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Community Structure of Macrozoobenthos from Upstream to Downstream of Purba District, North Sumatra

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Abstract The community and composition of benthic macrofaunal species are determined in three sampling stations from upstream to downstream in Purba District. Sampling was performed in November 2021 during the rainy season. The results showed a population shift from upstream to downstream based on the predominance of insect and mollusk groups. The upstream was populated by *Chironomus* sp. (Insecta: Chironomidae) with 124 ind/m^2, followed by *Helicorbis* sp. (Mollusca: Planorbidae) with 90 ind/m^2, and *Cambarincola* sp. (Oligochaete) with 89 ind/m^2. *Helicorbis* sp. with 298 ind/m^2 had the highest density in the midstream, followed by *Cambarincola* sp. (Oligochaete: Branchiobdllidae) with 285 ind/m^2, and *Melanoides* sp. (Mollusca: Thiaridae) with 184 ind/m^2. Furthermore, *Melanoides* sp. (533 ind/m^2), *Helicorbis* sp. (475 ind/m^2), and *Limnodrilus* sp. (288 ind/m^2, Oligochaete: Naididae) were the three most dominant taxa in the downstream. The Shannon's diversity index (*H'*) in upstream and downstream were both 2.12, while the downstream index was 1.90. There was a significant difference among stations based on relative taxa density ($F_{2,8}$ = 14.16, p = 0.005). Therefore, further research on other taxa groups, such as plankton and fish, should be conducted to increase the understanding of the anthropogenic effect on stream conditions in the Purba District.

Keywords Benthic Macrofauna, Correspondence Analysis (CA), North Sumatra, Spatial Distribution

1. Introduction

Water pollution is a global concern because it affects water quality and limits its usage for various purposes. Urban wastewater, agricultural runoff, and industrial discharge, which all flow directly into the catchment area and the rivers, are the primary sources of water pollution [20, 24]. Several physicochemical and microbiological standards are met before water can be used for drinking, farming, or recreational purposes to protect people and the environment. As a result, the quality is regularly monitored by assessing various physicochemical, microbiological, and biological parameters important for ecological and environmental health assessments. Globally, there is an increasing interest in monitoring freshwater habitats in order to maximize their value for commercial, ecological, and recreational purposes [18].

Unlike classic physicochemical evaluation methodologies, biological indicators provide a cumulative measure of ecosystem health based on the combined reactions of the targeted populations to all sorts of stressors experienced in the aquatic habitat [17]. As a result, by studying the species richness and community structure of a subset of organisms, it can provide an overall index of ecosystem health. Many studies have found that physicochemical conditions only indicate water quality at the time of sampling, whereas biological communities provide a more accurate reflection because they are continually changing [14]. Several species of freshwater organisms, including macrozoobenthos or benthic invertebrates, have been used to assess aquatic ecosystems. Furthermore, they are sensitive to chemical and physical stress and have been widely used as a good indicator of environmental status [5].

Purba District is part of the Simalungun Regency Development III sub-region and has the potential as a tourism area, agriculture for food commodities, and plantation land for horticultural commodities. Several rivers flow through this sub-district, including the Sigiring-giring River, the Siborobuttu River, and the Simanggohi River [2]. The upstream area is designated as a forest area with shrubs, and the river flow from this point passes through midstream and downstream areas that intersect with agricultural and human settlement areas. Agricultural runoff from various plantations, including coffee, tobacco, and cloves, is a pressure on the existing freshwater community. Then there will undoubtedly be an effect, such as an alteration in the dynamics of the quality of water resources not only in rivers but also in the waters of Lake Toba as a large water reservoir. The river created aquatic ecosystems that play an important role in the hydrological cycle and serve as a water catchment area for the nearby lake [9].

The use of macroinvertebrates in the biological assessment of water bodies has several advantages, the most important of which are the sampling technique and the lesser field requirements. Benthic macroinvertebrates are common and can be found in almost any aquatic habitat. Different groups have different environmental needs and pollution tolerances. They provide food for a variety of fish species. Small-order streams are often devoid of fish but rich in macroinvertebrate communities. Benthic invertebrates serve as indicators of local environmental conditions because they have limited mobility, their body size is ideal for easy collection and identification, and the sampling is simple and inexpensive [7]. There has been little research on the diversity and density of macrozoobenthos around rivers in Lake Toba. A previous study documented a diversity of 26 macrozoobenthos species in the Naborsahan River, which flows into Lake Toba, with no dominance of certain species based on observations at three different stations, indicating a homogeneous distribution in the river flow [3]. This study attempts to use the data on macrobenthos assemblages as an indicator of prospective environmental changes in the Purba region across a recent spatiotemporal scale, rather than giving an extra environmental impact assessment.

