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# Freshwater Metacommunity Structure of Suchhu River, Haa District, Bhutan

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**Abstract**

Bhutan is endowed with rich river systems which inhabit a multitude of aquatic species. However, the increasing developmental activities, urbanization, rural-urban migration, growing water demand, and land use alterations pose substantial risks and imminent threats to freshwater biodiversity. The study aimed to evaluate the diversity and spatial distribution of fish and benthic macroinvertebrates in Suchhu river, Haa. Data collection for the study was conducted during the monsoon and post-monsoon seasons, in July and October of 2021. The data collection followed a systematic random sampling, with samples collected at 1-kilometre intervals spanning 30 sampling stretches, each measuring 200 metres in length. Overall, a total of 632 fishes were encountered belonging to 8 species under 3 families from 30 sampling stretches. The overall fish species diversity in the river was $H'$= 0.68, species evenness $E_H$ = 0.33, and species richness $S_R$ = 2.50. Concomitantly, a total of 265 samples of macroinvertebrates were collected belonging to 10 families under 8 orders. A total of 10 species were recorded and the species diversity for macroinvertebrates was found to be $H'$= 1.73, species evenness $E_H$ = 1.57 and species richness $S_R$ = 0.83. A total of 13 species (9 phytoplankton and 4 zooplankton) under 9 families and 9 orders were recorded. The species diversity was found to be $H'$ = 1.68, species evenness $E_H$ = 0.65 and species richness $S_R$= 4.54. The study emphasizes addressing environmental impacts from development, urbanization, and land use changes to protect freshwater biodiversity. Analyzing fish and macroinvertebrate metacommunity structure enhances our understanding of ecological consequences, promoting freshwater ecosystem sustainability.

**Keywords**: Development, diversity indices, fish, macroinvertebrates, sustainability

## Introduction

Freshwater biodiversity is crucial for assessing ecosystem health, encompassing various species such as fish, mollusks, decapods, macroinvertebrates, meso and meiofauna, plankton, and aquatic plants (Thomsen *et al.*, 2012). Monitoring the health of the freshwater ecosystem is critical for understanding the sustainability of ecosystem services for future generations (Jackson *et al.*, 2016). Fish and fishery resources are significant human food sources and play an important role in biologically indicating river ecosystem health (Chen *et al.*, 2009; Dorji and Wangchuk, 2014; Lynch *et al.*, 2016). Besides fish, macroinvertebrates and other benthic organisms are essential biological indicators for assessing river ecosystem health (Hayati *et al.*,

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2017).

In recent years, many new fish species have been documented in Bhutan, including 114 fish species from 24 families (Gurung and Thoni, 2015; Wangmo and Rai, 2019) and 104 species of fish from the western part of the country under 16 families (National Research Centre for Riverine and Lake Fisheries [NRCRLF], 2017). Bhutan's stream ecosystems consist of three types of strata: pools, riffles, and cascades, resulting from distinct abiotic conditions (Riley *et al.*, 2005; Lepcha and Suwanmaneepong, 2022). The documentation of freshwater macroinvertebrates in Bhutan was initiated by the National Environment Commission (NEC) in 2006. Several new species have been documented in the country in recent years (Wangchuk *et al.*, 2017). Bhutan has a total of 18 orders and 89 families of macroinvertebrates, including 166 species of trichoptera (Dorji and Gurung, 2017). Additionally, Moog *et al.* (2008) recorded 166 different species of macroinvertebrates during their three-week journey across the nation. In Teobrongchuu stream, Punakha, 20 macroinvertebrate species from 13 different orders were identified (Wangyal *et al.*, 2011). Moreover, Mitra (2006) found 5 superfamilies, 10 families, 17 subfamilies, 24 genera, and 31 species of odonates. In Singyechu, Pasakha, Chukha, macroinvertebrates belonging to 7 orders and 33 families were found (Giri and Singh, 2013). Wangchuk and Eby (2013) identified 51 macroinvertebrate genera in Bumthang, encompassing 44 families and 8 subfamilies.

According to Dorji and Wangchuk (2014), the four streams in Punakha Dzongkhag, namely Dorokna, Jinchulum, Teobrongchuu, and Metsina, recorded 51 taxa from 51 families. However, research on orders such as Plecoptera, Diptera, and Hemiptera, excluding Trichoptera and Odonates, is limited (Dorji, 2021). Human activities, including urbanization, rural-urban migration, increased water demand, and land use changes, have led to significant degradation of freshwater ecosystems (Mouri, 2015). Additionally, construction of dams and reservoirs is another potential factor influencing the aquatic habitat and its quality (Scott Winton *et al.*, 2019). Bhutan has great potential for hydropower development, which may threaten freshwater biodiversity by altering its distribution, water systems, and interaction with freshwater organisms (Dorji and Wangchuk, 2014).

Bhutan lacks proper records of freshwater biodiversity despite its crucial role in freshwater ecosystems (Gurung *et al.*, 2013). Development of mega hydropower projects poses a significant threat to aquatic biodiversity in Bhutan, as it can potentially obstruct streams and disrupt fish migration patterns. Therefore, studying the metacommunity structure of fish and macroinvertebrates is crucial for understanding the effects of human activities on freshwater ecosystems. Analyzing the distribution patterns and interactions among species within a metacommunity can identify the factors shaping biodiversity and its resilience to environmental disturbances. This knowledge can inform conservation strategies and management practices aimed at mitigating the impacts of hydropower development and other anthropogenic stressors on freshwater biodiversity in Bhutan and elsewhere.

