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Environmental assessment of Sungai Perai, Penang, by using zooplankton as a bio-indicator

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Abstract

Zooplankton are crucial as bioindicators and aid in determining the level of water contamination. The effects of environmental disturbances can be detected through changes in species composition, abundance, and body size distribution of zooplankton. Using a plankton net, samples were collected from eight sampling sites during the neap and spring tides of January, February, April and May 2024. A total of 67 zooplankton taxa were recorded, including 44 Rotifera, 12 Cladocera, and 11 Copepoda. The predominant species viz: *Brachionus calyciflorus*, *Anuraeopsis fissa*, *Filnia longiseta*, *Filinia terminalis*, *Moina* sp, *Calanus* sp, *Cyclops* sp, *Brachionus angularis*, *Brachionus urceolaris*, *Argonotholca foliaceae*, *Asplachna* sp, *Testudinella* sp, and *Adineta vaga* were recorded in all the sampling sites in the river. The abundance of these species in any water body indicates a high degree of eutrophication in the river. *Moina, Daphnia, and Cyclops* also indicate the intrusion of organic matter and nutrients from runoffs and drains into the river. The Shannon H' are 1.37, 1.34, 1.27, 1.33, 1.28, 1.36, 1.42, and 1.31 for sites A, B, C, D, E, F, G, and H respectively indicating the presence of contaminants in the river. The community structure of the zooplankton of Sungai Perai is influenced by factors such as tidal events and water quality parameters such as nutrients, dissolved oxygen, and temperature. This study demonstrated that zooplankton could indicate the condition of the Sungai Perai through changes in its community structure, distribution pattern, and abundance of vulnerable genera and species.

Keywords: Allochthonous, Bioindicator, Environmental assessment, Eutrophic, Zooplankton

1. Introduction

Estuaries are areas of transition where freshwater and marine water combine, connecting rivers to the sea (Gazeau et al., 2005). They play a significant role in the land-sea interaction and are very susceptible to disturbance from both intense human activity and climate change. Rivers in estuaries are impacted by a variety of human activities, including thermal water discharge, harbors, industrial waste, and domestic sewage (Li et al., 2021). Since the river often occupies the lowest-lying parts of the landscape, it always reacts to disturbance stressors by sinking different chemical pollutants from point and non-point sources (Woodward et al., 2012). A critical aspect of the dangers arising from the extensive application of detergents and surfactants in domestic, agricultural, and industrial contexts in recent years is the contamination of coastal and riverine ecosystems. Notwithstanding Malaysia's increasing urbanization and industrialization, the nation's sanitary sewage systems, including those in densely populated and urbanized regions, remain of inferior quality (Alkhadher et al., 2023). Monitoring the ecosystems of rivers and estuaries impacted by land-based pollution, including industrial and municipal effluent, is essential. This monitoring facilitates the identification of potentially harmful pollutants and negative effects on the marine ecosystem, supplying crucial data for prospective environmental management and conservation initiatives (Masood et al., 2016).

The zooplankton community plays a crucial role in the transfer of energy within aquatic ecosystems and in the regulation and structure of the food webs in these environments (Shah et al., 2018). Zooplankton are extremely responsive to environmental fluctuations and frequently undergo swift changes in their abundance and variety because of environmental disturbances (Golmarvi et al., 2018). Fluctuations in the abundance, diversity, and community composition of zooplankton can indicate the change or disturbance of the environment; it has been reported by several studies that zooplankton can serve as an indicator of changes in trophic dynamics and the ecological state of aquatic environments related to changes in nutrient loading and climate (Rogers et al., 2020). Because zooplankton communities adapt quickly to environmental changes, they are useful as bioindicators for determining the health of aquatic ecosystems (Guermazi et al., 2023). The effects of pollution, nutrient loading, and habitat modifications can be reflected in their diversity, abundance, and community composition. Estuarine zooplankton assemblages are closely correlated with variations in the surrounding physico-chemical parameters throughout the tidal and diurnal cycles, in contrast to other aquatic environments (Marques et al., 2009).

In estuaries, tidal oscillation causes considerable water layer movement, which creates extremely dynamic salinity regimes that affect zooplankton population dispersion (Chew et al., 2015). Continuous monitoring of zooplankton community structures over an extended period yields valuable insights on changes in the environment (Ismail et al., 2022). Learning and figuring out how the dynamics of the zooplankton community change over time can also offer a profound understanding of how the ecosystem functions. This understanding serves as the foundation for creating predictive models based on anthropogenic and natural changes in the environment, particularly those brought on by changes in climate (Tommasi et al., 2013). Research on the abundance and distribution of zooplankton species would establish reference points for the impacted aquatic environments. To improve the use of zooplankton as bioindicators, more research is needed, particularly studies on how different species react to environmental stressors and pollution. Guidelines for their use in different aquatic habitats can be informed by this research. This study aims to determine the prevalence and spatial distribution of zooplankton species, as well as the factors that influence their abundance and dispersion in Sungai Perai. The specific objectives of the research are: (i) to assess the zooplankton diversity of the river (ii) to evaluate the water quality of the river (iii) to determine the relationship between the zooplankton and the water quality of the river (iv) to determine the pollution indicators among the zooplankton species identified in the river. The hypothesis for the research is that environmental factors, tides and seasons significantly influence the abundance and diversity of specialized indicator taxa of Sungai Perai.

2. Materials and Methods

Study area

Sungai Perai (5° 22' 59.99" N & 100° 21' 59.99") is in the state of Penang, Malaysia. Sungai Prai, another name for the Sungai Perai or Perai River, is a significant river in Seberang Perai, Penang, Malaysia. It divides Butterworth from Prai to the north, winding through the mangrove flatlands of Seberang Perai before emptying into the channel. Pollution has been an issue for the Sungai Perai, especially from industrial runoff and urban activity. According to studies, the river has higher than average pollution levels, which raises questions about the health of the ecosystem and possible effects on human health (Foo et al., 2021).