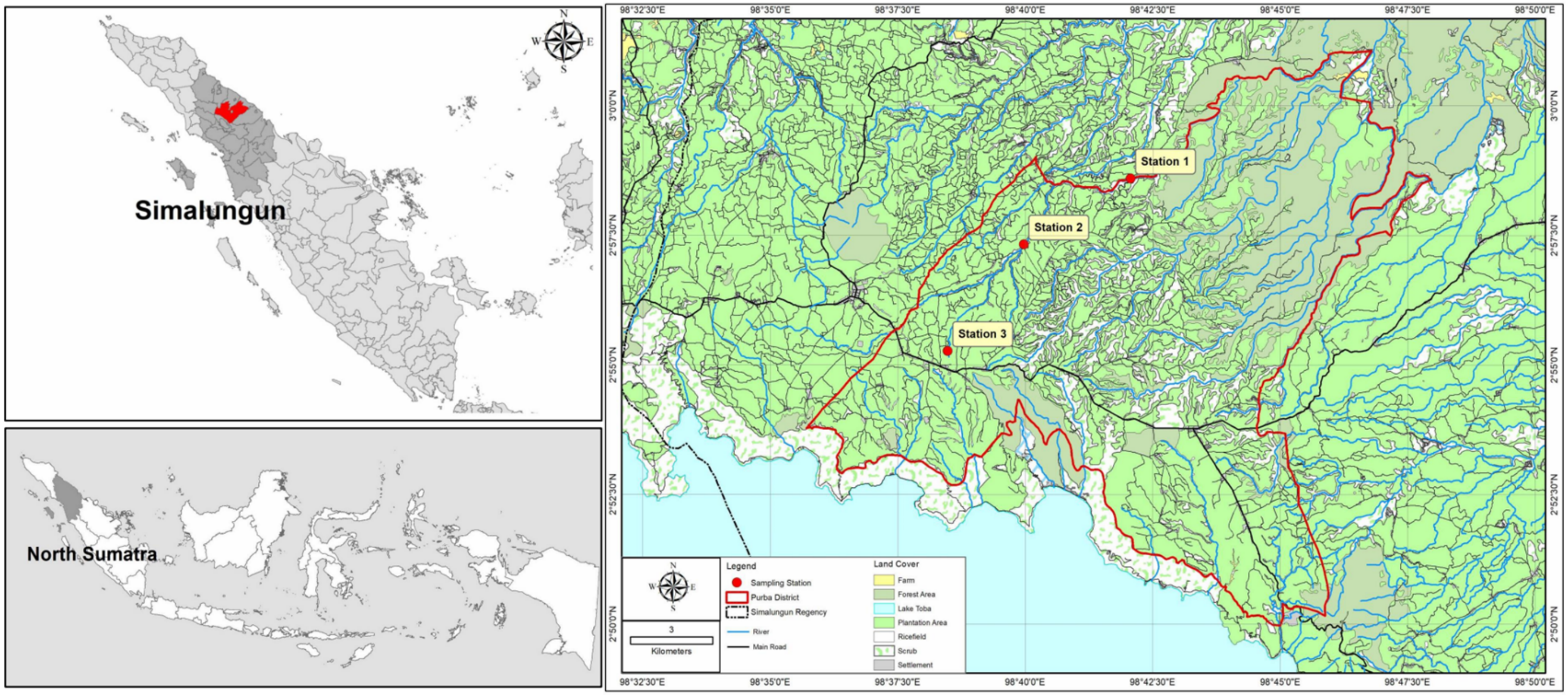
2. Methodology

Study Area and Sampling Site

This study was conducted in November 2021 during the rainy season along the rivers that flowed from upstream to downstream in Purba District, Simalungun Regency, North Sumatra (**Fig. 1**), which was situated in the northern portion of Lake Toba. Three stations represented the sampling site. Station 1 is an upstream characterized by the absence of anthropogenic activity; Station 2 is a midstream characterized by the presence of populated or residential area, and Station 3 is a downstream characterized by the presence of intensive agricultural activities and residential area.