## Materials and Method

### *Study area*

Suchhu is located in the Amochhu basin in Haa District. The start of sampling Stretch (0711306E; 3009838N) was located at about one hour walk from Shaba village, which is 16 km away from Sombaykha *Gewog* centre. The end of sampling sites (0711172E; 3005717N) was located at about 1.2 km upstream of Suchhu and Sheychhu confluence. The study sites correspond to the hydropower project sites which were planned to be constructed in the near future. The data collection for the study was carried out in the monsoon (July) and post monsoon (October) seasons of 2021.

*Materials required*

Materials required for data collection included fishing gear, which comprised cast nets and an electro-shocker, a Global Positioning System (GPS) user handheld device, a portable water analysis kit (PCS Testr), specimen containers, formalin (10%), ethanol (70%), and a camera. Samples were photographed and stored in formalin and ethanol using specimen containers to preserve them. The portable water analysis kit PCS Testr was used to measure on-Stretch physical parameters such as potential of hydrogen (pH), dissolved oxygen (DO), total dissolved solids (TDS), salinity, and temperature.

Specifically for the macroinvertebrates, the materials used included a D-Frame dip net with the mess size of 500-micrometre, forceps, and a tray. The advantages of using a D-Frame dip net are its affordability and suitability for low-gradient streams. Moreover, it is easy to handle and can be used to collect samples from more than one habitat (McIntosh, Fierro-Cabo, and Benavides, 2019).

*Sampling design*

The data collection approach involved the use of systematic random sampling, where samples were collected at intervals of 1 km (Arnab, 2017). Systematic sampling was adopted as the sampling sites were laid as per the hydropower project sites proposed in the river, which was mandatory to study the metacommunity structure in the river and simultaneously to study the impact assessment. GPS coordinates were recorded using a GPS logger to map the distribution of species (Wangmo and Rai, 2019). Furthermore, within each 1 km sampling interval, a 200 m transect line was established for data collection (Wangmo and Rai, 2019). A total of 30 sample plots under six sampling stretches were laid out which covered the overall six sites or components of the proposed hydropower project in the river.

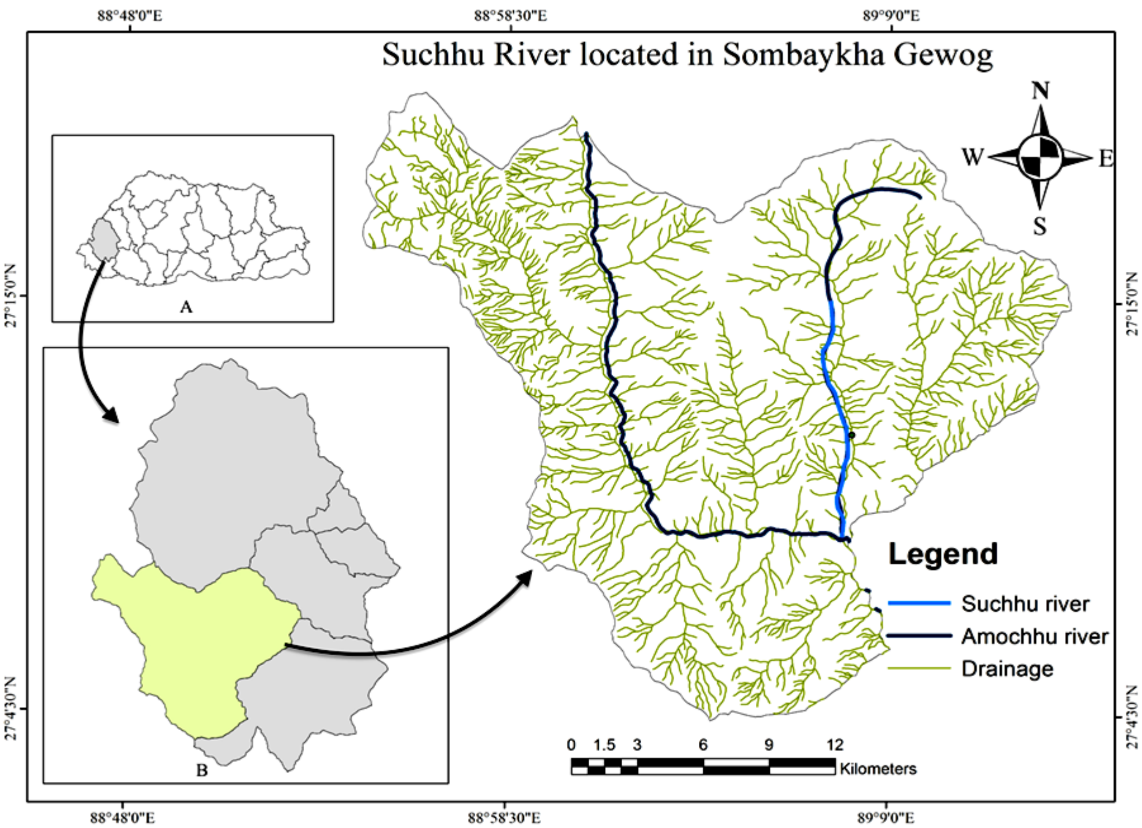


**Figure 1:** Map of Bhutan showing Haa (A); Location of Sombaykha Gewog under Haa (B) and the Sombaykha Gewog and Suchhu River

*Data collection*
*Fish sampling*
Various fishing techniques, including the use of cast nets, spinner hooks, temporary river diversion, and electro-shockers, were employed for fish sampling. A catch and release approach was followed, with only a necessary number of fish collected for voucher specimens, which were then deposited in the laboratory of the College of Natural Resources (CNR), Royal University of Bhutan.

