid water
<i>Channa punctata</i>	Rounded	Elongated sub Cylindrical	Inferior	Benthic