Benthic Macrofauna Collection and Identification

Benthic macrofauna samples were collected using an Ekman-Birge grab (±0.0025 m^2) with sediment penetration to a depth of 25 cm [22]. Three samples were collected from each station and were sieved through a 1 mm^2 mesh sieve. Furthermore, the residue materials were collected and preserved in a plastic bag containing the anaesthetizing solution of $MgCl_2$. The preserved materials were labeled, kept at cold temperatures, and transported to the laboratory for further analysis. Subsequently, the samples were rinsed in the laboratory, sieved (0.5 mm^2), and sorted manually. The benthic macrofauna was identified to the lowest possible taxonomic level using some identification guides [8, 25, 6].



Station 1 = Upstream, Station 2 = Midstream, Station 3 = Downstream.

Figure 1. Map of the sampling area in Purba District, Simalungun Regency, North Sumatra

Data Analysis

Numerical data were analyzed using the descriptive-quantitative approach. Each species' density (ind/m^2) was calculated and tested statistically using ANOVA generated from Minitab ver. 17.0. The following formula calculates relative species abundance (%).

$$Relative\ species\ abundance\ (\%) = \frac{ni}{N}\ x\ 100$$

Where ni is the number of individuals of a species, N is the total number of individuals in an area. Ecological indices such as Shannon's diversity index (*H'*), dominance index (*D*), equitability index (*J*) between stations, and correspondence analysis (CA) of benthic macrofaunal abundances were generated using PAST ver. 4.03.

3. Results and Discussion

A total of 3,921 individuals were collected from upstream to downstream in Purba District during the four weekly investigations in November 2021. Based on the species composition, the community was grouped into the following higher taxa (orders or classes): Insecta (5 species), Mollusca (5 species), Oligochaete (3 species), and Hirudinea (1 species). This study documented 14 species of benthic macrofauna belonging to 12 families, as shown in **Table 1**. Insects and molluscs were the dominant groups at each sampling station with varying densities. Most insect species have been identified as beneficiaries of environmental pollution monitoring and pollutant assessments [16]. Furthermore, macrobenthic mollusks are essential bioindicators, with some population shifts when exposed to certain environmental pressures and xenobiotics [19]. The highest density of benthic macrofaunal species in upstream was *Chironomus* sp. (Insecta: Chironomidae) with 124 ind/m^2, followed by *Helicorbis* sp. (Mollusca: Planorbidae) with 90 ind/m^2, and *Cambarincola* sp. (Oligochaete) with 89 ind/m^2. *Helicorbis* sp. with 298 ind/m^2 had the highest density in the midstream, followed by *Cambarincola* sp (Oligochaete: Branchiobdllidae) with 285 ind/m^2, and *Melanoides* sp (Mollusca: Thiaridae) with 184 ind/m^2. *Melanoides* sp. (533 ind/m^2), *Helicorbis* sp. (475 ind/m^2), and *Limnodrilus* sp. (288 ind/m^2, Oligochaete: Naididae) were the three most dominant taxa in the downstream. Regarding population density, the Chironomidae larvae decreased from midstream to downstream along the river flow. Chironomid larvae have been reported as a bioindicator species in river habitats, but their tolerance varies across species and can range from heavily to lightly polluted sites [13]. According to this study, chironomids have a low tolerance to pollutants, hence, their population is higher on the upstream side of the river in the Purba District. Furthermore, the molluscs, *Helicorbis* and *Melanoides*, were observed to experience a shift in population density in the midstream and downstream. Freshwater molluscs, including gastropods, are hololimnic organisms with limited mobility and thus serve as good bioindicators of habitat changes [11].

Table 1. Spatial distribution and density (ind/m^2) of benthic macrofauna from upstream to downstream in Purba District