The cast net used for sampling had a radius of 3 metres, and the distance between two sampling points was set at 50 metres, with each stretch covering up to one kilometre (Benton *et al.*, 2019). Additionally, seine nets were utilized, often in conjunction with the rock flip and kick sampling methods, wherever applicable (Benton *et al.*, 2019).

*Macroinvertebrate sampling*
Collection of macroinvertebrates involved the use of the kick-sampling technique with a D-frame net (Ghani *et al.*, 2016). Additionally, locally sourced mosquito nets were concurrently used to enhance collection efforts (Hartmann, 2007). To ensure the comprehensive collection of specimens, the substrate was deliberately disturbed and scooped with the net multiple times (Wangchuk and Eby, 2013). Sampling was conducted at designated sites, encompassing all distinctive habitat types within the study areas (Bradley *et al.*, 2017).

Macroinvertebrates that could be readily identified were photographed and documented in the field. Any unidentified macroinvertebrates were carefully collected and placed in labeled containers filled with 70% ethanol for subsequent laboratory identification (Carter *et al.*, 2017).

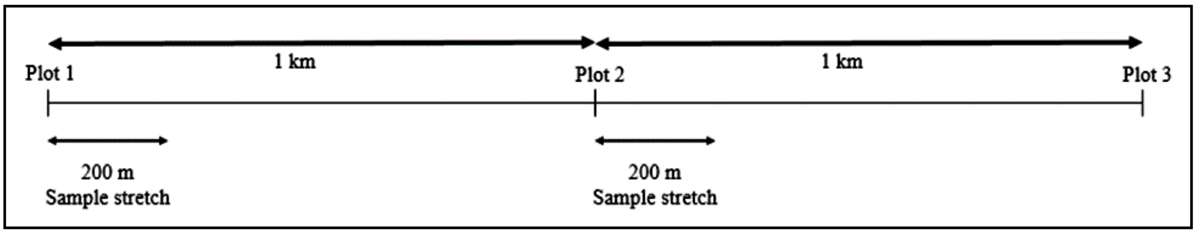


**Figure 2:** Sampling design for the data collection

*Data analysis*
Data were analyzed using Microsoft Excel and R Software. Descriptive statistics were computed to study the comparisons between different study sites. For the assessment of species diversity, the Shannon-biodiversity index, as proposed by Shannon and Weaver in 1949, was employed. This diversity index provides insights into the biotic density of the study Stretch and reveals variations in species richness and evenness across the study area. The value of the Shannon Diversity Index serves as an indicator of species diversity, with higher values signifying greater diversity (Peng *et al.*, 2018). Typically, this index falls within the range of 1.5 to 3.5 in most ecological studies. In some cases, it may be lower than 1.5 or, rarely, higher than 4 (Kessler *et al.*, 2005). The diversity index is calculated as follows:

Shannon Biodiversity Index [equation 1]
Where *H*' = Shannon diversity index,
*Pi* = relative abundance of each species and
*Ln* = logarithm to base *e*.

Species Evenness
Evenness (*E*) = [equation 2]
Where *H*' = Shannon diversity index,
*S* = Total number of species encountered,
*Ln* = logarithm to base *e*,
∑ = sum from species 1 to species *S* and
*s* = number of species (species richness).

Species Richness
Species richness formula = *Pi* [equation 3]
Where *Pi* = relative abundance of each species and
*Ln* = logarithm to base *e* and
*N* = total number of all individuals.

## Result and Discussion

*Fish species composition and dominance*

Overall, for the two seasons, a total of 632 samples of fishes were encountered belonging to 8 species under three families from 30 sampling plots. *Schizothorax richardsonii* Gray was the most dominant (*n* = 518, *RA* = 81.96%) followed by *Psilorhynchus homaloptera* McClelland (*n* = 77, *RA* = 12.18%) and the least dominant was *Pseudecheneis sulcata* McClelland (*n* = 2, *RA* = 0.32%). The overall species diversity of the river stretch was *H'* = 0.68, species evenness $E_H$ = 0.33, and species richness $S_R$= 2.50.

