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Water quality and plankton diversity to support aquaculture in the middle Mahakam Watershed, East Kalimantan, Indonesia

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Abstract. *Pagoray H, Suyatna I, Sukarti K, Kesuma AD, Butarbutar T, Raafi M, Suyatna MBB, Daru TP. 2025. Water quality and plankton diversity to support aquaculture in the middle Mahakam Watershed, East Kalimantan, Indonesia. Biodiversitas 26: 233-245.* The middle Mahakam watershed is associated with floodplain areas such as Semayang Lake, Melintang Lake, and Siran Lake, comprises some of the longest and widest rivers in East Kalimantan, and plays an important role in fisheries-based economic development. This study aimed to determine water quality in the middle Mahakam and asses its influence on the abundance, diversity, evenness and dominance of plankton in the context of aquaculture. Samples were collected at six sampling points: Pela River (Sangkuliman Village), Pela Lama, middle of Semayang Lake, Mahakam River, Enggelam Estuary, and Melintang Lake. At all sampling points, most parameters met the quality standards of East Kalimantan Provincial Government (2011), except pH, watercolor, COD, and phenol. Phytoplankton and zooplankton abundance was highest in the Mahakam River, with the most phytoplankton belonging to class Bacillariophyceae (49%), and most zooplankton to the Rotifera (63%). The diversity, evenness, and dominance of phytoplankton and zooplankton were relatively low at all sampling points. Various chemical and physical factors influence plankton, so their presence is dependent on and can affect the water quality. There is a need to pay attention to plankton-related aspects that can be used to estimate productivity and aquaculture potential.

Keywords: Abundance, diversity, middle Mahakam watershed, plankton, water quality

INTRODUCTION

The freshwater systems of East Kalimantan Province play an important role in economic development, in particular in the fisheries sector (Suyatna et al. 2017c; Subagyo et al. 2019). The Mahakam River is the largest in East Kalimantan, with an extensive watershed, and many tributaries, and is associated with flood plains, such as Semayang Lake, Melintang Lake, and Siran Lake (Suyatna et al. 2017a; Saptiani et al. 2018). Local communities have long used these waters for aquaculture using cage systems and for capture fisheries (Suyatna et al. 2021), so the waters of the Mahakam River have become the backbone of the community's economy (Dwijatenaya 2017).

Despite the potential, Mahakam River has long been under pressure from various activities, such as flooding in lakes and swamps rich in potential fish resources, specifically in Middle Mahakam (Suyatna et al. 2021). Several activities have also been reported to play a role in the degradation of water environment, including oil palm plantations, coal transportation, industry, intensive use of fertilizers and pesticides on agricultural land around river flows, soil erosion, and other human activities (Odulate et al. 2017; Djuwita et al. 2021; Suyatna et al. 2021). These activities often lead to water pollution, characterized by the presence of heavy metals (Suyatna et al. 2017b) and bacteria (Some et al. 2021). Water pollution is known to pose a significant risk to regional economic development, directly influenced by community cage cultivation patterns and indirectly by companies located around Mahakam River, thereby impacting water quality (Suyatna et al. 2021).

In line with previous studies, water quality significantly affects fish cultivation around Mahakam River due to the influence on the presence of natural food in the form of plankton. Suyatna et al. (2017c) reported that in poor water environmental conditions, only six species of phytoplankton and five species of zooplankton were identified compared to water free of pollution. In addition, plankton have been reported to be highly dependent on water quality (Gao et al. 2024). Organic materials containing high levels of nutrients could cause an increase in plankton population (Liu et al. 2021). Meanwhile, those containing a high level of heavy metals, oil, and high detergents caused a decline. This indicated that pollution of the aquatic environment typically affected all aquatic organisms (Pagoray and Ghitarina 2020).

According to several reports, phytoplankton are aquatic plants that are the main food source for zooplankton as well as various types of fish and shrimp. These plants also produce dissolved oxygen, which is essential for various water bodies (Richardson and Bendtsen 2017; Inyang and Wang 2020). The presence of plankton in water can be measured based on their abundance, which is influenced by physical, chemical, and biological environmental conditions, specifically dissolved oxygen content, temperature, visibility, availability of nutrients, nitrogen, and phosphorus (Takarina et al. 2019; Prasertsin et al. 2021). Therefore, plankton is often used as a biological indicator of water quality due to their short life cycle and responsiveness to changes in the aquatic environment (Febriansyah et al. 2023).