No.	Taxa	Station 1 (Upstream)			Total	Station 2 (Midstream)			Total	Station 3 (Downstream)			Total
		R1	R2	R3		R1	R2	R3		R1	R2	R3	
1	*Ecdyonurus* sp. Lv (Insecta)	15	10	12	37	8	0	0	8	0	4	4	8
2	*Chironomus* sp. Lv (Insecta)	46	55	23	124	37	25	0	62	0	12	19	31
3	*Cambarincola* sp. (Oligochaete)	17	26	46	89	87	98	100	285	157	96	31	284
4	*Ephemerella* sp. Lv (Insecta)	25	0	0	25	12	0	0	12	0	0	0	0
5	*Glossiphonia* sp. (Hirudinea)	0	0	0	0	0	0	0	0	12	15	0	27
6	*Helicorbis* sp. (Molluscs)	0	34	56	90	117	82	99	298	227	103	145	475
7	*Helix* sp. (Molluscs)	0	0	0	0	17	32	14	63	44	20	0	64
8	*Hydropsyche* sp. Lv (Insecta)	39	13	0	52	44	78	19	141	0	0	0	0
9	*Limnodrilus* sp. (Oligochaete)	0	0	0	0	0	23	9	32	144	47	97	288
10	*Melanoides* sp. (Molluscs)	0	25	0	25	50	57	77	184	149	203	181	533
11	*Pomacea* sp. (Molluscs)	0	0	0	0	14	12	35	61	72	69	28	169
12	*Rhithrogena* sp. Lv (Insecta)	12	25	35	72	0	0	0	0	0	0	0	0
13	*Theodoxus* sp. (Molluscs)	23	17	0	40	71	0	0	71	0	0	0	0
14	*Tubifex* sp. (Oligochaete)	0	0	13	13	34	32	15	81	91	54	32	177
	Total	177	205	185	567	491	439	368	1298	896	623	537	2056

Lv = larvae, R1, R2, R3 = replication

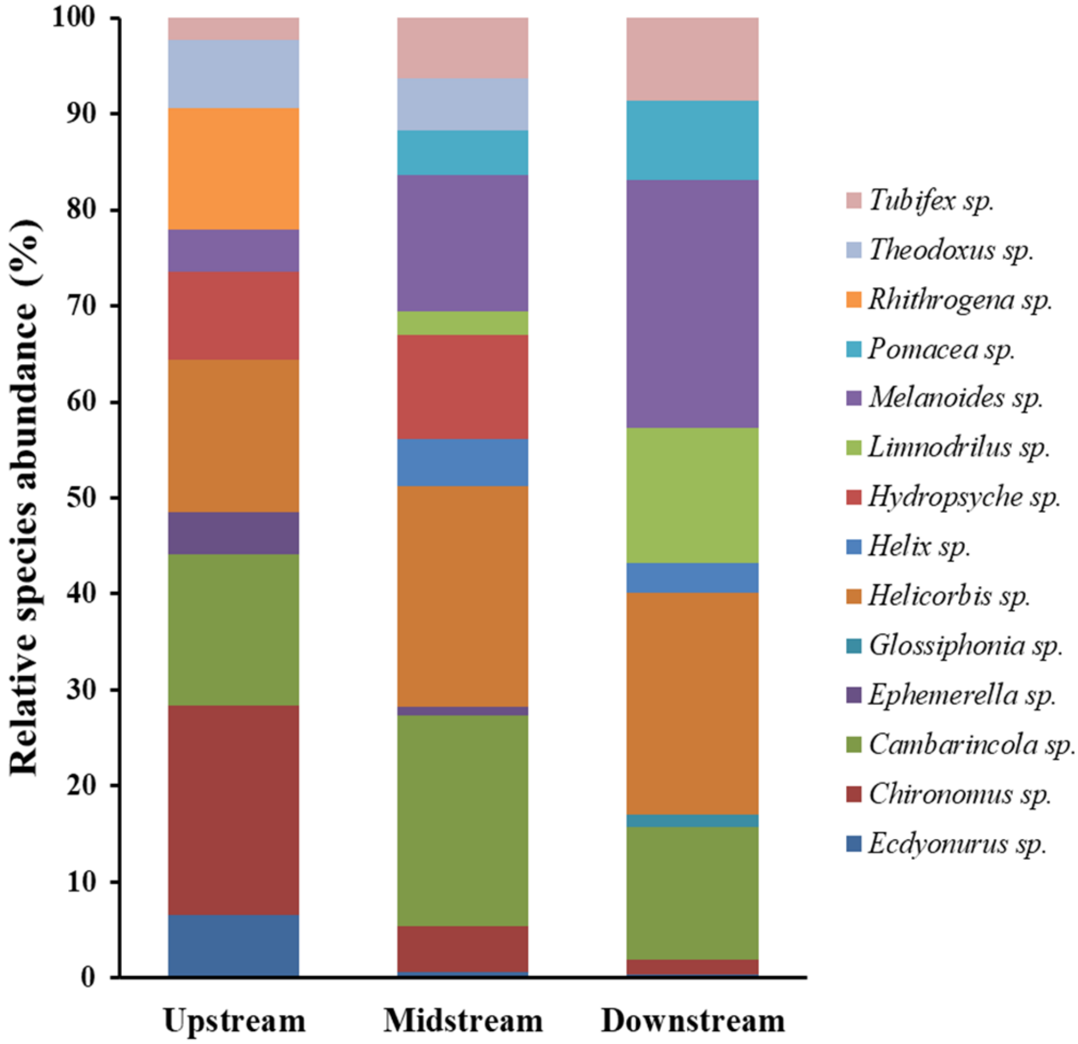
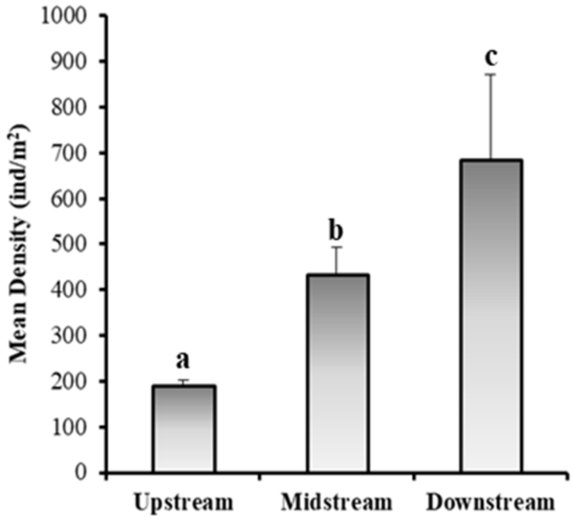