**Table 1:** Overall species diversity and relative abundance of fishes in Suchhu

| Sl. | Order | Family | Species | Count | RA |
|---|---|---|---|---|---|
| 1. | Siluriformes | Sisoridae | *Pseudecheneis sulcata McClelland* | 2 | 0.32% |
| 2. | Cypriniformes | Cyprinidae | *Garra quadratrirostris Menon* | 2 | 0.32% |
| 3. | Siluriformes | Sisoridae | *Parachiloglanis sp1* | 7 | 1.11% |
| 4. | Siluriformes | Sisoridae | *Parachiloglanis sp2* | 8 | 1.27% |
| 5. | Siluriformes | Sisoridae | *Creteuchiloglanis sp. Ng and Rainboth* | 8 | 1.27% |
| 6. | Cypriniformes | Cyprinidae | *Garra birostris McClelland* | 10 | 1.58% |
| 7. | Cypriniformes | Psilorhynchidae | *Psilorhynchus homaloptera McClelland* | 77 | 12.18% |
| 8. | Cypriniformes | Cyprinidae | *Schizothorax richardsonii Gray* | 518 | 81.96% |
| | | | Total | **632** | **100%** |

For the monsoon season, a total of 384 fish samples were encountered belonging to 7 species under 3 families. *Schizothorax richardsonii* was the most dominant (*n* = 297, Relative Abundance [*RA*] = 77.34%) followed by *Psilorhynchus homaloptera* (*n* = 72, *RA* = 18.75%) and the least dominant were *Garra birostris* and *Pseudecheneis sulcata* (*n* = 1, *RA* = 0.26%). The overall species diversity of the river stretch was *H'* = 0.69, species evenness $E_H$ = 0.35 and species richness $S_R$ = 2.32.

For the post-monsoon season, a total of 250 fishes were encountered belonging to six species under three families. *Schizothorax richardsonii* was the most dominant (*n* = 221, *RA* = 88.40%) followed by *Garra birostris* (*n* = 9, *RA* = 3.60%) and the least dominant was *Pseudecheneis sulcata* (*n* = 1, *RA* = 0.40%). The overall species diversity of the river stretch was *H'* = 0.53, species evenness $E_H$ = 0.29 and species richness $S_R$ = 2.09.

Shrestha *et al.* (2023) and Sharma *et al.* (2017) reported the prevalence of certain species in the Himalayan river systems, notably *Schizothorax richardsonii* and *Psilorhynchus homaloptera*. The predominance of *Schizothorax richardsonii* may be ascribed to its wide ecological niche and habitat preferences (Sharma *et al.*, 2021). The reduced evenness in species distribution within this study can be linked to the presence of *Schizothorax richardsonii*, a potential consequence of river segment fragmentation (Sharma *et al.*, 2017).

In contrast, Lin *et al.* (2023) found substantiation that *Pseudecheneis sulcata* exhibits the least dominance among riverine fish species. This observation might be associated with the species' affinity for low-flow river environments, diminished population sizes due to habitat fragmentation, and a comparatively lower predatory efficiency.

*Distribution pattern*

The study identified four prevalent aquatic habitats where the fish populations were captured, namely runs, cascades, ponds, and riffles. Ponds are characterized as sections of the stream marked by their notable depth and slow water currents. In contrast, riffle habitats are distinguished by their shallower depths and presence of swift, turbulent water. Runs are characterized as sections of the stream typified by a moderate current, a continuous water surface, and depths greater than those found in riffles (Lepcha, 2016).

The highest fish population was recorded in riffles, followed by ponds, while the cascade habitat had the lowest numbers. Adult fishes exhibit diverse resource utilization ways, from the sieving of phytoplankton and algae grazing to suction feeding on benthic invertebrates, as well as predation on other fish species, either whole or partially (Bone and Moore, 2008).

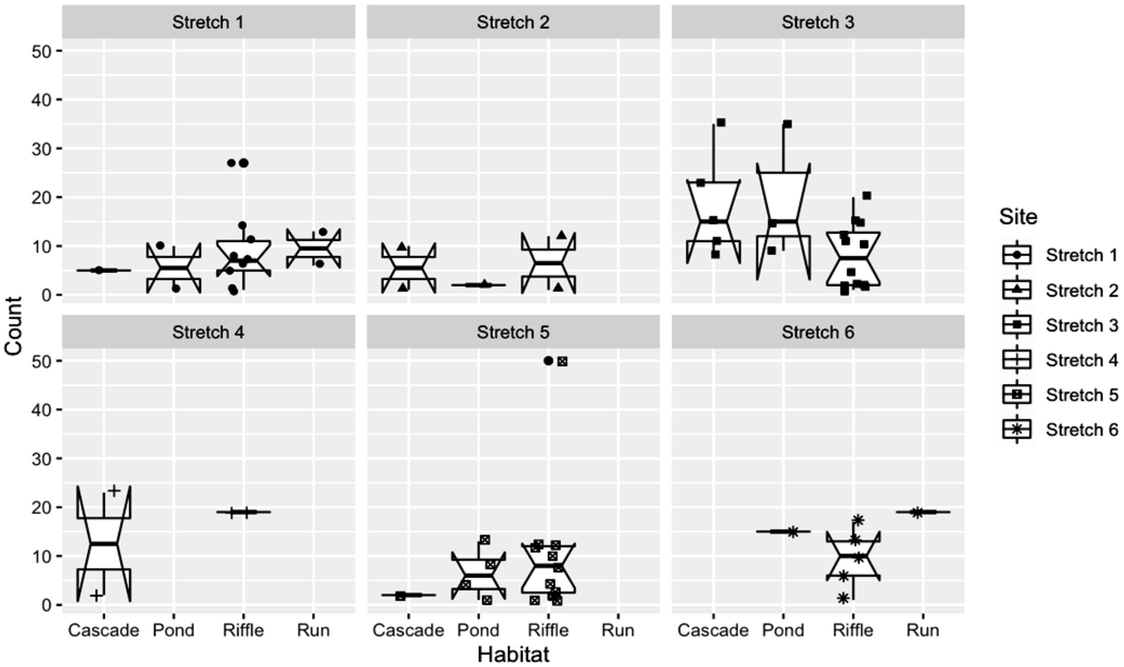


**Figure 3:** Overall distribution of fish in different habitats of the study sites

A Kruskal-Wallis rank sum test conducted to compare fish count between four habitats revealed no significant difference among the habitat groups, $\chi^2(3) = 1.496$, $p = 0.68$. The findings diverge from the report of Wangchuk *et al*. (2017) from Gamri River, Trashigang, Bhutan, in which the riffle habitat exhibited the lowest fish population. This discrepancy in findings may be attributed to the swifter water currents in the run habitat, along with a higher prevalence of riffle and pool habitats within the specific study sites.

