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Plankton distribution, abundance, diversity, and its potential in the tropical man-made lakes of Kenyir and Temenggor in Peninsular Malaysia

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Abstract. *Othman F, Yuslan A, Suhaimi H, Azani N, Kamal AHM, Sah ASRMD, Rasdi NW. 2024. Plankton distribution, abundance, diversity, and its potential in the tropical man-made lakes of Kenyir and Temenggor in Peninsular Malaysia. Biodiversitas 25: 3342-3358.* Kenyir and Temenggor Lakes, the largest artificial lakes in Malaysia, are the focus of this study due to their unique ecological characteristics and the limited information available. The study aimed to determine the diversity and abundance of plankton in various habitat ecosystems along Kenyir Lake and Temenggor Lake. The selection of three distinct sampling points, namely sampling point A (coastal zone), sampling point B (lotic zone), and sampling point C (lentic zone), was a strategic decision to ensure a comprehensive representation of the diverse habitat conditions. Samples were collected horizontally using a 30-micrometer-sized plankton net. At Kenyir Lake, thirty-two phytoplankton species were recorded, the major division of phytoplankton, with two hundred twenty-eight individuals belonging to Charophyta (43.75%). For zooplankton, Arthropoda (83.3%) was the highest recorded. At Temenggor Lake, thirty-one species of phytoplankton were recorded. The major division with one hundred sixty-five individuals belonging to Charophyta (32.3%). For zooplankton, the major division with two hundred forty-two individuals belonging to Arthropoda (82.4%). The Shannon diversity index, evenness, and species richness measurements revealed a range of index values due to variation in plankton species due to interaction and habitat conditions. The variation in planktonic abundance in Kenyir Lake and Temenggor Lake was attributed to their habitat preferences due to the freshwater lake's ecosystem's different zones and conditions.

Keywords: Distribution, freshwater lake, Kenyir, plankton, Temenggor

INTRODUCTION

Kenyir Lake and Temenggor Lake are significant reservoirs in Malaysia that require serious consideration regarding the conservation and administration of their resources, especially in the context of the vast areas of unexplored land surrounding them (Effendi et al. 2020). Temenggor Lake is in the Hulu Perak District of Malaysia, around 45 km from the district's main city, Gerik (Yap et al. 2016). Kenyir Lake, located in Terengganu, is the largest lake in Peninsular Malaysia, with Temenggor Lake following closely as the second largest (Ramlee et al. 2022). The location of this man-made reservoir lies to the south of the Ulu Titi Basah peak, which stands at an elevation of 1,533 meters (Arshad et al. 2022). Temenggor Lake is an artificial reservoir created by constructing the Temenggor Dam in the northern part of Perak. The purpose of building the dam was to generate electricity (Basri et al. 2019). The construction of this dam commenced in 1970 and concluded in 1974 (Subehi et al. 2014). The dam encompasses a vast expanse of 152 km^2 and can store 6,050 million cubic meters of water. This water body spans an area of 117,500 hectares within the Belum Forest Reserve (Khalik and Abdullah 2012).

Plankton, tiny creatures that move in the water's currents, play a crucial role in the aquatic ecosystem. Phytoplankton, serving as the primary producer of the aquatic food chain, uniquely converts energy into chemical energy found in food (Jiang et al. 2014; Rasdi et al. 2023). On the other hand, zooplankton functions as an intermediary between energy producers and consumers, facilitating the transport of dietary energy to higher trophic levels (Rasdi et al. 2018). The sensitivity of phytoplankton to environmental changes makes them valuable indicators of water quality and trophic status (Yuslan et al. 2021). Their abundance, diversity, and composition can provide insights into nutrient levels, temperature, light availability, and other limnological factors in aquatic ecosystems, including lotic, lentic, and coastal areas. The diversity, distribution, and variation of biotic parameters provide an excellent indication of energy turnover in aquatic environments (Forsberg 1982; Ghosh et al. 2012). For example, certain species may thrive in nutrient-rich environments, while others may dominate in areas with lower nutrient levels. Phytoplankton generates significant organic carbon at the bottom of these ecosystems (Shinde et al. 2012). Their sensitivity and variations in species composition are adequate justifications for promoting modifications to ecosystem composition.

Therefore, species diversity can be employed to distinguish between interactions that contribute to forming a particular pattern of community structure by environmental gradient changes. Research has demonstrated that even slight changes in the habitat and environment, such as the formation of lake zonation, can significantly impact biodiversity because neither gene flow nor adaptation from ecosystem sources occurs. A high diversity count signifies the stability of an ecosystem, while a low diversity count implies degradation of the environment. Freshwater zooplankton comprises many significant taxonomic groups; these forms demonstrate distinctive environmental and physiological characteristics. These organisms' distribution, variety, and abundance throughout an aquatic habitat offer information about the habitat's environmental conditions. Many environmental factors interact in an environment that promotes favorable spatial and seasonal situations for zooplankton development (Khanna et al. 2019; Ramlee et al. 2022).

Zooplankton diversity and density are influenced by various factors, including the nutritional status of the water body, abiotic variables, Dissolved Oxygen (DO), the food chain, and soil-water chemistry. Furthermore, zooplankton have been utilized as bio-indicators for monitoring aquatic ecosystems and water integrity (Dhembare 2011). Water temperature, turbidity, transparency, and dissolved oxygen all contributed to the growth of the rotifer population (Chandrasekhar 1996; Annalakshmi and Amsath 2012). Phytoplankton availability and zooplankton's distribution and abundance are influenced by interspecific and intraspecific factors (Ahmad et al. 2011). Nevertheless, due to the extensive region's unexplored potential, research on the composition and diversity of phytoplankton and zooplankton in Kenyir and Temenggor Lakes is limited.

This research aims to discover the variations in planktonic diversity, the interactions among plankton and environmental habitat variables, and the characteristics of communities influenced by habitat conditions, species composition, and population density. Due to natural and human activities, the regulation of water quality and ecological conditions on Kenyir Lake has become an essential issue. Therefore, it is crucial to evaluate the biodiversity of phytoplankton and zooplankton in Kenyir Lake and Temenggor Lake, as this will be a biological indicator of the ecological condition of the research site. Based on our estimations, the results of this research will be of greatest significance in establishing fundamental data to monitor environmental variations, identifying their interconnections, and clarifying their contributions to the determination of plankton community dynamics and variation in both man-made lakes. Thus, this could serve as a model for the conservation and management of aquatic ecosystems and contribute towards preserving and restoring these ecosystems.

MATERIALS AND METHODS

Study area and period

Kenyir Lake is the largest man-made lake in Southeast Asia and Malaysia (Figure 1). It was dammed in 1985 to provide water to the Sultan Mahmud Power Station (Dullah et al. 2020); its border to the south with Pahang and to the west with Kelantan. It is located in the eastern region of Terengganu and has an area of 260,000 hectares (Bhuiyan et al. 2016). It is also one of Malaysia's national park gates and serves as Terengganu's main ecotourism attraction.

Temenggor Lake is located in the Hulu Perak District of Malaysia, approximately 45 km from Gerik's district capital. Temenggor Lake is the second-largest lake in Peninsular Malaysia, after Kenyir Lake in Terengganu (Figure 1). Construction of this dam started in 1970 and finished in 1974. This artificial lake is located south of the 1,533-meter-tall Ulu Titi Basah peak. This lake emerged after the Temenggor Dam's establishment, which serves as a power generation facility in the northern region of Perak. Moreover, 117,500 hectares of the Belum Forest Reserve are submerged in the 6,050 million cubic meters of water contained within the dam's 152 km^2 of surface area.

The overall dimensions of this reservoir are considerable, measuring approximately 127 meters in depth and 537 meters in width. The multiple rivers flow include Sungai Sara and Sungai Singor in the east, Sungai Tiang and Sungai Kejor north, and Sungai Gadong west. The water from these rivers is used to fill the reservoir, an essential resource for water supply, generating electricity, and other purposes in the region. The sample was taken at three sampling points each in the Kenyir Lake and Temenggor Lake areas and was conducted once monthly for nine months, from February to October 2023. This investigation was carried out over three days per location, as there was no significant difference in weather between the days (Ogbuagu and Ayoade 2012; Ramlee et al. 2022).

Sampling point

Three different sampling points in Sungai Como, Kenyir Lake, were chosen for zooplankton and phytoplankton sampling: Point A, Point B, and Point C (Figure 1). In the freshwater ecosystems of Kenyir and Temenggor lakes, the coastal (littoral), lotic, and lentic zones exhibit distinct characteristics, each playing a crucial role in shaping plankton diversity and distribution. These conditions promote high primary productivity and diverse habitats for planktonic organisms (Kassim et al. 2015). The coastal zone, marked by shallow waters near the shore with emergent and submerged vegetation, supports relatively lower plankton diversity due to reduced light penetration and competition with macrophytes for nutrients (Ismail et al. 2023). Conversely, the lotic zone, consisting of flowing water habitats such as inflowing rivers and streams, showcases higher plankton diversity influenced by flow rate, turbulence, and nutrient availability. While increased flow rates may enhance plankton diversity by promoting nutrient mixing and dispersal, excessive turbulence can disrupt planktonic communities. In contrast, the lentic zone, representing the lakes' open, standing water areas, sustains diverse plankton communities influenced by nutrient availability, temperature stratification, and light penetration. Nutrient-rich waters near inflowing rivers and temperature stratification create distinct planktonic communities across different layers. Understanding these zone-specific characteristics is essential for assessing and managing the ecological dynamics of these freshwater ecosystems. Compared to lentic and lotic environments, phytoplankton's species composition and community structure are still poorly characterized in both systems (Chen et al. 2019).