Figure 2. The benthic macrofaunal assemblage from upstream to downstream of Purba District as expressed in relative species abundance (%)

There is a varied spatial distribution of the macrozoobenthic community along the streams in the Purba District as depicted in **Fig. 2**. The dipteran larvae, *Chironomus* sp. were mostly abundant in the upstream, then decreased in the midstream and downstream. The annelids, *Cambarincola* sp. occupied the higher position in the midstream than upstream and downstream which was relatively stable in terms of density. The bivalves, *Helicorbis* and *Melanoides* sp. have a high population level, peaking in downstream. Chironomids can indicate poor water quality because they are resistant to organic and industrial pollutants, so their presence and dominance are effective biological indicators of stream pollution [26]. Furthermore, the presence of metal-resistant bivalves strongly validates the moderate-to-poor stream quality as impacted by human interferences. Bivalves can accumulate significant amounts of metals from the environment and have been used in chemical monitoring (identifying and quantifying pollutants) and biomonitoring (estimation of environmental quality) [27]. We initially assumed that the upstream sites would have stable macrozoobenthos communities in terms of diversity and specific taxa. The presence of chironomids, on the other hand, began to suggest that the historical conditions were biologically polluted. A one-way ANOVA was performed to compare the total density of benthic macrofauna from upstream to downstream in the Purba District, as demonstrated in **Fig. 3**. The results showed a statistically significant difference in station density mean ($F_{2,8}$ = 14.16, p = 0.005). Furthermore, multiple comparisons using Tukey's HSD test revealed a significant difference between upstream and downstream (p = 0.004) but not between upstream and midstream (p = 0.089) or midstream and downstream (p = 0.078). **Fig. 4** presents the ecological index for the benthic macrofaunal community among stations. The Shannon's diversity index (H') in upstream and downstream were both 2.12, while the downstream index was 1.90. The diversity of macrozoobenthos was then categorized as moderate [10]. In communities with stable environments, diversity is higher than in communities with disturbed conditions.

According to Wilhm and Dorris [23], the environmental quality may be assessed through a species diversity scale (*H'*>3 = clean water, *H'* = 1–3 = moderately polluted, *H'*<1 = heavily polluted), while the inland rivers in Purba District are moderately polluted from upstream to downstream. Additionally, the benthic macrofaunal community showed an unequal abundance of different species based on each station's indexes of dominance (*D*) and equitability (*J*). An increase in the Simpson's index (*D*) indicates that the pollution load has increased. Some benthic macrofaunal species may have become intolerant of increased pollution and have vanished, resulting in a few species that have developed increased tolerance for adverse conditions. The equitability index (*J*) aims to evaluate the uneven representation of species in comparison to a hypothetical community where all species are equally prevalent. This implies that just a few species are numerous, whereas the majority are uncommon or missing, suggesting the uneven representation of most species. The results showed that the inland rivers in Purba District have the most equitable distribution of species [15].