In both the seasons, *Schizothorax richardsonii* was ubiquitously recorded in all the sites. Except for two sites (Figure 3), the distribution pattern of fish showed a fluctuating pattern in habitat preference. According to Singh and Agarwal (2013), the distribution of larger fish species is characterized by evenness across various habitat types, rather than a preference for a single habitat type. Furthermore, their observations indicate that these species tend to select their preferred habitat once they have attained an appropriate size. Notably, the juveniles of many species were observed to exhibit a preference for ponds, particularly in shallow side pools, where water velocity is relatively lower, and temperatures are higher in comparison to the deeper mid-stream regions.

Wilcoxon rank sum test with continuity correction was conducted to compare the fish count between two seasons. The test revealed a significant difference in fish counts between the two seasons ($W = 765$, $p = 0.003$). This could be because the monsoon season had a higher catch in overall fish count with a total of $n = 426$ and post monsoon with only $n = 250$ catches.

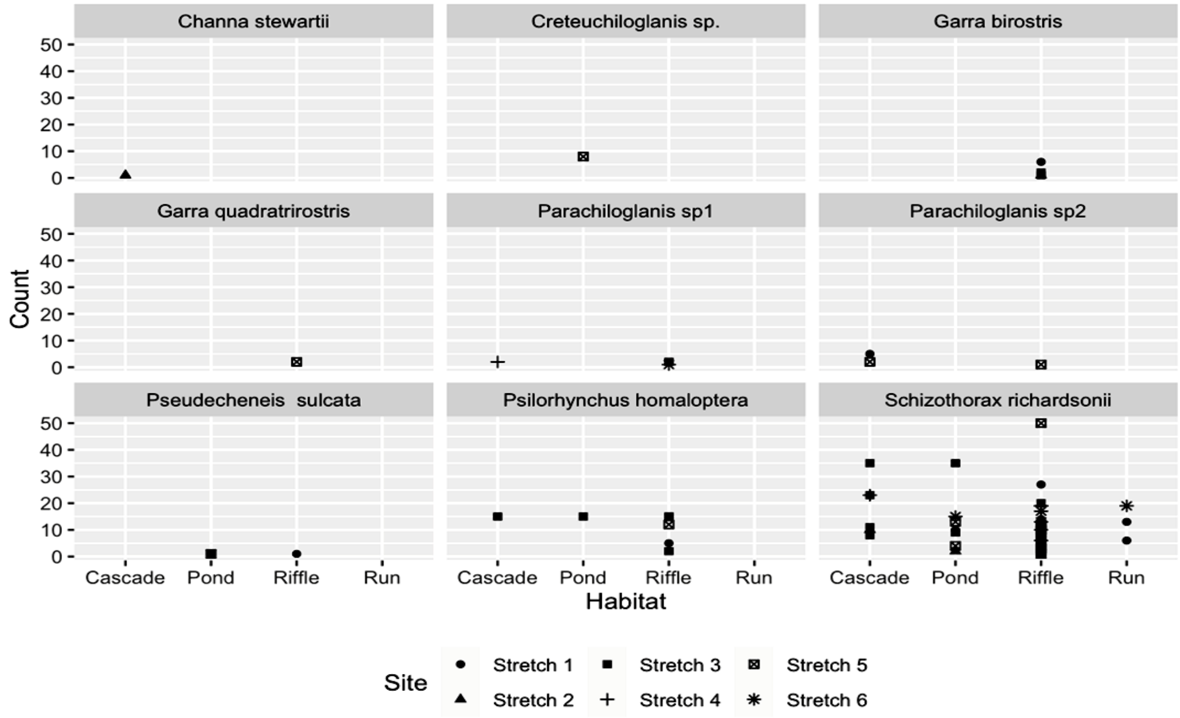


**Figure 4:** Overall distribution of species within different habitats of study sites

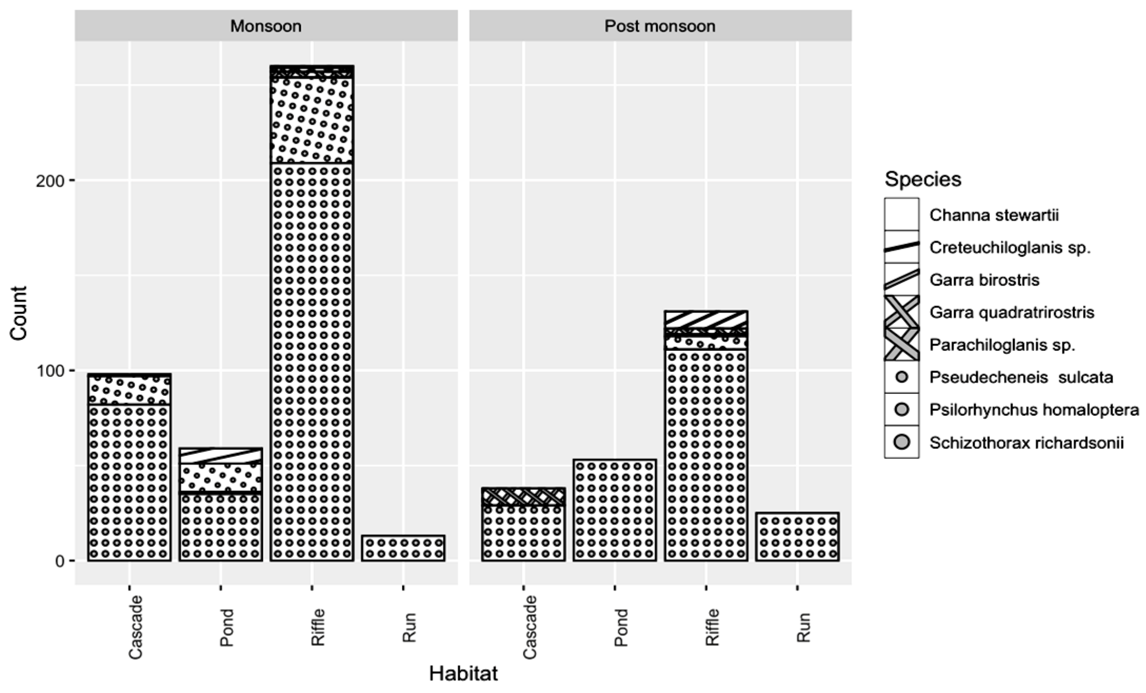


**Figure 5:** Distribution of species within different habitats of study sites in two seasons.

*Macroinvertebrates*

*Species composition and dominance*

A total of 265 samples of macroinvertebrates were collected belonging to 10 families under eight orders. *Heterocloeon* sp. under Baetidae family was the most dominant ($n$ = 115, $RA$ = 43.40%) followed by *Meryx rugosa* under Ulodidae family ($n$ = 55, $RA$ = 20.75%). A total of 10 species were recorded accounting to both the seasons. Overall, the species diversity was found to be $H'$ = 1.73, species evenness $E_H$ = 1.57 and species richness $S_R$ = 0.83.

For the monsoon season, a total of 103 samples of macroinvertebrates were collected belonging to 8 families under 7 orders. *Heterocloeon* sp. under Baetidae family was the most dominant ($n$ = 40, $RA$ = 32.79%) followed by *Meryx rugosa* under Ulodidae family ($n$ = 30, $RA$ = 17.24%). A total of nine species were recorded from the Suchhu. Overall, the species diversity was found to be $H'$ = 1.93, species evenness $E_H$ = 0.88, and species richness $S_R$ = 3.83.