Sampling Design

A boat was used for transport to all the sampling locations due to safety concerns. Eight sampling stations along Sungai Perai downstream to midstream were used to evaluate the composition and distribution of zooplankton as well as the factors about water quality (Figure 1). The sampling sites consisted of tributaries and significant drains directly draining into the main river. The climate of Penang according to the data from the Department of Meteorology Malaysia showed that Penang has a prolonged rainy season period from April to December and a brief dry season period from January to March. Sampling was done bimonthly during the neap and spring tides of January, February, April, and May 2024. January and February represent the dry season period while April and May represent the rainy season period. The tide table according to Kedah Pier Port tidal prediction was used to determine the neap and spring tide periods (Malaysia Marine Department, 2024). One-liter clean plastic sample bottles were used to store river water for water quality analysis following minimal standards of (APHA, 2017). After collecting samples, the bottles were stored in an icebox to stabilize the samples. At every sampling point, 40 liters of river water was collected using a 5-litre Van Dorn water sampler at 0.3-meter depth. For the zooplankton sampling, the water was then filtered through a 35-micrometer-mesh Wisconsin plankton net. This size is optimal for capturing small zooplankton, such as rotifers and small copepods, which typically range from about 20 to 200 microns in size .After that, the filtrate was put in a 100 mL plastic bottle and kept there for zooplankton analysis in 70% ethanol. Every sample bottle has the correct labeling and is capped properly (Ismail et al., 2022). All samples were collected in triplicates at each of the sampling points at a similar period. This is to provide estimates of the variability within the area.

Water quality assessment

Some water quality parameters were measured *in situ.* This includes pH, Electrical conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS)Salinity (Sal), Transparency (TRPC), Dissolved Oxygen (DO), and Temperature (Temp). EC, TDS, Sal, Temp, and DO were measured using YSI ProQuatro Multiparameter Meter SKU: 606950 United States of America (USA). pH was measured using the LAQUAtwin- pH-33 pH meter by HORIBA Japan. All the meters used for *in situ* measurements were calibrated in the lab before use. A 20cm diameter Secchi disc was used to measure the water's transparency (TRPC). The disc was dipped into the river until the disc vanished, at which point the depth was noted. After that, it was cautiously removed and plunged even more, and the depth at which it became visible was also noted. The average of the two readings is the value of transparency in feet (ft) (APHA, 2017). Biochemical oxygen demand (BOD), Phosphate (PO_4), Nitrite (NO_2), Ammonia (NH_3), Total suspended solids (TSS), and Chlorophyll-a were determined using standard procedures described (Radojević & Baškin, 2006).

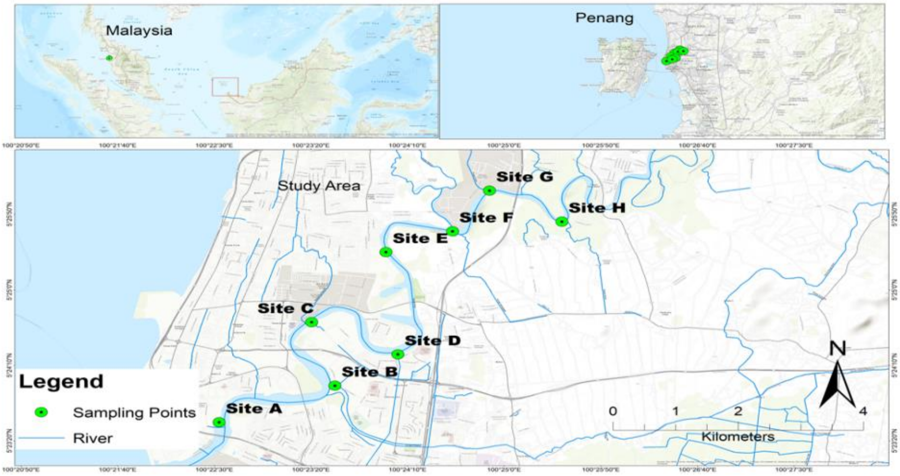

Figure 1. Map of Sungai Perai showing the sampling sites

Zooplankton assessment

In the laboratory, the sample bottle with the zooplankton was gently shaken to achieve uniform specimen distribution. Next, using an adjustable volume pipette, one milliliter of the sample was transferred into a Sedgwick-Rafter counting cell. Using a coverslip, the sample was covered at a 45-degree angle to prevent the formation of air bubbles. A compound microscope (Motic BA41 Hong Kong) with a camera adjusted for 4x and 10x magnification was used to examine the specimens (Ismail et al., 2022). The images were captured, and identification and classification were done using keys (Center for Freshwater Biology, 2013; Dang et al., 2015; Fernando, 1963). The zooplankton species per cubic meter was determined using the formula:

$$N = n\,(v/V) \times 1000$$

Where:

N: Total number of zooplankton per cubic meter.
n: Average number of zooplankton in 1 ml of the sample.
v: Volume of zooplankton concentrate (ml).
V: Volume of total water filtered (L) (Aboul Ezz et al., 2014).

Data Analysis

All the data collected in the present study were tabulated and appropriate graphs were constructed. The data were statistically treated to find biological indices. The diversity index was determined using the Multivariate Statistical Package (MVSP) 3.1. Pearson Correlation coefficient (r) analysis was computed using GraphPad Prism 7 software for the zooplankton with the water quality parameters at $p \leqslant 0.05$.