The sampling points were chosen based on the area's physical characteristics, as described in Table 1, to resemble the varying physical conditions of the plankton habitat. Therefore, point A, point B, and point C in Kenyir and Temenggor Lakes were chosen for zooplankton and phytoplankton sampling (Figure 1).

Sampling protocol and data collection

Figure 2 shows the protocol for sample collection. Phytoplankton and zooplankton were collected using a plankton net with a mesh size of 30 micrometers. Two different towing methods, hand and boat towing, were used to collect the sample horizontally (Schwoerbel 2016). For five minutes at a determined depth, the net was horizontally held. At each sampling point, three 50 ml bottles sanitized beforehand were used to collect replicates from a 200 mL bucket of collective plankton. A drop of 40% formalin was put in to prevent bacteria decomposition during the preservation process (Abd Latif et al. 2014).

Furthermore, the scraping method obtained samples that focused on the objects in the body of water, like leaves, dead trees, and stones (Sabki et al. 2012). A portable YSI probe meter was used to take water quality parameters that include Dissolved Oxygen (DO), pH, salinity, turbidity, and parameters with three replicates for the precision of the data collected. Three replicates from separate water samples were used to determine the chlorophyll concentration at the sampling point. Methanol was used to extract the water sample and shaken at 30 Hz. Once done with centrifugation, the supernatant was collected. A microplate reader was used for the analysis of chlorophyll by pipetting 200 µL into a 96-well plate (Wang et al. 2019).

Data analyses

After sampling, the phytoplankton and zooplankton were taken to the laboratory for species identification and analysis. The process of identifying metazoan plankton requires the study of specimens that have been preserved in formalin. Monographs and descriptions in the original literature provide the opportunity to compare a sample with identified species (McManus and Katz 2009).

Table 1. Sampling points and description in Kenyir and Temenggor Lakes, Malaysia

Sampling point	Coordinate	Description
Kenyir Lake		
Point A	5° 2' 13.0164" N, 102° 50' 44.2968"' E	Sample was taken from a stony area with a lotic water current
Point B	5° 2'7.7676" N, 102° 50'46.0824" E	Sample was taken at a coastal zone area with lotic and lentic water current
Point C	5° 2' 11.382" N, 102° 50' 47.3568"' E	Sample was taken at the area with lentic water current
Temenggor Lake		
Point A	5° 33' 19.8108" N, 101° 21' 3.9672" E	Sample was taken from the coastal zone area with a lotic water current
Point B	5° 33' 16.5816" N, 101° 21' 6.9408"' E	Sample was taken at the profundal zone with lotic and lentic water currents.
Point C	5° 33' 13.6008" N, 101° 21' 11.286" E	Sample was taken in the area with a lentic water current

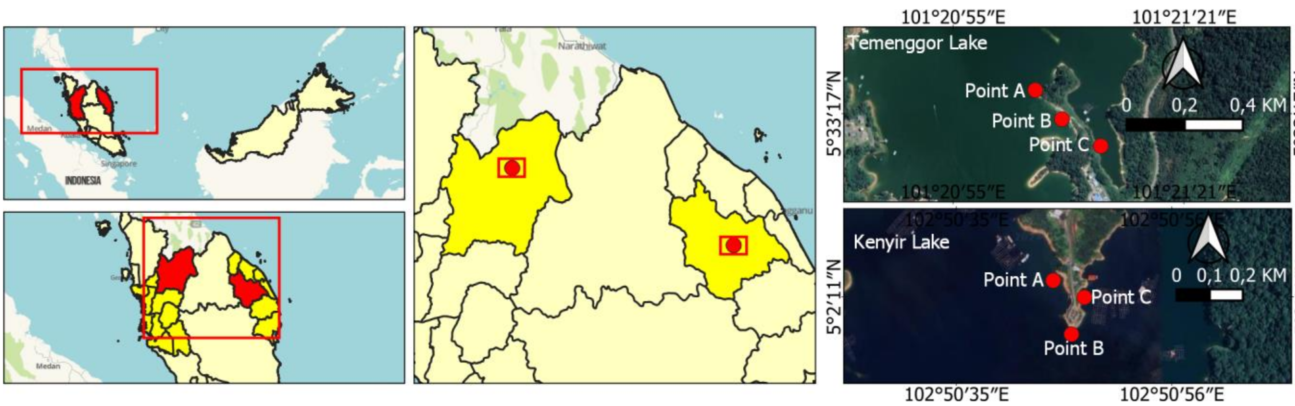

Figure 1. Study location of sampling points in Kenyir Lake, Hulu Terengganu, Terengganu, and Temenggor Lake, Hulu Perak, Perak, Malaysia. The label on the map indicates different sampling points

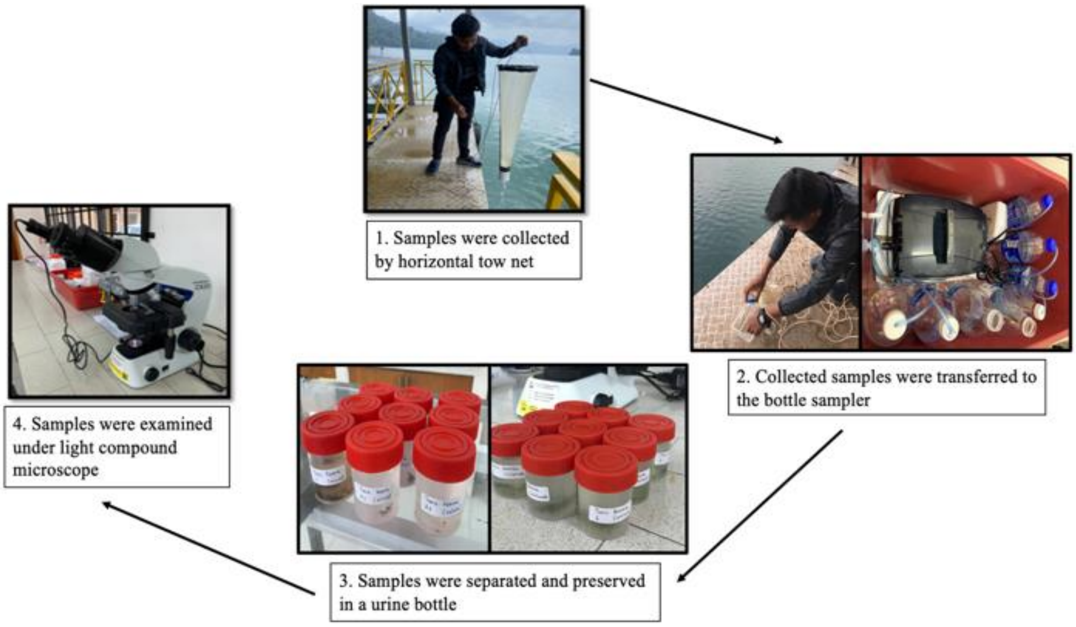

Figure 2. The graphical flow of sampling protocol of phytoplankton and zooplankton

This method is particularly efficient for Crustaceans, which frequently dominate the plankton captured by plankton net. Although it is typically feasible to accurately identify adult stages, certain larval forms, such as many copepod nauplii, cannot be definitively recognized to species by light microscopy and may remain undescribed. Morphospecies identification is typically feasible for diatoms and other larger organisms with recognizable hard structures, however it is generally challenging for small flagellates (McManus and Katz 2009). The samples were examined using an OLYMPUS light compound microscope. Photos were taken with a Dino-Lite digital microscope and recorded using Dino-Capture 2.0 software.

Species analysis and identification of the zooplankton and phytoplankton were done at the laboratory once the sampling was conducted. Plankton were isolated and identified according to their morphological structure (Bellinger and Sigee 2015; Bledzki and Rybak 2016). For example, different species of copepods were identified by studying their body shape, segments of the antenna and caudal rami (Dussart and Defaye 2001; Lopes et al. 2001; Yuslan et al. 2022). The mean±Standard Deviation (SD) was used to present the water quality study results. Meanwhile, the estimation of the relationship between parameters at different sampling points was assessed using a one-way Analysis of Variance (ANOVA). The significance level for the mean difference between sampling points was established using multiple comparison tests by Tukey and Duncan. The statistical level was set to $P < 0.05$. The evenness Index, Shannon's diversity index, and species richness were determined by the number of individuals per mL of the examined and counted samples (Shannon and Weaver 1949; Sihombing et al. 2017).