For the post monsoon season, a total of 147 samples of macroinvertebrates were collected belonging to 8 families under 6 orders. *Heterocloeon* sp. under Baetidae family was the most dominant ($n$ = 75, $RA$ = 51.02%) followed by *Epeorus* sp. under Heptageniidae family ($n$ = 33, $RA$ = 22.45%) and the least abundant species were *Agnetina* sp. under the family Perlidae and *Gerris* sp. under the family Gerridae ($n$ = 2, $RA$ = 1.36%). A total of 8 species were recorded. Overall, the species diversity was found to be $H'$ = 1.44, species evenness $E_H$ = 0.69, and species richness $S_R$= 3.23.

The lower species diversity recorded could be attributed to the timing of data collection, which coincided with the rainy seasons. These conditions correspond to lower diversity indices, primarily due to surface runoff from adjacent land use practices causing siltation and compromising the topsoil and nutrient content. Consequently, these factors contribute to diminished oxygen levels (Wangchuk and Eby, 2018), potentially impacting species composition.

Mayfly species such as *Heterocloeon* sp. are recognized as standard bioindicators for the monitoring of water quality (Alhejoj *et al.*, 2020). Ephemeroptera, including mayflies, are particularly sensitive to pollution and are typically restricted to high-quality, minimally polluted aquatic sites. Together with caddisflies and stoneflies, they form the core trio of indices frequently employed in assessing the health of aquatic ecosystems. Their broad habitat range and high sensitivity to pollution render them invaluable as indicators of water quality (Voshewll and Wright, 2002).

**Table 2:** Overall species diversity and relative abundance of macroinvertebrates in Suchhu

| Sl. | Order | Family | Species | Count | RA |
|---|---|---|---|---|---|
| 1 | Plecoptera | Perlidae | *Agnetina sp.* | 2 | 0.75% |
| 2 | Hemiptera | Gerridae | *Gerris sp.* | 2 | 0.75% |
| 3 | Diptera | Tabanidae | *Tabanus sp.* | 7 | 2.64% |
| 4 | Megaloptera | Corydalidae | *Neochauliodes formosanus Asahina* | 11 | 4.15% |
| 5 | Coleoptera | Ulodidae | *Meryx rugosa Saussure* | 15 | 5.66% |
| 6 | Trichoptera | Hydropsychidae | *Arctopsyche sp.* | 18 | 6.79% |
| 7 | Hemiptera | Aphelochiridae | *Aphelocheirus longlingensis Chen* | 19 | 7.17% |
| 8 | Odonata | Cordulegastridae | *Cordulegaster sp.* | 21 | 7.92% |
| 9 | Ephemeroptera | Heptageniidae | *Epeorus sp.* | 55 | 20.75% |
| 10 | Ephemeroptera | Baetidae | *Heterocloeon sp.* | 115 | 43.40% |
| | | | Total | **265** | **100%** |