3. Results

Water quality analysis

The mean values of the water quality parameters of Sungai Perai during the study period are shown in Table 1. EC values 0.12 µS/cm at site G (neap tide) to 413 µS/cm at site A (spring tide), TDS varied from 73.23 mg/L at site G (neap tide) to 98,466 mg/L at site A (spring tide), Salinity ranged from 0.05 ppt at G (neap tide) to 60.87 ppt at site A (spring tide). pH values ranged between 6.4 to 7.8. The lowest and highest pH values were recorded at sites B and C respectively during spring tide. The highest and lowest values of DO (1.83-10.74 mg/L) were recorded at sites E and C during spring and neap tide respectively. BOD values ranged from 0.24 mg/L at C (spring tide) and neap tide at site F to 7.14 mg/L at D (spring tide). Site E has the lowest TSS value of 0.01 mg/L (spring tide) and the highest value of 0.43 mg/L (spring tide) at site E. PO_4 concentrations ranged between 0.27 mg/L at site B to 4.41 mg/L at site A. Both the highest and the lowest values of PO_4 were recorded during the neap tides. Transparency was lowest at site F (0.1 ft) during neap tide and was highest at site B during spring tide (6 ft). NO_2 values range from 63.83 µg/L at site A to 109.6 µg/L at site E. Both the highest and lowest values were recorded during neap tide. NH_3 ranges between 0.5 mg/L at site A to 0.74 mg/L at sites A and H. The highest and the lowest values were recorded during neap tide. Temperature values are between 28.9° C to 31.27° C. The lowest temperature was recorded during neap tide at site H while the highest temperature was recorded at site D during spring tide. Chlorophyll-a value ranges between 0.26 µg/L in site D to 6.89 µg/L in site A. The highest chlorophyll values were recorded during the spring tide while the lowest chlorophyll values were recorded during neap tides. EC, TSS, pH, DO, BOD, PO_4, TRPC, NO_2, NH_3, and Temperature showed no significant difference ($P>0.05$) spatially across the sampling sites, while TDS, Salinity, Temperature and Chlorophyll-a showed significant spatial variation ($P<0.05$). The results from the T-test showed that there is a significant difference in EC, TSS, PO4, and NO_2 ($P<0.05$) and a very high significant variation ($P<0.01$) in NH_3, pH, TDS, TRPC, and salinity showed during spring and neap tides.

Zooplankton composition of Sungai Perai

A total of 67 zooplankton species with a population of 3442 individuals per cubic meter (m^3) belonging to Rotifera, Copepoda, and Cladocera were recorded at Sungai Perai during the study period. The Rotifers have the highest taxa and individuals with 2665 individuals/m^3 (77.4%), followed by Copepoda with a total of 475 individuals/m^3 (13.8%) and Cladocera with 302 individuals/m^3 (8.8%) (Figure 1). The order Ploima has the highest species with a total of 36 species from 10 families. The family Brachionidae has highest species abundance with a total of 19 species. The rotifers have the highest species richness with 44 species, followed by Cladocera with 12 species and the Copepods being the least with 11 species. The species with the highest relative abundance are *Brachionus calyciflorus* (13.72%), *Anuraeopsis fissa* (7.78%), *Fiilnia longiseta* (6.58%), *Filinia terminalis* (6.1%), *Moina* sp (5.92%) and *Adineta vaga* (5.23%). *Brachionus calyciflorus*, *Anuraeopsis fissa*, *Filnia longiseta*, *Filinia terminalis*, *Moina* sp, *Calanus* sp, *Cyclops* sp, *Brachionus angularis*, *Brachionus urceolaris*, *Argonotholca foliaceae*, *Asplachna* sp, *Testudinella* sp, and *Adineta vaga* are present in all the sampling sites throughout the sampling period (Table 2). The highest zooplankton population was recorded during the neap tide with a total of 1865 individuals/m^3 while the spring tide had the least population with 1577 individuals/m^3. But species richness is higher during the spring tide with a total of 60 species and lowest during the neap tide with a total of 55 species. Statistical analysis of the one-way repeated measures ANOVA revealed that there was no ($P>0.05$) significant difference in the zooplankton abundance between sampling sites during the study period. Results from T-test showed that there is no significant difference in the zooplankton abundance ($P>0.05$) during neap and spring tide. The total zooplankton population was higher during the rainy season than the dry season with a total of 1837 individuals/m^3 and 1605 individuals/m^3 individuals respectively. There is no significant difference ($P>0.05$) in the seasonal abundance of the zooplankton of Sungai Perai as obtained from T-test.

Table 1. Descriptive statistics of physicochemical characteristics of surface water of Sungai Perai at the sampling sites