RESULTS AND DISCUSSION

Water quality of Kenyir and Temenggor Lakes

Table 2 shows the water quality parameters at sampling points A, B, and C differed, indicating that the three sampling points had varying environmental conditions. The maximum temperature observed was (27.45±0.10°C) at sampling point C, whereas (26.29±0.49°C) and (26.11±0.29°C) were recorded at sampling points A and B, respectively, indicating the optimal temperature parameter for phytoplankton growth and development. The salinity of all sample points was less than 0.5 ppt, indicating that the river was pure freshwater. The highest turbidity (NTU) was reported at sampling point A (3.39±0.17), followed by sampling points B (2.81±0.37) and A (2.33±0.09). Sampling point A has a pH of (7.03±0.05), while sampling points B and C have pH values of (5.65±0.09) and (6.49±0.65), respectively. The dissolved oxygen, DO for sampling point A has the highest (8.34±0.12) among sampling points B and C (5.58±0.28) (6.12±0.11).

According to Table 2, the water quality parameters at sampling points A, B, and C differed, indicating that the three sampling points had varying environmental conditions. The maximum temperature observed was (28.45±0.22°C) at sampling point C, whereas (26.32±0.43°C) and (27.47±0.42°C) were recorded at sampling points A and B, respectively, indicating the optimal temperature parameter for phytoplankton growth and development. The salinity of all sample points was less than 0.5 ppt, indicating that the river was pure freshwater. The highest turbidity (NTU) was reported at sampling point C (4.20±0.22), followed by sampling points A (3.06±0.35) and B (2.33±0.24). Sampling point B has a dissolved oxygen, DO of (8.03±0.09), while sampling points A and C have pH values of (5.93±0.18) and (7.06±0.17), respectively. The pH for sampling point B has the highest (8.53±0.29) among sampling points A and C (7.06±0.86; 6.93±0.81), respectively.

Table 2. Water quality parameters across three sampling points in Kenyir and Temenggor Lake, Malaysia (Mean±SD)

Parameter	Sampling point		
	Point A	**Point B**	**Point C**
Kenyir Lake			
Temp. (°C)	26.29±0.49[b]	26.11±0.29[b]	27.45±0.10[a]
Salinity (ppt)	0.05±0.01[a]	0.03±0.01[a]	0.06±0.02[a]
pH	7.03±0.05[a]	5.65±0.09[b]	6.49±0.65[a]
DO	8.34±0.12[a]	5.58±0.28[c]	6.12±0.11[b]
Turbidity (NTU)	3.39±0.17[a]	2.81±0.37[ab]	2.33±0.09[b]
Chl *a* (µg/mL)	11.14±0.63[a]	11.39±0.64[a]	15.76±4.31[a]
Temenggor Lake			
Temp. (°C)	26.32±0.43[c]	27.47±0.42[b]	28.45±0.22[a]
Salinity (ppt)	0.04±0.01[ab]	0.03±0.01[b]	0.05±0.02[a]
pH	7.06 ±0.86[b]	8.53±0.29[a]	6.93±0.81[b]
DO	5.93±0.18[c]	8.03±0.09[a]	7.06±0.17[b]
Turbidity (NTU)	3.06±0.35[b]	2.33±0.24[b]	4.20±0.22[a]
Chl *a* (µg/mL)	11.29±0.16[a]	11.49±0.57[a]	15.75±4.75[a]

Note: All values are mean±standard deviation (n=3). The different small letters indicate significant differences between water quality parameters ($P<0.05$)

The fertility of the waters in the sampling locations is affected by physical elements such as temperature, turbidity, light, and current, as well as chemical factors including salinity, dissolved oxygen, pH, and nutrient content (Mellard et al. 2011; Putri and Tjahjaningsih 2019; Syaifudin et al. 2019), many factors can influence phytoplankton and zooplankton growth in aquatic environments. According to Liwutang et al. (2013), generally, phytoplankton can develop well at 20 to 30°C; temperatures affect the distribution, composition, and phytoplankton abundance in the waters. High temperatures will increase the phytoplankton abundance and the chlorophyll-a contents. In contrast, low temperatures will reduce the phytoplankton abundance and the chlorophyll-a contents. The chlorophyll-a level content in the waters can indirectly indicate the phytoplankton abundance, which can determine these water's fertility levels (Al Diana et al. 2021). The nutrient content in the waters is closely related to the phytoplankton abundance, as the higher the nutrient content in the waters, the greater the phytoplankton abundance and the chlorophyll-a. Magumba et al. (2014) stated that the nitrogen element is very significant to the chlorophyll content, especially chlorophyll-a, which is chlorophyll type t mostly found in seawater phytoplankton (Arief and Laksmi 2006). Chlorophyll-a contributes 95% to primary productivity in the aquatic environment (Widyorini 2009). Therefore, according to Ismail (2012), algal blooms can develop when chlorophyll-a levels increase, indicating rapid growth of certain phytoplankton species, leading to high cell densities (Ramlee et al. 2022). However, no algal bloom was observed during the investigation in these areas, as the chlorophyll-a level was below the eutrophic range determined by Carlson's trophic status index (Carlson 1977; Ayoade et al. 2019).

Variation of phytoplankton in Kenyir Lake

Based on Table 3 and Figure 4, in sampling points A, B, and C, 32 phytoplankton species were recorded in Kenyir Lake. Therefore, 228 individuals of phytoplankton belonged to Charophyta (43.75%), followed by Chlorophyta (28.13%), Bacillariophyta (6.25%), Euglenophyta (9.38%), Gyrista (3.13%), Cyanobacteria (6.25%) and Ochrophyta (3.13%) (Figure 3). At point A, 13 phytoplankton species belonging to phylum Charophyta were found. However, the highest number of individuals found is *Pediastrum simplex*, 9 individuals that belong to the phylum Chlorophyta. At point B, 11 phytoplankton species from phylum Charophyta were found among the 32 species recorded in Table 5. The dominant species recorded from species of *Phacus* sp.2 that belong to phylum Euglenophyta, respectively. At point C, the dominant species found was recorded at phylum Charophyta with 11 species. *Pseudopediastrum boryanum*, which belongs to phylum Chlorophyta, has the highest number of phytoplankton individuals found compared to the other 7 phyla recorded at point C in Kenyir Lake.

Variation of zooplankton in Kenyir Lake

Table 4 and Figure 6 show that in sampling points A, B, and C, 30 zooplankton species were recorded in Kenyir Lake. Therefore, 157 individuals belong to Arthropoda (83.3%), followed by Rotifera (13.3%) and Ciliophora (3.3%) (Figure 5). At point A, 13 species of zooplankton belonging to phylum Arthropoda were found. At point B, 14 zooplankton species from phylum Arthropoda were found among the 30 species recorded in Table 4. At point C, the dominant species found was recorded at phylum Arthropoda, fifteen species. Calanoid copepods that belong to the phylum Arthropoda have the highest number of zooplankton individuals found at point C.

Variation of phytoplankton in Temenggor Lake

Based on Table 5 and Figure 8, in sampling points A, B, and C, 31 phytoplankton species were recorded in Temenggor Lake. Therefore, 165 individuals belong to Charophyta (32.3%), followed by Gyrista (25.8%), Bacillariophyta (16.1%), Chlorophyta (16.1%), Dinoflagellata (6.5%) and Heliozoa (3.2%) (Figure 7). At point A, 8 species of phytoplankton belonging to phylum Charophyta were found. At point B, 7 phytoplankton species from phylum Charophyta were found among the 31 species recorded in Table 5. At point C, the dominant species found was recorded at phylum Charophyta 10 species.

Variation of zooplankton in Temenggor Lake

Table 6 and Figure 10 show that 17 zooplankton species are recorded in Temenggor Lake in sampling points A, B, and C. The two hundred forty-two individuals belong to Arthropoda (82.4%), followed by Rotifera (11.8%) and Ciliophora (5.9%) (Figure 9). At point A, 15 species of zooplankton were found. At point B, 14 zooplankton species were found among the 17 species recorded in Table 6. At point C, the dominant species found was recorded at phylum Arthropoda with 14 species.

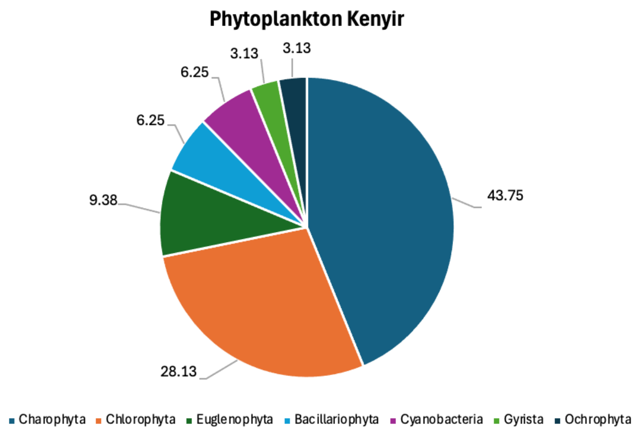

Figure 3. Relative abundance of phytoplankton phylum in Kenyir Lake, Malaysia. Different area shade in the chart indicates the relative abundance percentage of the phylum

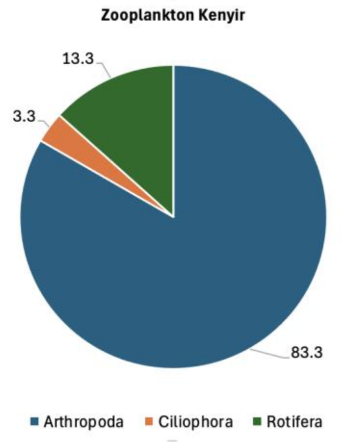

Figure 5. Relative abundance of zooplankton phylum in Kenyir Lake, Malaysia. Different area shade in the chart indicates the relative abundance percentage of the phylum