Error bars represent mean ± standard error
Different letters above the error bars indicate significant differences at the 0.05 and 0.01 levels.

Figure 3. Relative density (ind/m^2) of benthic macrofaunal community

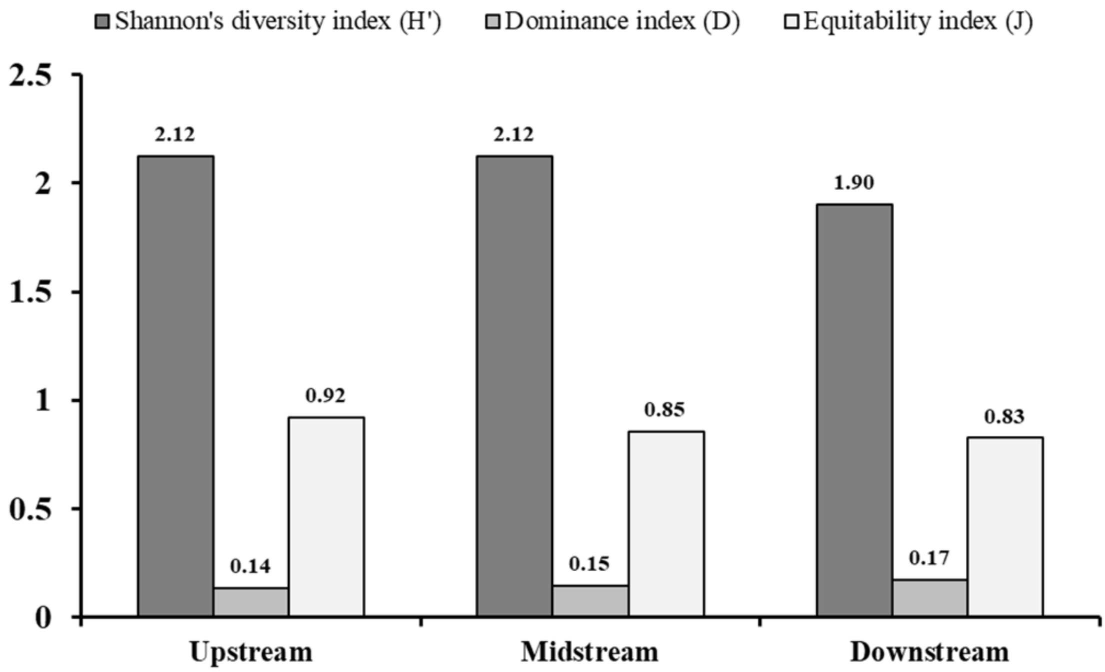


Figure 4. Ecological index of benthic macrofauna in Purba District

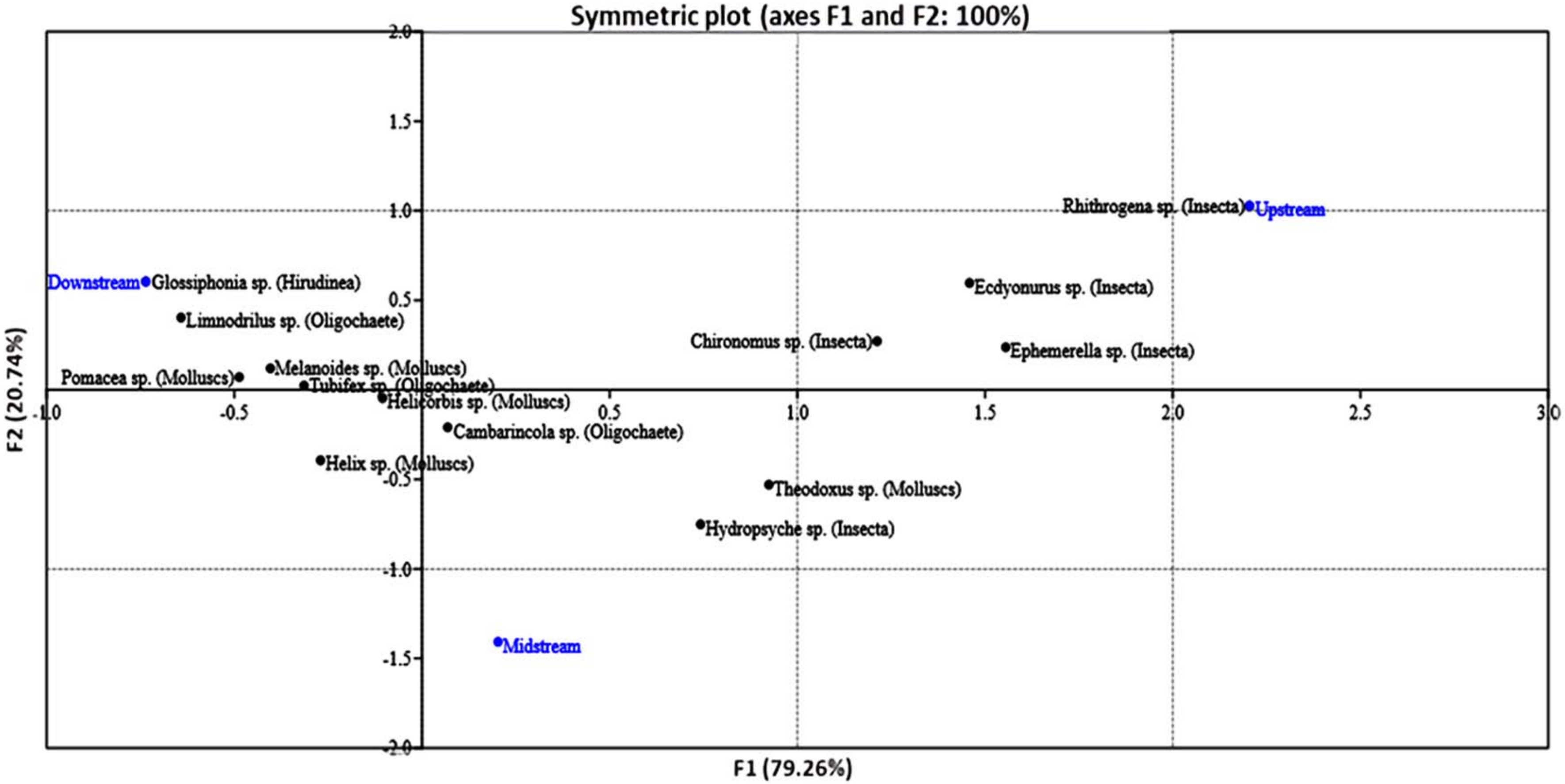


Figure 5. Correspondence analysis (CA) of abundances of benthic macrofauna in Purba District

Correspondence analysis (CA) was used to observe the spatial effect on the distribution and abundance of the benthic macrofaunal community from upstream to downstream, as presented in **Fig. 5**. The plot of benthic macrofaunal abundances separated the upstream and downstream along the F1 axis describing the most significant part of data variances (79.26%). The position of benthic macrofaunal taxa on the CA quadrant was generated, indicating that *Rhithrogena* sp (Odonata: Heptageniidae) was specialized to occupy the upstream habitat. Furthermore, almost all insects existed upstream except *Hydropsyche* sp (Trichoptera: Hydropsychidae), which was positioned within the midstream quadrant of the CA plot. The genus, *Rhithrogena* (nymphs) is a group of insects that primarily occupy the cold, fast-flowing, and well-oxygenated upstreams [21]. Half of the benthic macrofaunal community significantly overlapped from midstream to downstream habitats. The results could be attributed to similar pressures exposed by anthropogenic activities at each station, which then alter the environmental conditions favorable to the composition of benthic macrofaunal communities [4]. Sedimentation and nutrient loading (heavy metal exposure) due to agricultural activities in the stream may have an influence on the occurrence and density of certain benthic taxa, especially in the midstream and downstream areas [28, 29].

This study has several data limitations that require deeper investigation, including the substrate condition in each station i.e clay, sand, and silt [1]. Other studies also reported that the occurrence of benthic macrofauna was related to water velocity for species dwelling on the surface or with low mobility [12]. Therefore, further research on other taxa groups, such as plankton and fishes, is needed to increase the understanding of the habitat condition related to the anthropogenic effect on stream conditions in the Purba District.

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