Parameters	**Site A**	**Site B**	**Site C**	**Site D**	**Site E**	**Site F**	**Site G**	**Site H**	P Value
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	
EC (µS/cm)	80.6±13	40.8±70	55.9±10	5.10±6.55	2.45±2.78	2.09±3.19	1.27±1.88	1.66±1.87	P>0.05
TDS (mg/L)	27992± 33066	20671.± 31594	2126± 28654	3336.6± 4380	1588.5± 1755.05	1387.4± 2108.60	382.35± 415.89	747.76± 979.92	P<0.05
SALINITY	32.66±46.9	19.41±30	13.2±18.4	2.91±3.97	1.32±1.51	1.11±1.77	0.66±1.03	0.91±1.06	P<0.05
pH	7.17±0.43	6.99±0.32	6.98±0.43	6.92±0.36	6.82±0.35	6.89±0.30	6.89±0.32	6.96±0.30	P>0.05
DO (mg/L)	4.4±1.83	6.02±2.58	4.37±1.66	4.99±2.06	4.33±2.13	3.45±0.59	4.292.56	5.48±1.78	P>0.05
BOD (mg/L)	3.14±1.82	1.95±0.88	2.62±2.01	2.82±2.38	3.14±1.83	1.77±1.19	2.14±1.34	2.72±0.96	P>0.05
TSS	0.08±0.06	0.07±0.07	0.09±0.06	0.06±0.07	0.12±0.12	0.07±0.06	0.06±0.07	0.09±0.10	P<0.05
$P0_4$ (mg/L)	1.35±1.25	0.99±0.71	1.30±0.86	1.27±0.69	1.45±1.19	1.31±0.87	1.23±0.99	1.28±0.86	P>0.05
TRPC (ft)	0.88±0.90	1.6±2.03	0.41±0.26	0.89±0.89	0.64±0.51	0.73±0.79	0.68±0.40	0.91±10	P>0.05
$N0_2$ (µg/L)	83.5±10.4	83.1±10.50	83.13±9.9	86.7±12.1	96.7±18.40	82.6±12.30	79.3±8.10	83.69±11.1	P>0.05
NH_3 mg/L	0.65±0.10	0.64±0.08	0.64±0.04	0.65±0.07	0.65±0.06	0.62±0.07	0.62±0.07	0.62±0.62	P>0.05
Temp	31.22±0.70	31.13±0.50	30.71±0.47	30.59±0.9	30.86±1.10	30.48±0.80	29.71±0.90	29.25±0.60	P<0.05
Chlrp a	2.29±2.13	0.81±0.84	1.67±1.22	0.52±0.24	1.33±0.69	0.99±0.69	2.31±1.21	1.0±0.93	P<0.05

ANOVA test results. $p>0.05$: No significant difference across the sampling sites, $p<0.05$: There is a significant difference across the sampling sites

Table 2. Spatial distribution and frequency of occurrence (%) of zooplankton in Sungai Perai

Species	**Site A**	**Site B**	**Site C**	**Site D**	**Site E**	**Site F**	**Site G**	**Site H**
Moina sp	+	++	+	+	+	++	+	+
Simucephalus sp	–	–	+	–	–	–	–	–
Daphnia sp	–	–	–	+	–	+	–	+
Ceriodaphnia sp	–	–	–	–	+	–	–	–
Chydorus sp	–	–	–	–	+	–	+	–
Camptocercus sp	–	–	–	–	–	–	+	–
Eurycercus sp	–	–	–	–	–	–	+	–
Macrothrix sp	–	+	–	–	–	–	–	–
Diaphanosoma sp	–	+	+	+	+	+	+	+
Sida sp	–	–	–	–	–	–	+	–
Diaphanosoma brachyurum	+	+	–	+	–	–	–	+
Camptocercus sp	+	–	–	–	–	–	–	–
Diaptomus sp	–	+	–	–	–	–	–	–

Species	Site A	Site B	Site C	Site D	Site E	Site F	Site G	Site H
leptodiaptomus sp	–	–	+	–	–	–	–	+
Calanus sp	+	+	+	+	+	+	+	+
Cyclops sp	+	+	+	+	+	+	+	+
Diacyclops sp	–	+	–	–	+	+	+	+
Microcyclops sp	+	+	+	+	–	+	+	–
Mesocyclops sp	+	+	+	+	+	–	+	+
Eucyclops sp	–	–	–	–	+	+	+	+
Limnocalanus sp	–	–	+	–	+	+	+	+
Brachionus calyciflorus	+	+	+	++	++	++	++	++
Brachionus quadridentatus	–	–	–	–	–	–	–	+
Brachionus angularis	+	+	+	+	+	+	+	+
Brachionus urceolaris	+	+	+	++	+	+	++	++
Brachionus falcatus	–	+	+	+	+	–	+	+
Brachionus plicatilis	–	–	–	–	–	–	+	–
Brachionus rotundoformes	–	–	+	–	–	–	–	–
Brachionus durgae	–	–	–	+	–	–	–	–
Brachionus rubens	–	–	–	–	–	–	+	–
Keratella sp	+	+	+	–	+	–	–	+
Keratella cochlearis	–	–	–	+	–	–	+	–
Keratell tropica	–	+	+	–	+	–	–	–
Keratella quadrata	–	+	–	–	–	–	–	–

Table 2. Continued.

Species	Site A	Site B	Site C	Site D	Site E	Site F	Site G	Site H
Anureopsis fissa	+	+	++	++	++	+	+	+
Anuraeopsis navicula	+	+	–	+	+	–	+	+
Notholca sp	+	–	–	+	–	–	+	–
Euclanis alata	+	–	–	–	–	+	+	–
Plationus patulus	–	–	–	+	+	–	–	–
Argonotholca foliaceae	+	+	+	+	+	+	+	+
Asplanchna priodonta	+	–	+	+	+	+	+	+

Species	**Site A**	**Site B**	**Site C**	**Site D**	**Site E**	**Site F**	**Site G**	**Site H**
Asplanchna sp	+	+	+	+	+	+	+	+
Ascomorpha sp	+	+	-	-	+	+	+	-
Trichocerca pusilla	+	-	+	+	+	+	+	+
Trichocerca rattus	-	-	+	-	+	+	+	+
Tichocerca capucina	+	+	-	+	+	+	-	-
Tichotria sp	-	-	-	-	+	-	-	-
Lecane sp	+	+	-	-	+	+	+	-
Lecane curvinicornis	-	-	+	+	-	+	+	-
Lecane decipiens	-	+	-	-	-	-	-	-
Lecane lunaris	-	-	+	+	-	-	-	-
Polyarthra vulgaris	-	-	-	+	-	+	+	-
Synchaeta okai	+	+	-	+	++	+	+	+
Bipalpus hudsoni	-	-	-	-	-	-	-	+
Colurella sp	+	+	+	+	+	+	+	-
Rhinoglena sp	-	-	-	+	-	-	-	-
Diglena sp	-	-	-	-	-	+	-	-
Filinia longiseta	+	+	+	+	+	+	+	+
Filinia teminalis	+	+	+	+	++	+	+	+
testudinella sp	+	+	+	+	++	+	+	+
Pompholyx sp	+	-	-	+	+	-	-	-
Hexathra mira	-	+	+	+	-	-	-	-
Adineta vaga	+	+	+	+	+	++	++	+
Abrochtha sp	-	-	-	-	-	+	-	-
Rotaria neptunia	-	-	-	-	+	+	+	+
Rotaria sp	+	+	-	-	+	-	-	-
Collotheca sp	+	-	-	-	-	-	+	+