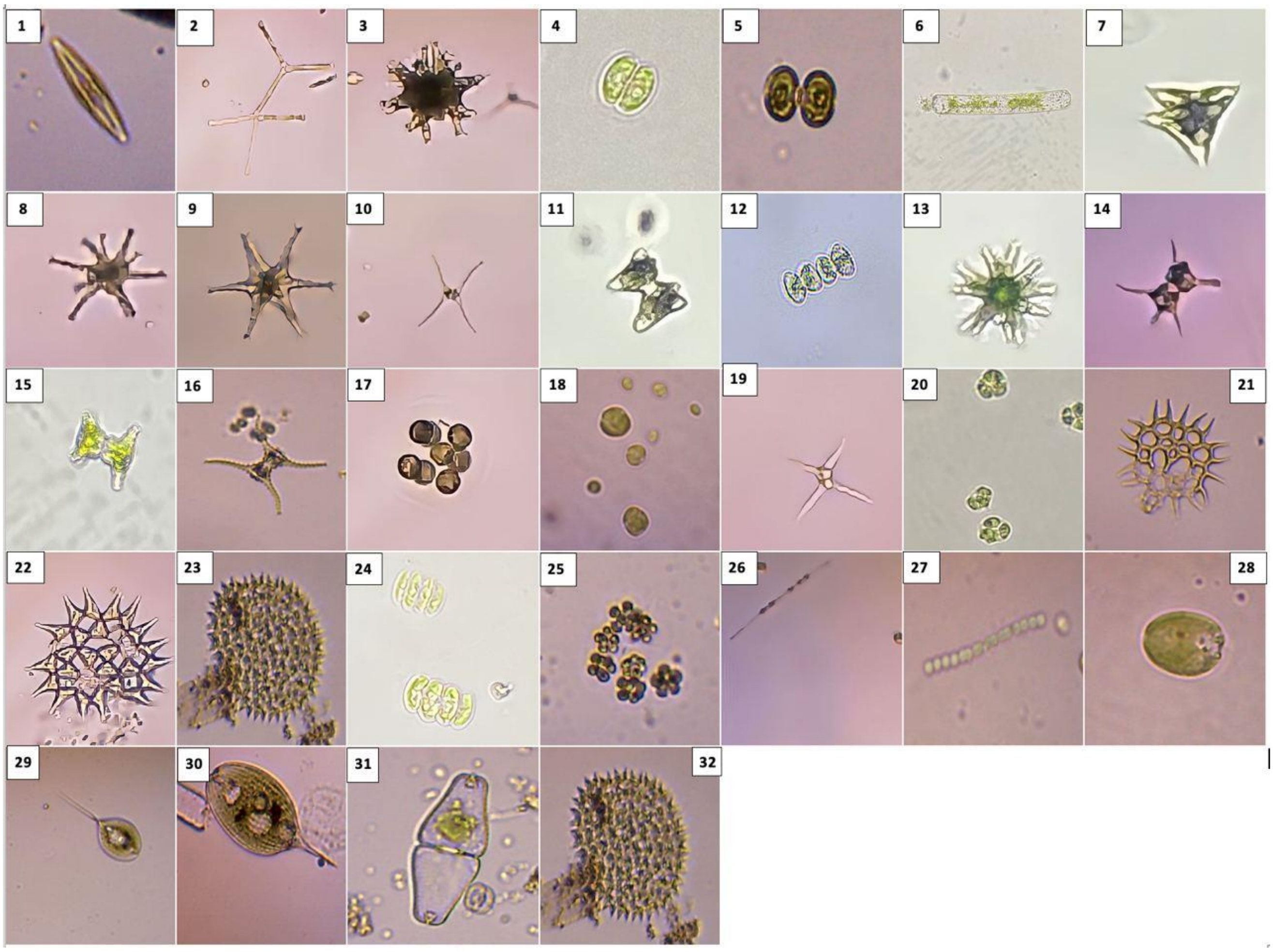

Figure 4. Phytoplankton species recorded in Kenyir Lake, Malaysia: 1. *Frustulia* sp.; 2. *Thalassionema nitzschioides*; 3. *Ankistrodesmus* sp.; 4. *Cosmarium depressum*; 5. *Cosmarium* sp.; 6. *Mougeotia* sp.; 7. *Staurastrum aculeatum*; 8. *Staurastrum anatinum*; 9. *Staurastrum arachne*; 10. *Staurastrum chaetoceras*; 11. *Staurastrum gracile*; 12. *Staurastrum punctulatum*; 13. *Staurastrum rotula*; 14. *Staurastrum* sp.1; 15. *Staurastrum* sp.2; 16. *Staurastrum tetracerum*; 17. *Chlamydocapsa* sp.; 18. *Chlorella vulgaris*; 19. *Lagerheimia* sp.; 20. *Oocystis lacustris*; 21. *Pediastrum biradiatum*; 22. *Pediastrum simplex*; 23. *Pseudopediastrum boryanum*; 24. *Scenedesmus quadricauda*; 25. *Sphaerocystis* sp.; 26. *Cylindrospermopsis raciborskii*; 27. *Pseudanabaena* sp.; 28. *Euglena* sp.; 29. *Phacus* sp.1; 30. *Phacus* sp.2; 31. *Amphora* sp.; 32. *Ochromonas* sp.

Table 3. Species list of phytoplankton in Kenyir Lake, Malaysia

Phylum, species	Point A (%)	Point B (%)	Point C (%)
Bacillariophyta			
Frustulia sp.	14.29	38.10	47.62
Thalassionema nitzschioides	32.14	25.00	42.86
Charophyta			
Ankistrodesmus sp.	0.00	41.67	58.33
Cosmarium depressum	56.25	43.75	0.00
Cosmarium sp.	35.00	40.00	25.00
Mougeotia sp.	47.37	0.00	52.63
Staurastrum aculeatum	25.00	40.00	35.00
Staurastrum anatinum	60.00	0.00	40.00
Staurastrum arachne	24.00	28.00	48.00
Staurastrum chaetoceras	15.00	30.00	55.00
Staurastrum gracile	24.00	36.00	40.00
Staurastrum punctulatum	23.53	35.29	41.18
Staurastrum rotula	63.64	0.00	36.36
Staurastrum sp.1	22.22	77.78	0.00
Staurastrum sp.2	36.36	63.64	0.00
Staurastrum tetracerum	22.22	50.00	27.78
Chlorophyta			
Chlamydocapsa sp.	0.00	35.71	64.29
Chlorella vulgaris	33.33	25.93	40.74
Lagerheimia sp.	23.08	0.00	76.92
Oocystis lacustris	10.53	36.84	52.63
Pediastrum biradiatum	20.00	0.00	80.00
Pediastrum simplex.	62.50	37.50	0.00
Pseudopediastrum boryanum	25.00	10.00	65.00
Scenedesmus quadricauda	30.77	46.15	23.08
Sphaerocystis sp.	26.32	42.11	31.58
Cyanobacteria			
Cylindrospermopsis raciborskii	55.56	44.44	0.00
Pseudanabaena sp.	0.00	0.00	100.00
Euglenophyta			
Euglena sp.	28.00	36.00	36.00
Phacus sp.1	100.00	0.00	0.00
Phacus sp.2	0.00	100.00	0.00
Gyrista			
Amphora sp.	25.93	33.33	40.74
Ochrophyta			
Ochromonas sp.	36.36	0.00	63.64

The abundance and variation of phytoplankton and zooplankton in Kenyir Lake and Temenggor Lake are significant freshwater ecosystems in Malaysia that play crucial roles in shaping their productivity and overall ecosystem dynamics. The plankton comprises all those aquatic organisms that drift passively or whose powers of locomotion are insufficient to enable them to move contrary to the motions of their in-habitat water mass (Sagala 2016). A motile species may move vertically in a laterally flowing water current. The movement of plankton depends on nutrition supply; hence, they reproduce very quickly on the surface of little streams and many pools when their nutrition is available (Sharip et al. 2019).

Additionally, planktonic communities act as sensitive indicators of water quality, with their composition reflecting shifts in nutrient levels, temperature, and other environmental factors (Chandel et al. 2024). The impact of temperature on phytoplankton diversity seems to be mostly mediated by zooplankton activity and community structure changes. Still, the strength of the zooplankton impact on phytoplankton varies with the bloom development (Lewandowska et al. 2014). Furthermore, phytoplankton contribute significantly to oxygen production through photosynthesis, while zooplankton play a key role in nutrient cycling through consumption and excretion.

Phytoplankton are the primary producer organisms supporting zooplankton and fishes in aquatic environments. Their abundance directly impacts the availability of organic matter for consumption by other organisms. Thus, phytoplankton are placed at the trophic strata's base or the aquatic food web (Ruegg et al. 2021). Phytoplankton also plays a major role in global carbon dioxide fixation and maintains the water body's oxygen level, which is designated as dissolved oxygen through photosynthesis (Pal and Choudhury 2014; Abd Hamid et al. 2019).