*Distribution Pattern*

Overall, the tributaries corresponding to Stretch 5 recorded the highest count of macroinvertebrates ($n$ = 75) encompassing eight different species followed by Stretch 4 ($n$ = 37) with six species and the least was recorded Stretch 3 ($n$ = 23) with four species. The higher count in the tributaries account mainly towards the accessibility in the sampling sites especially for the macroinvertebrates as compared to the other sites.

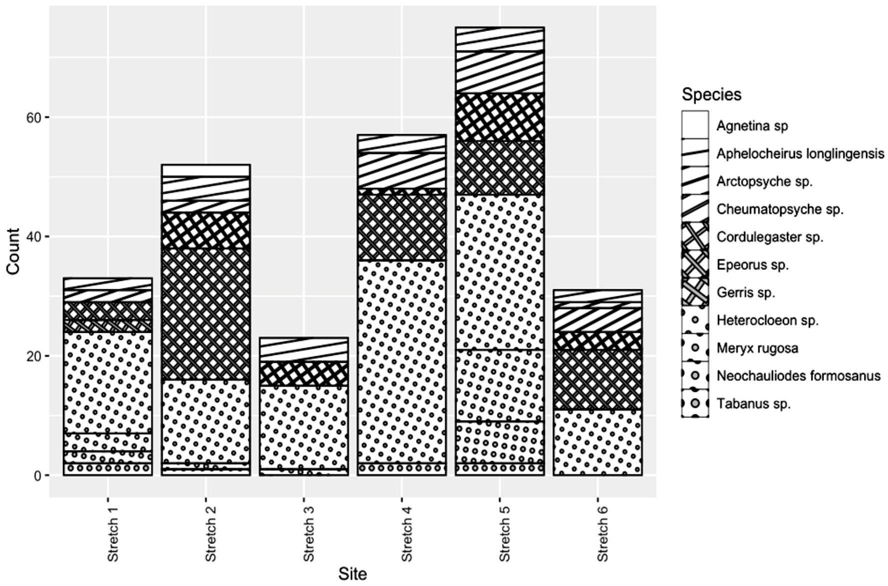


**Figure 6:** Overall distribution pattern of macroinvertebrates in different sites

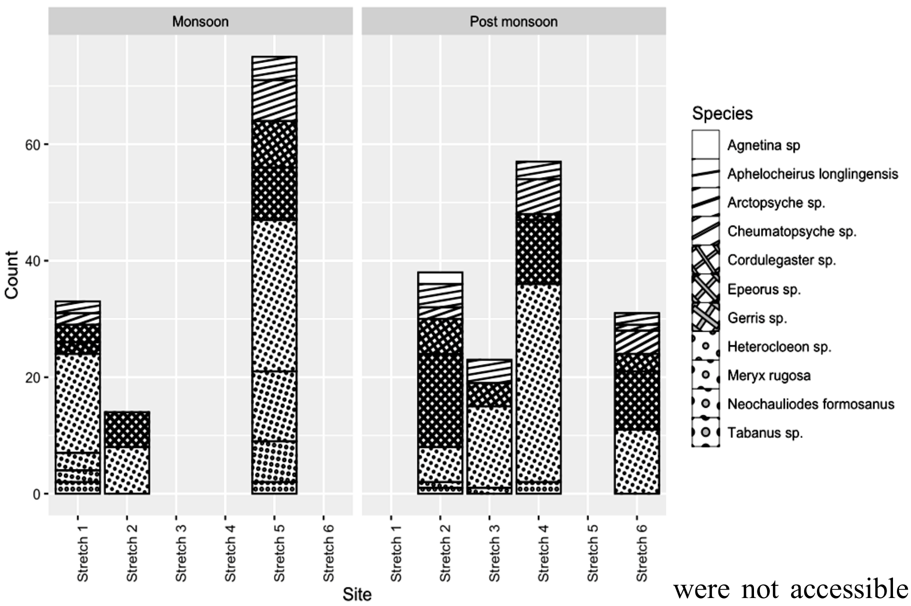


**Figure 7:** Distribution pattern of macroinvertebrates between two seasons

For the monsoon season, the Stretch 2 encompassed the highest count of macroinvertebrates ($n$ = 32) followed by Stretch 5 ($n$ = 30) and the least was recorded from 1-2 km downstream of powerhouse ($n$ = 3). The higher count in the powerhouse and tributaries account mainly towards the accessibility in the sampling sites especially for the macroinvertebrates while other sites were not accessible due to the rugged terrain as well as the higher river discharge during the summer season.

For the post monsoon season, the cumulative species from the tributaries encompassed the highest count of macroinvertebrates ($n$ = 45) followed by intake ($n$ = 38) and the least was recorded from Stretch 1 ($n$ = 12). The macroinvertebrate counts in the tributaries and at the Stretch 4 primarily could be from enhanced accessibility at these sampling locations. Additionally, in contrast to the monsoon season, the macroinvertebrate population increased due to reduced discharge and water velocity, rendering sampling more practicable.