(-): Absent; (+): Persent (0.01-1.00 %); (++): Rare (1.01-10.00 %); (+++): Common (10.01-60.00 %) Abundant

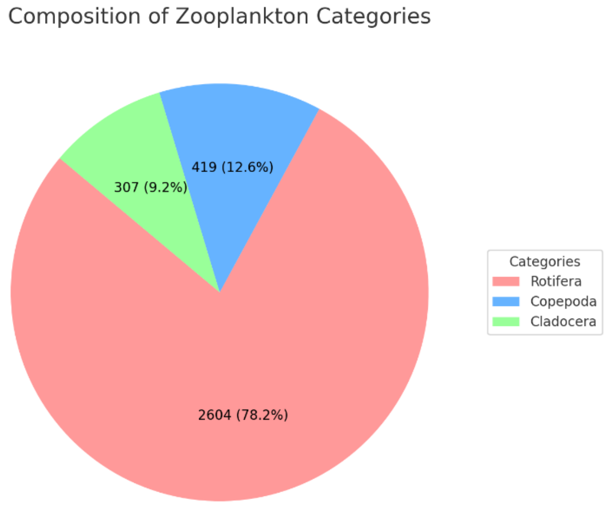

Figure 2. Relative abundance of the Zooplankton taxa of Sungai Perai

Community structure of the zooplankton of Sungai Perai

The results from the community structure analysis of zooplankton of Sungai Perai are shown in Table 3. The zooplankton showed a spatial variability in community structure, with site G having the highest species richness with 41 species followed by site E with 37 species. Site C has the least species richness with 31 species. Shannon diversity (H) is highest at site G followed by sites A and F with H values of 1.423, 1.366, and 1.357 respectively. The lowest H value of 1.273 was recorded at site C. Evenness was highest in A with a value of 0.916 followed by site B and site G with a value of 0.882. The lowest evenness was recorded at site E. The dendrogram of the Jaccard similarity index revealed that 50% of the zooplankton species were present in all the sampling sites. Four clusters were formed which are: sites A and B, C and D, E, F and G, and site H. Sites A and B and F and G have the highest similarity (Figure 3).

Table 3. Diversity indices of zooplankton of Sungai Perai across the sampling sites

Station	Shannon H	Evenness	Species Richness
Site A	1.366	0.916	31
Site B	1.34	0.882	33
Site C	1.273	0.862	30
Site D	1.327	0.86	35
Site E	1.28	0.816	37
Site F	1.357	0.894	33
Site G	1.423	0.882	41
Site H	1.317	0.875	32

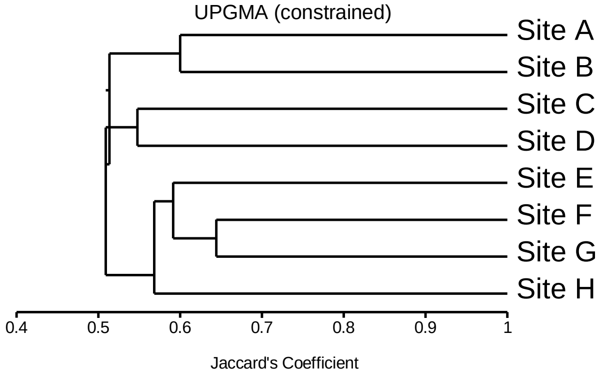

Figure 3. Dendrogram and Jaccard similarity index for the zooplankton at the Sites A to H

Correlation between zooplankton community and water quality parameters

The heat map of the correlation Pearson (r) matrix of the zooplankton and water quality parameters of Sungai Perai is depicted in Figure 4 and the cluster analysis is depicted in Table 4. Cladocera has a strong positive correlation (r=0.5) with Copepoda and a positive correlation with EC (r=0.41), TDS (r=0.32), DO (r=0.39), Sal (r=0.38) and PO_4 (r=0.36). They also have a negative correlation with NO_2 (r=-0.33), NH_3, (r=-0.47) and Temp (r=-0.3). Copepoda are positively correlated with PO_4 (r=0.42), BOD (r=0.3), DO (r=0.3) and Cladocera (r=0.54). They are negatively correlated with TRPC (r=-0.3), NO_2 (r=-0.6), Temp (r=-0.3), and Rotifers r(=0.4). Rotifers have a strong positive correlation with NO_2 (r=0.74) and a positive correlation with NH_3 (r=0.47), DO (r=0.31), and Chlrp-a (r=0.3). They are negatively correlated with Temp (r=-0.36), BOD (r=-0.3), and Copepoda (r=-0.37). Results from cluster analysis showed that there are two main clusters formed, one representing the neap tide and the other representing the spring tide. These clusters depict neap and spring tidal effects on the environmental conditions of Sungai Perai. This further demonstrates the tidal effects on the environmental conditions of Sungai Perai.