Table 4. Species list of zooplankton in Kenyir Lake, Malaysia

Phylum, species	Point A (%)	Point B (%)	Point C (%)
Arthropoda			
Calanoid copepods	59.26	0.00	40.74
Calanus finmarchicus	0.00	50.00	50.00
Ceriodaphnia laticaudata	22.22	33.33	44.44
Ceriodaphnia rigaudi	0.00	25.00	75.00
Ceriodaphnia sp.	66.67	33.33	0.00
Chydorus sp.1	33.33	0.00	66.67
Chydorus sp.2	0.00	0.00	100.00
Chydorus sp.3	0.00	100.00	0.00
Chydorus sphaericus 1	100.00	0.00	0.00
Chydorus sphaericus 2	50.00	25.00	25.00
Cyclopoida nauplius	0.00	100.00	0.00
Cyclops scutifer	14.29	57.14	28.57
Cyclops sp.	0.00	100.00	0.00
Daphnia catawba	100.00	0.00	0.00
Daphnia magna	66.67	0.00	33.33
Daphnia parvula	0.00	0.00	100.00
Daphnia pulex	66.67	0.00	33.33
Daphnia sp.	0.00	100.00	0.00
Macrocyclops albidus	75.00	0.00	25.00
Macrocyclops fuscus	28.57	71.43	0.00
Mesocyclops edax	0.00	0.00	100.00
Microcyclops rubellus	0.00	33.33	66.67
Moina micrura	0.00	28.57	71.43
Moina sp.1	0.00	100.00	0.00
Moina sp.2	100.00	0.00	0.00
Ciliophora			
Trachelius ciliophora	0.00	0.00	100.00
Rotifera			
Brachionus plicatilis	22.22	33.33	44.44
Brachionus sp.	0.00	100.00	0.00
Keratella cochlearis	23.08	30.77	46.15
Notholca laurentiae	50.00	50.00	0.00

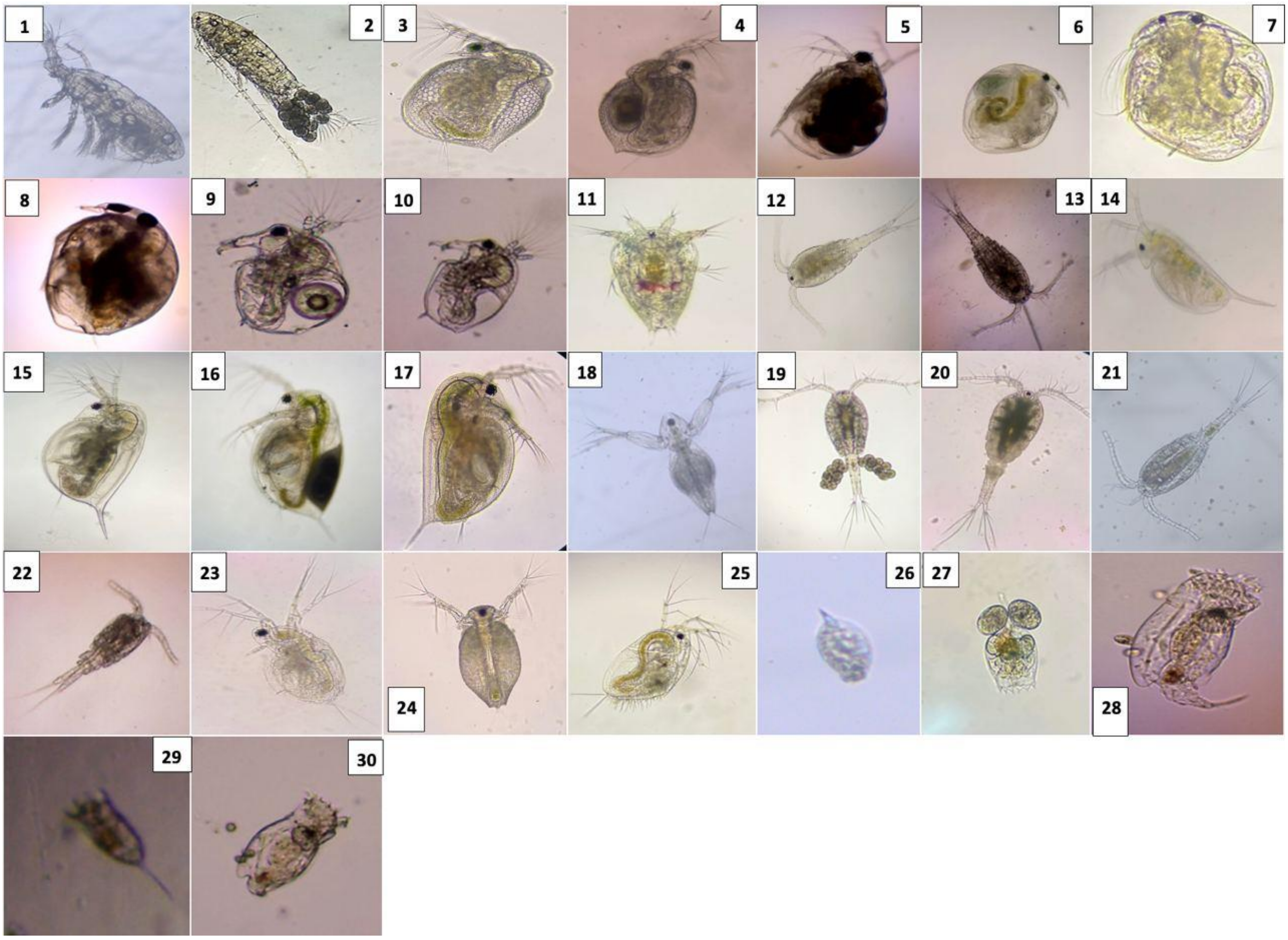

Figure 6. Zooplankton species recorded in Kenyir Lake, Malaysia: 1. *Calanoid copepods*; 2. *Calanus finmarchicus*; 3. *Ceriodaphnia laticaudata*; 4. *Ceriodaphnia rigaudi*; 5. *Ceriodaphnia* sp.; 6. *Chydorus* sp.1; 7. *Chydorus* sp.2; 8. *Chydorus* sp.3; 9. *Chydorus sphaericus* 1; 10. *Chydorus sphaericus* 2; 11. *Cyclopoida nauplius*; 12. *Cyclops scutifer*; 13. *Cyclops* sp.; 14. *Daphnia catawba*; 15. *Daphnia magna*; 16. *Daphnia parvula*; 17. *Daphnia pulex*; 18. *Daphnia* sp.; 19. *Macrocyclops albidus*; 20. *Macrocyclops fuscus*; 21. *Mesocyclops edax*; 22. *Microcyclops rubellus*; 23. *Moina micrura*; 24. *Moina* sp.1; 25. *Moina* sp.2; 26. *Trachelius ciliophora*; 27. *Brachionus plicatilis*; 28. *Brachionus* sp.; 29. *Keratella cochlearis*; 30. *Notholca laurentiae*

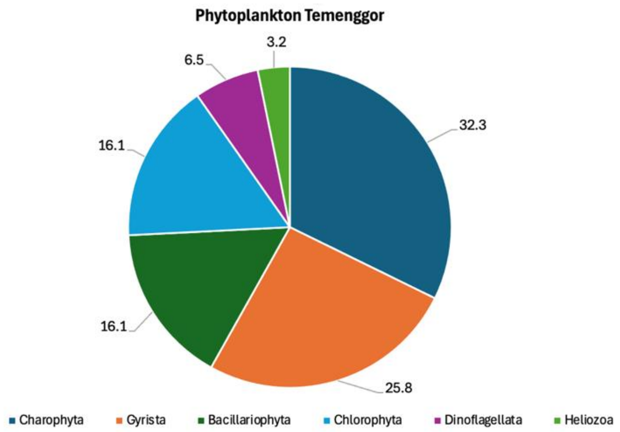

Figure 7. Relative abundance of phytoplankton phylum in Temenggor Lake, Malaysia. Different area shade in the chart indicates the relative abundance percentage of the phylum

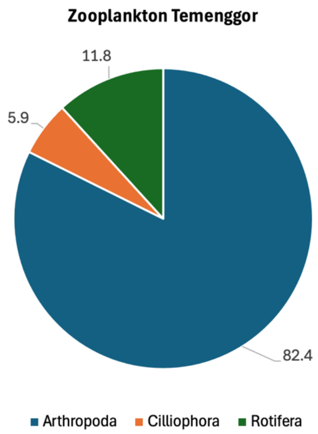

Figure 9. Relative abundance of zooplankton phylum in Temenggor Lake, Malaysia. Different area shade in the chart indicates the relative abundance percentage of the phylum

Figure 8. Phytoplankton species recorded in Temenggor Lake: 1. *Cyclotella* sp.; 2. *Melosira varians*; 3. *Nitzschia* sp.; 4. *Pinnularia* sp.; 5. *Thalassionema nitzschioides*; 6. *Closterium parvulum*; 7. *Cosmarium cucurbita*; 8. *Cosmarium depressum*; 9. *Cosmarium* sp.; 10. *Hyalotheca dissiliens*; 11. *Micrasterias pinnatifida*; 12. *Micrasterias* sp.; 13. *Netrium* sp.; 14. *Staurastrum* sp.; 15. *Xanthidium* sp.; 16. *Actinastrum* sp.; 17. *Botryococcus braunii*; 18. *Pediastrum duplex*; 19. *Pediastrum* sp.; 20. *Tetraspora* sp.; 21. *Ceratium* sp.; 22. *Nusuttodinium aeruginosum*; 23. *Amphora* sp.; 24. *Cymbella* sp.1; 25. *Cymbella* sp.2; 26. *Navicula* sp.1; 27. *Navicula* sp.2; 28. *Navicula* sp.3; 29. *Skeletonema costatum*; 30. *Synura petersenii*; 31. *Acanthocystis* sp.