The abundance and diversity of plankton are strongly influenced by the physicochemical and biological quality of water. To support fish resources, it is also essential to know the types that are dangerous and poisonous. In highly polluted water, it is possible to develop several types of plankton, such as those from the cyanophyceae class (blue-green algae). Several other genera can also be obtained, such as *Anabaenopsis*, *Microcystis*, *Anabaena*, *Coelosphaerium*, *Oscillatoria*, *Nostoc*, *Hapalosiphon*, *and Lyngbya*, which are not consumed by fish due to their poisonous nature (Aida et al. 2022). Water polluted by organic matter has a positive relationship with the abundance of plankton. The higher the phosphate content in a body of water, the higher the abundance of plankton (Darmawan et al. 2018). This indicates that it is necessary to conduct an exploration of water quality, including color, ammonia, nitrate, nitrite, pH, DO (dissolved oxygen), BOD (Biochemical Oxygen Demand), conductivity, temperature, turbidity (Singh et al. 2017; Verma et al. al. 2022), several heavy metals (Hg, As, Se, Cu, Zn, Mn, Fe, Ni, Pb and Cd) (Suyatna et al. 2017b), and identification of plankton types, abundance and diversity (Effendi et al. 2016). Therefore, this study aims to determine water quality in Middle Mahakam River, which influences the abundance, diversity, evenness, and dominance of plankton for aquaculture purposes.

MATERIALS AND METHODS

Observation area

Water sampling was carried out in January 2021 at six points in middle Mahakam water, Kutai Kartanegara District, East Kalimantan Province, Indonesia. Sampling points are presented in Table 1 and Figure 1.

Table 1. Water sampling sites in middle Mahakam, Kutai Kartanegara District, East Kalimantan Province

Sampling site name	Sampling code	Site condition	Coordinate	
			Latitude	Longitude
Pela River (Sangkuliman Village)	11 Ds Sangkul	Settlement area	0° 14' 18.7" S	116° 33' 16.6" E
Pela Lama	14 Pela Lama	Settlement area	0° 14' 04.0" S	116° 32' 19.5" E
Middle Semayang Lake	12 Dan Sem Teng	Fishing area	0° 14' 38.6" S	116° 29' 09.5" E
Mahakam River	13 Sei Mhkm	River transportation line	0° 14' 17.9" S	116° 34' 01.3" E
Enggelam Estuary	15 Ma Enggel	Peat and residential areas	0° 13' 59.1" S	116° 18' 48.6" E
Melintang Lake	16 Dan Melint	Fishing area	0° 15' 06.3" S	116° 20' 15.6" E

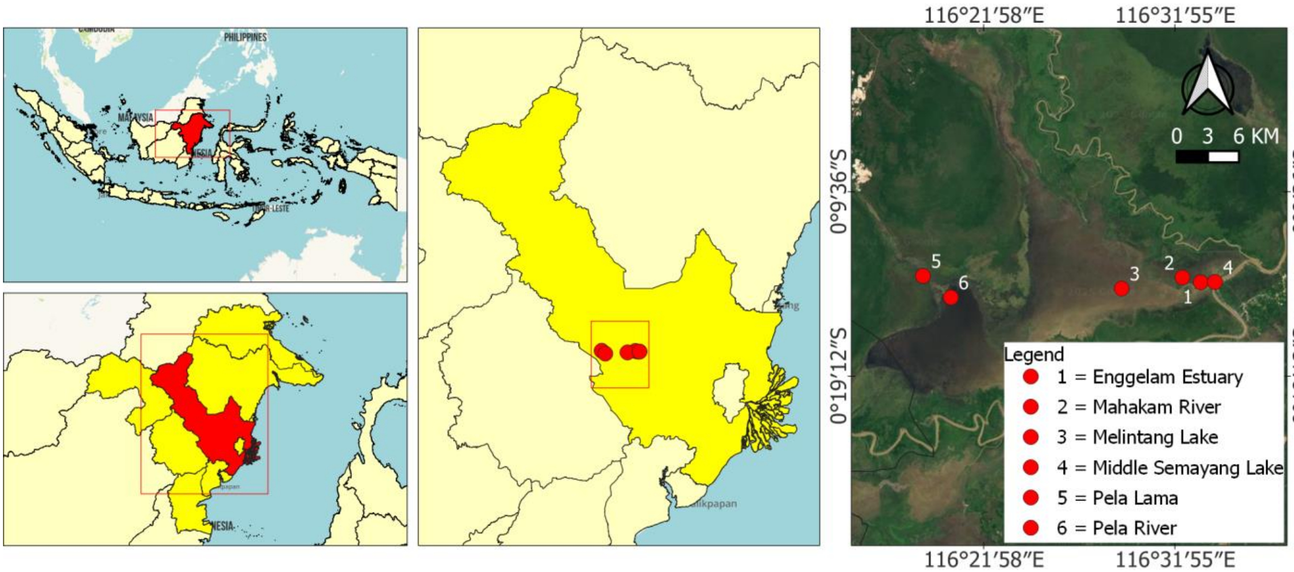

Figure 1. Distribution of water sampling points in middle Mahakam water, Kutai Kartanegara, East Kalimantan, Indonesia