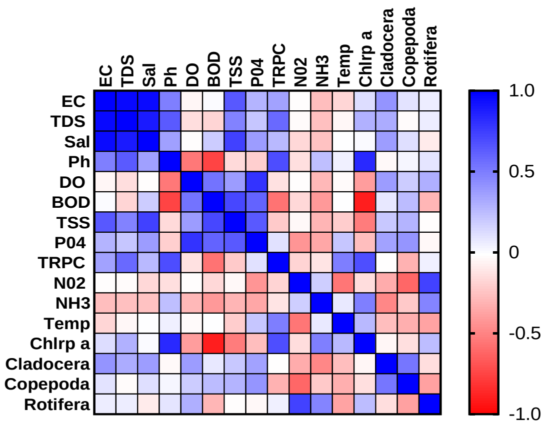

Figure 4: Heat map of the Pearson correlation between the Zooplankton and physicochemical parameters of Sungai Perai

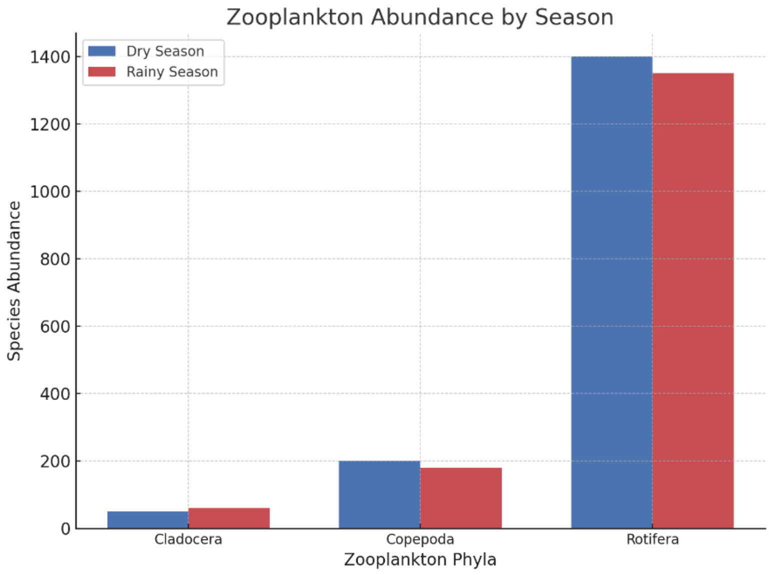

Figure 5. Seasonal variation of the Zooplankton of Sungai Perai

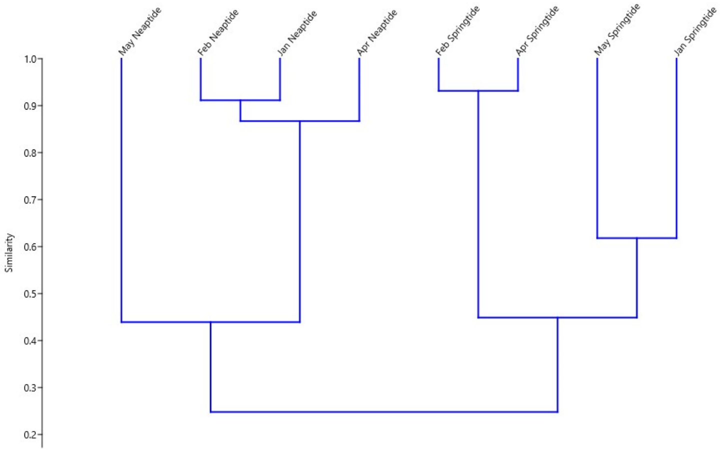

Figure 6. Bray-Curtis cluster analyses of the environmental conditions of Sungai Perai

4. Discussion

Water quality assessment

A variety of physico-chemical and biological characteristics can be used to generally indicate the quality of natural water. In the Sungai Perai, tidal changes influenced various water quality parameters, thus affecting the composition and distribution of zooplankton. Salinity, electrical conductivity and total dissolved solids were high during spring tides. This is similar to the findings of (Haris & Omar, 2008; Wan Omar et al., 2016). Estuaries and coastal rivers receive more seawater due to spring tides, which raises their salinity levels (Samsudin et al., 2023). The salinity levels were higher at Site A, which is the closest to the shore and decreased upstream where it was lowest at Site H. During high tide, ocean water flows into the estuary, increasing salinity levels. When an estuary is not well-mixed due to limited tidal action or strong stratification. In that case, this influx can result in localized areas of higher salinity compared to the open ocean such as the case of site A which records extremely high salinity at certain periods. Secondary salinity where more salts enter an estuary water through human activities, such as irrigation, mining, and industrial processes could also explain the reason behind the high salinity at Site A. Furthermore, as previous studies have also noted, Site H was situated upstream of the estuary and received less saltwater inflow, which resulted in decreased salinity and conductivity (Yap et al., 2011). The degree of saltwater incursion into freshwater systems is restricted by the weaker tidal currents during neap tides. Research indicates that neap tides cause a significant reduction in the length of saltwater intrusion, which lowers the salinity levels in the river (Garcés-Vargas et al., 2020).

The pH values recorded in this study are within the optimum range (6.5-8.2) for most river organisms(Ibrahim & Kutty, 2013). Hashem et al., (2021) reported a pH of a similar range (6.6-7.6) at Sungai Petani. The DO values recorded in the present study are within the range reported by Hashem et al., 2021 at Sungai Petani and (Yap et al., 2011) at Malaysian coastal waters. Fish, invertebrates, and plants are among the freshwater organisms whose life depends on the amounts of dissolved oxygen (DO). Dissolved oxygen may vary significantly in water depending on several environmental conditions (Fondirest Environmental, 2013). DO is an essential measure of ecosystem health and water quality. A healthy aquatic habitat is indicated by high dissolved oxygen levels, but low levels might stress or even kill sensitive organisms. Healthy water should generally have dissolved oxygen concentrations above 6.5-8 mg/L. Fish may experience stress at levels under 5 mg/L, and hypoxic conditions can result from values below 3 mg/L, which are frequently insufficient to sustain most of the aquatic life (US EPA, 2013). High DO was recorded during the spring tide in the present study as compared to neap tide where the DO was low. High turbulent exchanges of spring tides strengthen the circulation, enhance exchange with the atmosphere, and increase the dissolved oxygen content of tidal rivers, while stratification and reduced turbulence during neaps should lead to less oxygenated conditions (Nelson et al., 1994). The rise in nutrient levels due to anthropogenic inputs in rivers and the decay of algal blooms consume significant amounts of dissolved oxygen during decomposition. This process can lead to hypoxic conditions, negatively affecting aquatic life in the river. Pollutants from industrial discharges can have a direct effect on oxygen levels and water quality. The amount of DO in the river is further decreased by certain industrial activities that generate organic compounds that need oxygen to break down (Oparaku et al., 2022).