Zooplankton, a vital food source for many fish species, contribute to fisheries productivity by supporting the growth and reproduction of small fish (Lomartire et al. 2021; Suhaimi et al. 2022); even a diverse plankton community can contribute to overall biodiversity in the freshwater ecosystem (Amorim and Moura 2021). As the primary energy source in the plankton-based food web, the zooplankton community has become a key component of the aquatic ecosystem (Ismail and Mohd Adnan 2016); the zooplankton community is an important factor in the aquatic food chain (Lomartire et al. 2021). Zooplankton plays a key role in nutrient cycling through consumption and excretion. Zooplankton is pivotal in the food chain since it allows nutrient intake onto the lower level and provides food to the upper levels. Therefore, the malfunctions of each trophic level affect even the predator-prey interaction, leading to severe ecosystem degradation (Lomartire et al. 2021).

Zooplankton are crucial for the survival of juvenile fishes in aquatic ecosystems, while phytoplankton are vital for the existence of zooplankton communities in aquatic ecosystems (Rasdi et al. 2020). Zooplankton, which feed on phytoplankton, serve as energy transfer intermediaries on the food web. Phytoplankton population changes can cascade through the ecosystem, affecting the abundance and distribution of zooplankton and its higher trophic levels, such as fish. The fluctuation and quantity measurement of phytoplankton and zooplankton in lakes is essential due to the significance of these tiny creatures in freshwater ecosystems.

Quantifying the abundance of phytoplankton and zooplankton in lakes offers crucial insights into the dynamics and conservation of freshwater ecosystems (Xiong et al. 2020). It assists in evaluating the water quality, the dynamics of trophic levels, and the lake's general condition, thus contributing to efficient methods for conservation and management. Moreover, the abundance and variation of phytoplankton and zooplankton in a freshwater food web can affect the ecosystem (Su et al. 2021); the positive outcomes include increased primary and secondary productivity, supporting diverse organisms, and supporting fish populations.

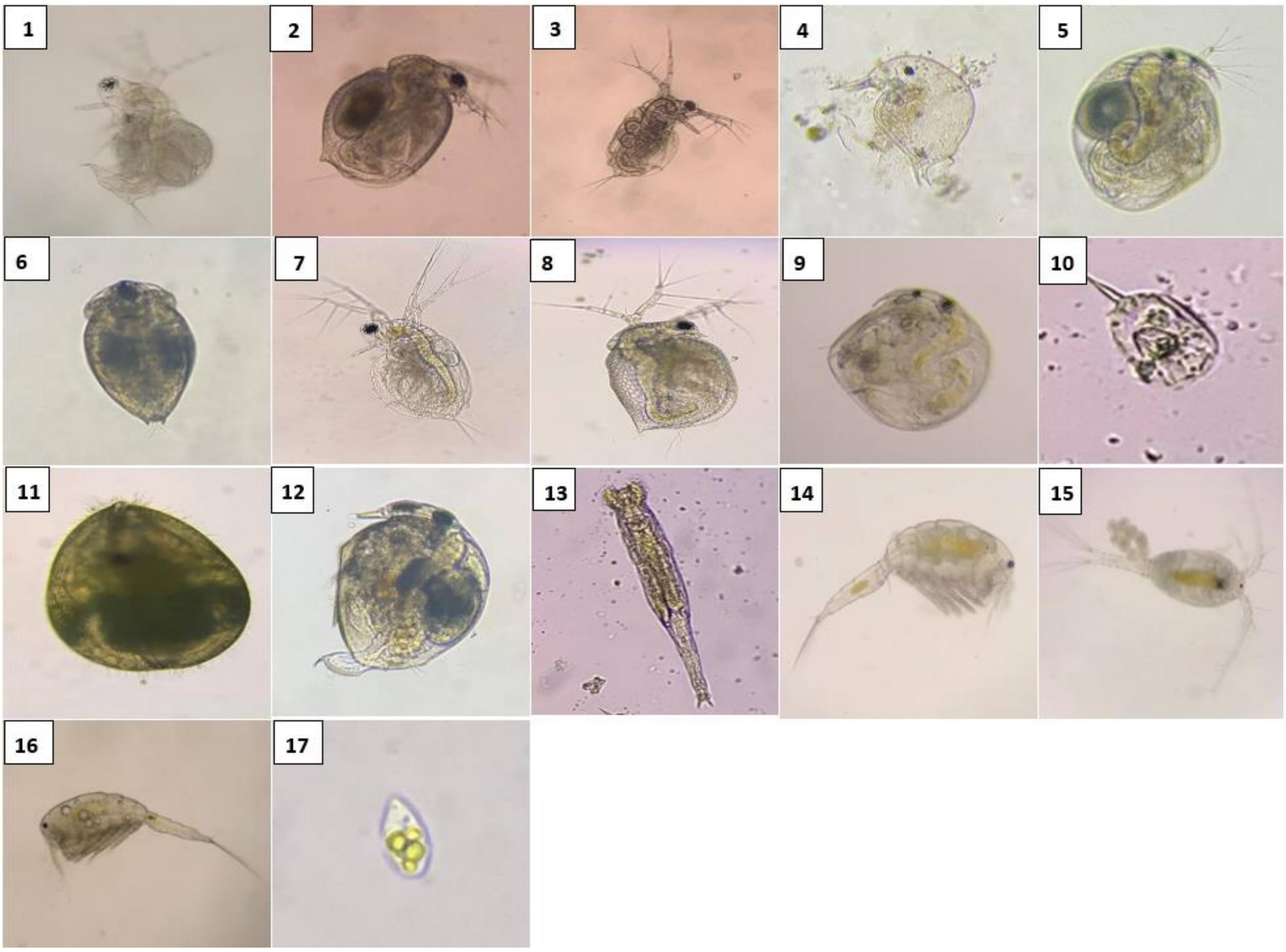

Figure 10. Zooplankton species recorded in Temenggor Lake: 1. *Ceriodaphnia rigaudi*; 2. *Ceriodaphnia sp.*; 3. *Chydorus ovalis*; 4. *Chydorus* sp.1; 5. *Chydorus* sp.2; 6. *Chydorus sphaericus*; 7. *Macrocyclops* sp.; 8. *Mesocyclops edax*; 9. *Mesocyclops fuscus*; 10. *Moina macrocopa*; 11. *Moina micrura*; 12. *Moina* sp.1; 13. *Moina* sp.2; 14. *Monospilus dispar*; 15. *Urotricha farcta*; 16. *Lecane lunaris*; 17. *Rotaria neptunia*

Shannon's diversity index, evenness indexes, and species richness

Table 7 showed the Shannon diversity index of phytoplankton in Kenyir Lake, which revealed that phytoplankton in sampling point A with H': 3.24 of diversity index and 0.94 evenness index was more diverse than the other sampling sites. It was discovered that rocky places had a higher diversity of phytoplankton, mainly diatom species, which tended to be attached in rocky areas with strong currents or streams. While sampling point C recorded with H': 3.15 of diversity index and 0.91 evenness index followed by sampling point B with H': 3.14 of diversity index and 0.91 evenness index.

The highest species richness of phytoplankton in Kenyir Lake (Table 8) belonging was phylum of Charophyta in sampling point B (47.31%) and followed by Chlorophyta (24.55%) and other distributions of Euglenophyta (11.38%), Bacillariophyta (8.98%), Gyrista (5.39%), Cyanobacteria (2.40%), were recorded. Meanwhile, in sampling point A, the distribution division of Charophyta (45.39 %) was the highest, followed by Chlorophyta (26.97%) and other distributions of Euglenophyta (9.21%), Bacillariophyta (7.89%), Gyrista (4.61%), Cyanobacteria (3.29%). In sampling point C, Charophyta (38.28%), followed by Chlorophyta (35.41%), and other distributions of Bacillariophyta (10.53%), Gyrista (5.26%), Euglenophyta (4.31%), Ochrophyta (3.35%) and Cyanobacteria (2.87%) were recorded respectively.

Table 7 shows the Shannon diversity index and evenness index of phytoplankton in Temenggor Lake. This revealed that phytoplankton in sampling point C, with H': 3.23 of diversity index and 0.94 of evenness index, was more diverse than the other sampling sites. Sampling point A was recorded with H': 3.08 of diversity index and 0.90 of evenness index, followed by sampling point B with H': 2.96 of diversity index and 0.86 of evenness index.