Overall, taking in account all the orders of macroinvertebrates in both the seasons, Ephemeroptera recorded the highest for all the six stretches, which indicates that water is relatively clean and the habitats are intact. The species under the order Ephemeroptera are generally sensitive to pollution.

The order Ephemeroptera was found to be both ubiquitous and the most abundant in all six study stretches during both seasons. Coleoptera species are primarily associated with very clean waters (Allen *et al.*, 2010; Alloys, 2013). Additionally, Ephemeroptera, Plecoptera, Tricoptera, and Odonata have been observed as indicative of clean water conditions (Miserendino and Pizzolon, 2003). Among these, Ephemeropterans were the dominant group, with Ephemerelidae and Beatidae emerging as the most prominent families, found across all zones. However, Simuliidae and Chironomidae, which typically signal ecological degradation in impacted areas (Rai *et al.*, 2020), were notably absent. These findings collectively affirm the good health and quality of the river ecosystem.

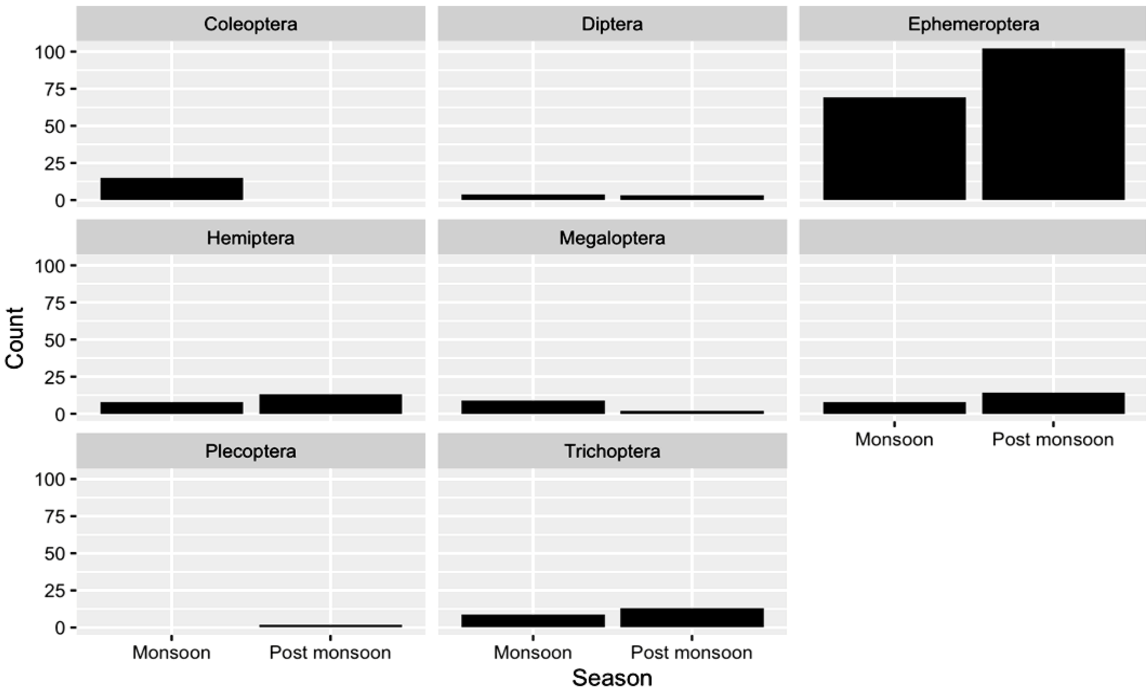


**Figure 8:** Distribution pattern of orders in two seasons

## Conclusion

Suchhu river has good water quality with minimal pollution as indicated by the presence of a diversity of fish and sensitive species of macroinvertebrates such as mayflies under the order Ephemeroptera. The study showed that a total of 632 fishes belonging to 8 species under 3 families and 265 samples of macroinvertebrates belonging to 10 families under 8 orders were encountered from the 30 sampling plots. *Schizothorax richardsonii* was the most dominant species among the fishes ($n$ = 518, $RA$ = 81.96%), while *Heterocloeon* sp. under Baetidae family was the most dominant among macroinvertebrates ($n$ = 115, $RA$ = 43.40%). The overall species diversity for fishes and macroinvertebrates was found to be $H'$ = 0.68, species evenness $E_H$ = 0.33, and species richness $S_R$= 2.50, and $H'$ = 1.73, species evenness $E_H$ = 1.57 and species richness $S_R$ = 0.83 respectively. No rare, threatened, endemic species or endangered species as per IUCN Red List of Threatened species were encountered from the study site.

Assessing water quality through biological parametres, such as the presence of aquatic species such as fish and macroinvertebrates serves as an indicator of healthy water quality. For instance, species within Ephemeroptera order are typically sensitive to pollution and are typically found in high-quality, minimally polluted environments. Alongside caddisflies and stoneflies, they constitute one of the three most commonly used indices for evaluating the health of aquatic ecosystems. The adaptability of the fish and macroinvertebrates to diverse habitats and heightened sensitivity to pollution render them valuable indicators of water quality. The prevalence of aquatic species across all sites could be attributed to limited human development and intervention, as settlements and developmental activities are generally situated at a distance from the river.

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