The BOD of Sungai Perai was higher than that of Tekala River (0.04-1.2 mg/L) Selangor, Malaysia as reported by (Hanafiah et al., 2018). BOD was also found to be higher during spring tides and lower during neap tides in the present study. This may be attributed to increased nutrient-rich water input from the sea which stimulates more microbial activity leading to more BOD. Stored nutrients and organic nutrients matter from bottom sediments and other terrestrial sources are released by tidal currents during spring tides which in turn increases BOD (Brazell, 2009). Factors such as reduced water exchange and sediment resuspension, lesser organic matter inputs, and reduced microbial growth during spring tides could be responsible for low BOD during the neap tides (Samsudin et al., 2023). The nutrients in the Sungai Perai in the present study were found to be higher during neap tides. Neap tides are associated with stable water conditions, and this could result in reduced vertical mixing, increased residence leading to nutrient build-up, replenishment of nutrients from bottom sediments, additional nutrient input from terrestrial sources, and increased phytoplankton growth which in turn leads to higher nutrients during spring tides (Fu et al., 2023). The river receives nutrient runoff from nearby agricultural areas that utilise fertilisers. High fertilizer-derived nitrogen and phosphate levels can lead to eutrophication, which produces algal blooms that, when they break down, reduce oxygen levels. As a result of increased urbanisation, more wastewater—often containing nutrients and organic matter—is being dumped into rivers. This raises nitrogen levels, exacerbates eutrophication and encourages the growth of toxic algae (Nuraqilah, 2022).

Zooplankton distribution and abundance

Zooplankton have been proposed as good indicators of ecosystem conditions due to their taxonomic diversity and varied life history strategies, responsiveness to ecosystem changes simple sampling methods that are cheaper and less time-consuming than intensive fishery surveys, and easier process of identification than some other biological organisms that may be used for indicators (Barbiero et al., 2018). The zooplankton of the Sungai Perai is characterized by a community strongly dominated by rotifers. The dominance of rotifers in rivers has also been reported by (Ismail et al., 2022), at Sungai Pinang. The reason for this domination is that rotifers, as opposed to other zooplankton species, are simply more adapted to the harsh conditions of flowing water (lotic) habitats. They can endure the swift currents and turbulence that rivers provide.

Rotifers thrive in fluctuating salinity levels, allowing them to survive in tidal zones where salt concentrations fluctuate (Napiórkowski & Napiórkowska, 2013). It has been reported that the apparent dominance of rotifers in rivers may be due to their relatively short generation times compared to the larger crustacean zooplankton (Lair, 2005). The copepods were the next in abundance among the zooplankton of Sungai Perai. Nutrient inputs in the river from the point and non-point sources exacerbate the growth of phytoplankton which in turn provides food for the copepods, which supports their growth (Dzierzbicka-Glowacka et al., 2018). Cladocerans contribute a relatively small number of species to the fauna of rivers and streams of the world. They prefer lentic water habitats like lakes and ponds, which may be responsible for their low abundance in Sungai Perai. Because of the weak swimming ability of the cladocerans, they are easily swept by currents in the river, thus affecting their reproductive capacity (Sa-Ardrit & Beamish, 2005). The zooplankton of Sungai Perai were found to be affected by tidal events, as they were more abundant during the neap tide. This may be because neap tides stabilize the water's conditions, increasing the number of phytoplankton, which provides food for zooplankton and increases the rate of growth and reproduction in zooplankton populations. The transfer of zooplankton between estuarine and coastal habitats can be influenced by tidal dynamics. Neap tides may facilitate more favorable conditions for the influx of zooplankton from adjacent marine areas, contributing to higher local abundances (Naz et al., 2011). Higher zooplankton diversity and richness at site G can be attributed to stable water conditions and high nutrients which lead to increased primary productivity that supports higher biomass of phytoplankton. This large biomass of phytoplankton provides ample resources for the zooplankton to flourish (Oparaku et al., 2022). Among the rotifers *Filnia longiseta*, *Filinia terminalis*, *Brachionus calyciflorus*, *Brachionus angularis*, *Brachionus urceolaris*, *Argonotholca foliaceae*, *Asplachna* sp, *Testudinella* sp, and *Adineta vaga* were present at all the sampling sites during the study period. These species have been identified as bioindicators of eutrophication and also indicators of high suspended solids and turbidity (Ferdous & Muktadir, 2009). *Brachionus* species were found to be able to exist in polluted waters and are considered bioindicators (Abdel-Aziz et al., 2011). *Brachionus calyciflorus* is a euryhaline species that can tolerate a wide range of salinities. This adaptability allows it to thrive in various freshwater environments, including rivers where salinity levels may fluctuate due to seasonal changes or anthropogenic influences. This rotifer species is known for its resilience to various environmental stressors, including changes in temperature and dissolved oxygen levels. Such tolerance allows *B. calyciflorus* to maintain stable populations even in conditions that might adversely affect other zooplankton species (Gama-Flores et al., 2020). *Filinia longiseta* and *Filinia terminalis* across all the sampling sites in Sungai Perai indicate human influence in the enrichment of nutrients at the river catchments (Basińska et al., 2010). *Argonotholca foliaceae* is mostly found in waters with higher concentrations of organic matter and nutrients, which are frequently linked to organic pollution from sewage, agricultural runoff, or industrial discharge (Aboul Ezz et al., 2014). The presence of *Asplanchna* sp indicates long-term exposure to environmental pollutants in a water body (Gophen, 2005). *Testudinella* sp is among the zooplankton reported to be bioindicators of moderately polluted water bodies (Khan et al., 2023). Among the Cladocera, *Moina* sp was abundant throughout the study period. This is in agreement with the findings of Rashid and Prakash (2022) who reported *Moina* sp dominated the Vikram Tearth Sarovar and that the reason could be because the species flourishes in polluted waters. *Moina* species strongly resist various contaminants, including high salinity, low oxygen, and organic matter. Their propensity to flourish in deteriorated habitats is demonstrated by the fact that they are frequently seen in large numbers in waters with high sewage pollution levels (Parmar et al., 2016). *Cylops* sp and *Calanus* sp were members of copepods that were present throughout the study period at all the sampling sites. In freshwater systems, *Cyclops* species are commonly employed as indicators of eutrophic conditions. Their population tends to rise in surroundings abundant in nutrients, that are frequently caused by agricultural runoff and other human activities (Parmar et al., 2016). *Calanus* species are known to adapt to changes in environmental conditions, such as pollution levels. These copepods may bioaccumulate contaminants, allowing researchers to determine the quantities of dangerous compounds in aquatic food webs. Studies have demonstrated that substantial quantities of persistent organic pollutants (POPs) can be discovered in *Calanus*, indicating levels of pollution in their environments (Boldrocchi et al., 2023). One of the most used diversity indices in environmental monitoring is the Shannon-Wiener Diversity Index (H′). There are three distinct pollution status levels based on H'. H′ values of 1–3 indicate a moderate level of contaminants, H′ values of greater than 3 indicate the absence of contaminants in a water body, and H′ values of 1 indicate a high level of pollution (Salusso & Moraña, 2000). Based on the zooplankton H' index score across the sampling sites and this classification, Sungai Perai was deemed to be contaminated.