The highest species richness of phytoplankton was recorded in Temenggor Lake (Table 8), belonging to the phylum of Charophyta in sampling point A (37.13%). At point A, the highest species richness recorded is Charophyta, followed by Gyrista (31.74%), Chlorophyta (14.37%), Bacillariophyta (12.57%), and Dinoflagellata (4.19%). Meanwhile, at sampling point B, the distribution division of Charophyta (33.33%) was the highest, followed by Bacillariophyta (21.01%), Chlorophyta (20.29%), Gyrista (15.22%), Dinoflagellata (7.25%), and Heliozoa (2.90%). In sampling point C, the highest species richness is Charophyta (25.22%), followed by Bacillariophyta (22.57%), Gyrista (22.12%), Chlorophyta (20.35%), Dinoflagellata (4.87%), Heliozoa (4.87%) and were recorded respectively.

Table 9 shows the Shannon diversity index and evenness index of zooplankton in Kenyir Lake. This revealed that phytoplankton in sampling point C, with H': 2.56 of diversity index and 0.75 of evenness index, was more diverse than the other sampling sites. Sampling point B recorded H': 2.47 in the diversity index and 0.73 in the evenness index, followed by sampling point A with H': 2.36 in the diversity index and 0.69 in the evenness index.

The highest species richness of zooplankton in Kenyir Lake (Table 10) was in the phylum of Arthropoda in sampling point A (89.83%), followed by Rotifera (10.17%). Meanwhile, in sampling point B, Arthropoda (60.00 %) was the highest, followed by Rotifera (40.00 %). In sampling point C, Arthropoda (83.10%) was followed by Rotifera (14.08%) and Ciliophora (2.82%).

Table 9 shows the Shannon diversity index and evenness index of zooplankton in Temenggor Lake. This revealed that zooplankton in sampling point C, with H': 2.59 of diversity index and 0.91 evenness index, was more diverse than the other sampling sites. Sampling point A was recorded with H': 2.58 of diversity index and 0.91 evenness index, followed by sampling point B with H': 2.52 of diversity index and 0.89 evenness index.

The highest species richness of zooplankton in Temenggor Lake (Table 10) was in the phylum of Arthropoda in sampling point C (92.55%), followed by Rotifera (7.45%). Meanwhile, in sampling point A, Arthropoda (84.11%) was the highest, followed by Rotifera (14.02%) and Ciliophora (1.87%). In sampling point B, Arthropoda (81.25%) was followed by Rotifera (18.75%).

The utilization of the Shannon diversity index facilitated the comprehensive assessment of phytoplankton and zooplankton diversity in Kenyir Lake and Temenggor Lake. In Kenyir Lake, sampling point C exhibited the highest diversity (H': 2.37) and evenness (0.86) for phytoplankton, while in Temenggor Lake, sampling point C demonstrated the highest diversity (H': 3.18) and the lowest evenness (0.02). For zooplankton communities, Kenyir Lake's sampling point A displayed the highest diversity (H': 3.24), evenness (0.95), and species richness (53.01), indicative of a diverse population in both shallow coastal waters and the pelagic depth zone. In Temenggor Lake, sampling point A exhibited the highest zooplankton diversity (H': 2.73) and evenness (0.95). Variations in diversity and evenness were observed across different sampling points and lakes, underscoring the influence of specific ecological factors in each aquatic ecosystem.

Table 5. Species list of phytoplankton in Temenggor Lake, Malaysia

Phylum, species	Point A (%)	Point B (%)	Point C (%)
Bacillariophyta			
Cyclotella sp.	16.67	0.00	83.33
Melosira varians	36.36	18.18	45.45
Nitzschia sp.	0.00	50.00	50.00
Pinnularia sp.	25.00	40.00	35.00
Thalassionema nitzschioides	20.00	36.00	44.00
Charophyta			
Closterium parvulum	38.89	33.33	27.78
Cosmarium cucurbita	26.32	31.58	42.11
Cosmarium depressum	22.22	33.33	44.44
Cosmarium sp.	40.00	28.00	32.00
Hyalotheca dissiliens	0.00	71.43	28.57
Micrasterias pinnatifida	0.00	0.00	100.00
Micrasterias sp.	58.33	0.00	41.67
Netrium sp.	47.83	39.13	13.04
Staurastrum sp.	44.44	22.22	33.33
Xanthidium sp.	82.35	0.00	17.65
Chlorophyta			
Actinastrum sp.	13.64	50.00	36.36
Botryococcus braunii	25.00	0.00	75.00
Pediastrum duplex	23.08	26.92	50.00
Pediastrum sp.	20.00	35.00	45.00
Tetraspora sp.	38.46	11.54	50.00
Dinoflagellata			
Ceratium sp.	28.00	32.00	40.00
Nusuttodinium aeruginosum	0.00	66.67	33.33
Gyrista			
Amphora sp.	50.00	0.00	50.00
Cymbella sp.1	41.67	0.00	58.33
Cymbella sp.2	40.91	0.00	59.09
Navicula sp.1	26.92	23.08	50.00
Navicula sp.2	40.00	20.00	40.00
Navicula sp.3	30.00	20.00	50.00
Skeletonema costatum	48.15	44.44	7.41
Synura petersenii	100.00	0.00	0.00
Heliozoa			
Acanthocystis sp.	0.00	26.67	73.33

Table 6. Species list of zooplankton in Temenggor Lake, Malaysia

Phylum, species	Point A (%)	Point B (%)	Point C (%)
Arthropoda			
Ceriodaphnia rigaudi	50.00	20.00	30.00
Ceriodaphnia sp.	47.06	23.53	29.41
Chydorus ovalis	43.75	37.50	18.75
Chydorus sp.1	60.00	20.00	20.00
Chydorus sp.2	0.00	0.00	100.00
Chydorus sphaericus	25.00	0.00	75.00
Macrocyclops sp.	44.12	35.29	20.59
Mesocyclops edax	43.75	25.00	31.25
Mesocyclops fuscus	33.33	27.78	38.89
Moina macrocopa	44.83	24.14	31.03
Moina micrura	45.45	31.82	22.73
Moina sp.1	27.78	27.78	44.44
Moina sp.2	12.50	33.33	54.17
Monospilus dispar	0.00	22.22	77.78
Cilliophora			
Urotricha farcta	100.00	0.00	0.00
Rotifera			
Lecane lunaris	40.00	60.00	0.00
Rotaria neptunia	40.91	27.27	31.82

Table 7. Shannon diversity index and evenness index of phytoplankton in Kenyir Lake and Temenggor Lake, Malaysia

Point	Shannon Diversity index	Evenness
Kenyir Lake		
A	3.24	0.94
B	3.14	0.91
C	3.15	0.91
Temenggor Lake		
A	3.08	0.90
B	2.96	0.86
C	3.23	0.94

Table 8. Richness (%) of phytoplankton in Kenyir Lake and Temenggor Lake, Malaysia

Species richness (%)	A	B	C
Kenyir Lake			
Charophyta	45.39	47.31	38.28
Chlorophyta	26.97	24.55	35.41
Bacillariophyta	7.89	8.98	10.53
Gyrista	4.61	5.39	5.26
Cyanobacteria	3.29	2.40	2.87
Euglenophyta	9.21	11.38	4.31
Ochrophyta	2.63	0.00	3.35
Temenggor Lake			
Charophyta	37.13	33.33	25.22
Chlorophyta	14.37	20.29	20.35
Bacillariophyta	12.57	21.01	22.57
Gyrista	31.74	15.22	22.12
Heliozoa	0.00	2.90	4.87
Dinoflagellata	4.19	7.25	4.87

Table 9. Shannon Diversity Index and Evenness Index of zooplankton in Kenyir Lake and Temenggor Lake, Malaysia

Point	Shannon Diversity index	Evenness
Kenyir Lake		
A	2.36	0.69
B	2.47	0.73
C	2.56	0.75
Temenggor Lake		
A	2.58	0.91
B	2.52	0.89
C	2.59	0.91

Table 10. Species richness (%) of zooplankton in Kenyir Lake and Temenggor Lake, Malaysia

Species richness (%)	A	B	C
Kenyir Lake			
Arthropoda	89.83	60.00	83.10
Rotifera	10.17	40.00	14.08
Ciliophora	0.00	0.00	2.82
Temenggor Lake			
Arthropoda	84.11	81.25	92.55
Rotifera	14.02	18.75	7.45
Ciliophora	1.87	0.00	0.00

Species richness involves quantifying the total count of distinct species within a given ecological community. In contrast, species evenness elucidates individuals' equilibrium or distributional proportionality among various species (Chao and Chiu 2015). Both parameters are crucial for understanding and safeguarding ecosystems' vitality and diversity. Diversity indices, explaining species richness and diversity uniformity, serve as ecological indicators in community diversity assessment. Ramlee et al. (2022) study indicated higher plankton diversity in Kenyir Lake, potentially attributed to its longer natural lake history, making it more vulnerable to eutrophication under uncontrolled nutrient enrichment. However, despite good diversity indices (H': 2.37 and evenness 0.86), plankton's abundance and community composition in Temenggor Lake were not well-distributed.

Climate change can significantly affect plankton populations and their distribution in lakes. As temperatures rise, lakes experience changes in their physical and chemical properties, impacting plankton dynamics (Adrian et al. 2009). Warmer temperatures can disrupt the natural stratification of lakes, affecting nutrient cycling and plankton productivity. Altered precipitation patterns also influence freshwater input and nutrient concentrations, affecting the balance between different plankton species (Jeppesen et al. 2009). These interconnected effects underscore the importance of considering climate change in studying and managing lake plankton populations. Charophyta demonstrated prominence in Kenyir and Temenggor water bodies, known to inhabit various aquatic environments in Malaysia and exhibit specialization based on specific environmental conditions. The murky water quality observed at these sampling points provided an optimal habitat for desmid algae, aligning with findings from Celewicz et al. (2022). The biophysical state observed at both sample points indicates a tributary condition, where river water enters the lake carrying contaminants like animal feces and organic debris (Ramlee et al. 2022). Runoff water fosters excessive phytoplankton development, providing a habitat for various fish species and wild animals (Reid et al. 2019). High nutrient concentrations, irradiance, food web structure, and physicochemical conditions influence phytoplankton populations (Wisha et al. 2018; Andriyani et al. 2020). Natural lakes recorded higher zooplankton species than man-made lakes due to their greater variation and less stability in water level fluctuations (Zhou et al. 2020).

Diverse phytoplankton communities in freshwater lakes also play a crucial role in shaping food web dynamics and increasing primary productivity (Jia et al. 2020; Susilowati et al. 2023). The presence of varied phytoplankton species forms the base of the food chain, supporting a diverse zooplankton community and benefiting the higher trophic levels. This diversity fosters stable food web dynamics, filling ecological niches and enhancing resilience to fluctuations (Kassim et al. 2020; Flood et al. 2023). Additionally, it aids in nutrient cycling, mitigates harmful algal blooms, and contributes to improved water quality. Overall, a diverse phytoplankton community enhances the resilience and sustainability of freshwater lake ecosystems.

Similarly, high zooplankton diversity in aquatic ecosystems is essential to maintain stability by compensating for specific species declines, ensuring efficient energy transfer, and regulating predator-prey dynamics (Burian et al. 2020); the diverse zooplankton communities support enhanced nutrient cycling, promoting ecosystem health and productivity. This diversity also provides resilience to environmental changes, contributing to overall biodiversity and offering essential ecosystem services. Pollution and human activities significantly pressure plankton populations and marine ecosystems (Worm et al. 2006; Doney et al. 2012). Chemical pollutants, including agricultural and industrial runoff, introduce toxins that can directly harm plankton or disrupt their ecological balance through eutrophication (Glibert et al. 2005; Lazim et al. 2024). Physical pollutants such as plastic debris pose additional threats, with microplastics being ingested by plankton and potentially transferring toxins up the food chain (Thompson et al. 2009). Overfishing further disrupts plankton dynamics by altering predator-prey relationships (Worm et al. 2006). These impacts underscore the urgent need for comprehensive measures to mitigate pollution and human activities to safeguard plankton populations and the health of ecosystems.

The ecological dynamics and health of freshwater lake ecosystems, such as Kenyir and Temenggor lakes, can be significantly impacted by variations in plankton species. As primary producers, plankton are of utmost importance in these ecosystems as they facilitate nutrient cycling and energy transfer, significantly affecting upper trophic levels. Variations in the composition of plankton species could potentially indicate alterations in environmental factors, including the accessibility of nutrients, water temperature, and light penetration. Following these variations, the stability and resilience of the entire ecosystem may be affected. Additionally, variations in pollution inputs and nutrient levels generate diverse responses from various plankton species, which can affect water quality. Moreover, plankton community modifications can potentially disturb trophic relationships and biodiversity within these ecosystems, which may result in reorganizations of the community structure and the extinction of species. Furthermore, specific species of plankton, most notably cyanobacteria, can generate harmful algal blooms, which pose potential risks to aquatic organisms and human well-being. A comprehension of the consequences of fluctuations in plankton is critical for developing efficient management and conservation approaches that seek to safeguard the ecological viability of lakes such as Kenyir and Temenggor in the context of continuous environmental transformations, considering the complex relationship of freshwater ecosystems.

Plankton plays a fundamental role in aquatic ecosystems. They're vital as a direct food source for many organisms and contribute significantly to the carbon cycle and overall ecosystem health. Human activities can indeed disrupt this delicate balance. Pollution introduces harmful substances into the water, affecting plankton populations directly or indirectly through the food chain. Overfishing disrupts the natural predator-prey dynamics, potentially leading to harmful algal blooms due to unchecked plankton growth. Maintaining the health of plankton populations is crucial for the well-being of marine and freshwater ecosystems.

The species composition aligns with findings from previous research on tropical reservoirs, with Rotifera predominating in natural lakes, consistent with its role as the primary zooplankton group in tropical lakes (Sharma and Sharma 2019; Arcifa et al. 2020; Elmoor-Loureiro et al. 2023). The diversity and species composition of zooplankton is negatively affected by reservoirs, which are less productive than natural lakes. The study underscores the intricate ecological dynamics and diverse compositions of phytoplankton and zooplankton communities in Kenyir Lake and Temenggor Lake freshwater ecosystems. Understanding and monitoring species richness, evenness, and diversity are crucial for effective management and conservation strategies, increasing productivity and preserving ecological integrity.

One key aspect is seasonal variation, where temperature and nutrient availability fluctuations profoundly impact plankton abundance and diversity throughout the year (Reynolds 2006). Moreover, considering the role of plankton in nutrient cycling sheds light on their significance as primary producers, converting nutrients into organic matter through photosynthesis (Smith et al. 2007). Understanding predator-prey interactions is equally crucial, as plankton is a vital food source for various organisms, and their populations can be influenced by predation pressure from fish and other predators. Additionally, physical factors such as water temperature, light penetration, and turbulence significantly shape plankton distribution within the lake, contributing to spatial variability in abundance and diversity (Winder and Sommer 2012). By examining these ecosystem dynamics, we gain insights into the complex interplay of factors that govern plankton communities and their responses to environmental changes in lakes.

Invasive species significantly threaten plankton populations, exerting profound ecological impacts on aquatic ecosystems. By disrupting natural biotic interactions and competitive dynamics, these non-native species can engender the displacement and decline of Indigenous plankton taxa. Invasive species often exhibit rapid proliferation rates and aggressive resource acquisition strategies, enabling them to outcompete native plankton for essential resources such as nutrients and habitat space. Moreover, introducing invasive species can introduce novel diseases and parasites to native plankton communities, potentially causing population declines or even extinctions among susceptible species. Consequently, the ecological ramifications of invasive species on plankton populations extend beyond mere competitive exclusion, encompassing disruptions to trophic dynamics and ecosystem functioning. Effective management strategies, including early detection, prevention, and control measures, are imperative to mitigate the adverse impacts of invasive species on plankton and safeguard the integrity of aquatic ecosystems.

Addressing the possibility that the sampling method may not capture the full diversity of plankton species in the lakes is crucial for ensuring the accuracy and comprehensiveness of the study. One approach is to employ multiple sampling techniques that target different plankton size fractions and habitats within the lakes (Caron et al. 2012). For example, vertical and horizontal net tows can capture plankton from various depths and locations within the water column. Finally, engaging in collaborative efforts with other researchers and leveraging existing datasets can further enhance the scope and reliability of plankton biodiversity assessments in the lakes. By employing these strategies, researchers can minimize the potential biases associated with sampling methods and improve our understanding of the full diversity of plankton species in the lakes. Therefore, standard sampling protocols and methods have been used in this study to ensure that all plankton data collected are sufficient to picture the distributions and abundance of plankton at both lakes of Kenyir and Temenggor.

In conclusion, the abundance of phytoplankton and zooplankton recorded in this research exhibited substantial variation across the sample stations in Kenyir Lake and Temenggor Lake. This may indicate their specific ecological niche or habitat preferences, influenced by the lake's zonation and overall condition. The ecological lake condition changes may lead to a rise in phytoplankton and zooplankton populations, benefiting fish and other aquatic animals. Therefore, long-term management of aquatic species in Malaysian freshwater lakes may depend on proper oversight of phytoplankton and zooplankton density variations. However, another variable that must be investigated further is the additional component impacts on the phytoplankton and zooplankton abundances. Overall, the impact of high phytoplankton and zooplankton abundance and variation in a freshwater food web depends on the specific dynamics of the ecosystem. This knowledge may be advantageous for advancing sustainable fisheries and overall lake management, especially in conserving aquatic ecosystems and assessing their susceptibility to biological richness. Therefore, to ensure the comprehensiveness and precision of plankton biodiversity studies in lakes, it is essential to use a rigorous approach incorporating various sampling techniques. This approach is necessary to encompass the entire range of plankton species in lake ecosystems. Consequently, sampling points were selected based on the area's physical characteristics to resemble the varying physical conditions of the plankton habitat. This entails employing both vertical and horizontal net tows to capture plankton from diverse depths and spatial distributions throughout the water column. Additionally, a multi-faceted approach enhances the comprehensiveness of biodiversity assessments by revealing a broader array of planktonic taxonomy, including rare or cryptic ones. Moreover, collaborative endeavors among researchers and utilizing existing datasets further enrich the depth and reliability of these assessments.

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