The quality of natural water is generally governed by the interactions of the physical-chemical and biological parameters. The zooplankton of Sungai Perai showed a positive correlation with Dissolved oxygen. Dissolved oxygen has been determined to be an essential factor in the growth of zooplankton in estuaries. Abdul et al., (2016) reported that in a tropical coastal estuary, zooplankton species increased their abundance where DO concentrations were high. High nutrients in rivers lead to an increase in the growth of primary producers which serves as food for the zooplankton thereby indirectly increasing their population (Sun et al., 2023). Temperature negatively correlated with zooplankton abundance in Sungai Perai because, in many aquatic invertebrates, the relationship between temperature and development rate is inversely linear (Edmondson & Vinberg, 1971). Higher temperatures change the dissolved oxygen and water viscosity, which affects zooplankton feeding, which is influenced by water viscosity differentially and favours different species at different temperatures. Higher temperatures can also reduce the zooplankton's growth, existence, and feeding rates due to the reduced dissolved oxygen (LaBerge & Hann, 1990). The positive correlation of Copepoda and Cladocera with phosphate is because an increase in phosphate leads to increased food availability which enhances their growth (Tibúrcio et al., 2015). Adamczuk (2024) reported Cladoceran growth is determined by an increase in phosphate. The negative correlation of Cladocera with nitrite and ammonia is due to the synergistic negative effect on their development and reproduction (Yu et al., 2022). Nitrite and ammonia combined have combined toxic effects that lead to the reduction in the metabolic rate of Cladocerans, reducing their reproductive output due imbalance in energy distribution (Medeiros et al., 2016). It is possible to improve predictive models of changes in water quality by integrating zooplankton data with the findings of conventional chemical monitoring (Rashid & Prakash, 2022). Finding the sources of pollution, for instance, can be aided by associations between nutrient levels and zooplankton diversity (Pinto et al., 2023). The health status of Sungai Perai could be enhanced via the following: (i) Implementation of regulations that restrict the number of pollutants released by industries surrounding the river (ii) Enhance wastewater treatment and encouraging industries to embrace cleaner manufacturing and waste management procedures (iii) Education for local communities about the significance of water quality preservation and the river's ecological importance (iv) Establish riparian buffer zones along the riverbanks, serving to filter runoff, minimize erosion and habitat for wildlife (v) Encourage sustainable agricultural practices that lessen pesticide and fertilizer runoff into the river (vi) Implementation of upcycling programs that transform waste into valuable items, leading to a decrease in pollution and an increase in the involvement of the community.

5. Conclusions

The present study depicts the possibility of using zooplankton to assess the environmental conditions of the Sungai Perai through fluctuations in their community structure and the presence of sensitive genera and species. Several pollution indicators, particularly eutrophication, were identified. *Brachionus,* the most abundant zooplankton in the Sungai Perai, is considered a target taxon for more intensive monitoring of environmental conditions and conservation planning in aquatic environments. The spatio-temporal variation in the community structure of the zooplankton is driven by factors such as tidal events, nutrients, dissolved oxygen, temperature, and anthropogenic inputs. Furthermore, the findings of this study indicate that Sungai Perai is under anthropogenic pressure, as evidenced by the plethora of pollution indicators (Zooplanktons). Based on the findings of the present study the overall ecological health of Sungai Perai could be improved by ensuring pollution control measures through regulation of industrial and discharges, community engagement and enlightenment, sustainable agricultural practices, regular environmental assessments, and innovative solutions such as upcycle initiatives. Finally, more research is needed, particularly studies on how individual Zooplankton species react to environmental stressors and pollution.

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Conflict of interests

The authors affirm that they have no competing interests to disclose.

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