Water quality

Water sampling was spread from Enggelam Estuary, which was identified as being near peatland water where water was dark brown but appeared black in the river body to Semayang Lake. In addition, water samples were taken using a 5 L capacity jerry can, and analyzed at Water Quality Laboratory, Faculty of Fisheries and Marine Sciences, Universitas Mulawarman.

In this study, water quality measurements included physical components, namely temperature, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), and color, chemical components, such as pH, Dissolved Oxygen (DO), phosphate (PO_4-P), nitrite (NO_2-N), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrate (NO_3-N), ammonia (NH_3 -N), arsenic (As), selenium (Se), cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), zinc (Zn), and phenol. The microbiological component, including fecal coliform (APHA 2017; Verma et al. 2022; Omer et al. 2024) was also assessed.

Plankton

The water volume used for plankton community analysis was 100 L, collected using a 10 L bucket and filtered by pouring through a T180 Plankton Net. The water was put into a tube then put into a sample bottle with 0.5% Lugol preservative, and labeled with a code (Sano et al. 2020). The plankton abundance was calculated by taking an aliquot of the preserved sample (1 mL for phytoplankton and 2.5 mL for zooplankton), placing it in a Sedgwick-Rafter chamber, and counting the number of cells under a microscope. Plankton was identified using the microscopy method (Dhargalkar and Ingole 2004; MMR 2024; Peperzak et al. 2020).

Plankton abundance

Plankton abundance calculation were carried out based on the guidelines proposed by Dhargalkar and Ingole (2004) and Hastuti et al. (2018):

$$N = n \text{ x } \frac{Vr}{Vo} \text{ x } \frac{1}{Vs} \text{ x } 1000$$

Where: N: Number of individuals per liter; n: Number of individuals based on observations; Vr: Volume of filtered water (100 mL); Vo: Volume of water observed (1 mL); Vs: Volume of filtered sample (100 L).

Diversity index (H')

Diversity index generally described the abundance and evenness of a species found in a population (Hossain et al. 2017). In addition, diversity was determined using the Shannon-Wiener (H') formula (Holmberg 2024):

$$H' = -\sum \left[\frac{ni}{N}\right] \log \left[\frac{ni}{N}\right]$$

Where: H': Species diversity index; ni: Number of individuals per species of the ith species (i from 1 to S, where S: The number of species present); N: Number of individuals of all species.

The criteria for the biota diversity index are:

H' < 1: Species diversity is small, population is unstable; H' 1-3: Species diversity is moderate, population is moderate; H' > 3: Species diversity is large, population is stable.

Evenness index (E)

Evenness index (Shannon Index) shows the relative abundance of the plankton species in an area (Isdianto et al. 2024):

$$E = \frac{H'}{\ln(S)}$$

Where: E: Species evenness index; H': Species diversity index; S: Number of species in the population.

Evenness index criteria ranged from 0-1. When evenness index value was close to 1, then the distribution of individuals between species was relatively even.

Dominance index (D)

Species dominance index (Simpson's Domination Index) revealed abundance of a particular plankton species in a community (Holmberg 2024). In addition, it could be calculated using the equation below:

$$D = \sum \frac{(ni)^2}{N^2}$$

Where: D: Species dominance index; ni: Number of individuals of each species; N: Total number of individuals.

Dominance index value ranged between 0-1, and when dominance index value was close to 0, there were no dominant species or high diversity.

RESULTS AND DISCUSSION

Water quality

Water quality is a very important parameter because it describes the relative size of water condition that is needed for the development of aquaculture and human interests. This condition is influenced by surrounding activities apart from weather conditions. Water quality parameters generally consists of physical, chemical, and biological aspects. These parameters influence the life of aquatic organisms (Supriyanto and Koestoer 2022; Omer 2024). The results of water quality measurements at sampling points are presented in Table 2.

Results of laboratory analysis, physical, chemical, and biological content showed that almost all parameters at all sampling points met quality standards according to East Kalimantan Provincial Government (2011), except for pH, watercolor, COD, and phenol.

Table 2. Water quality parameter values analysis at six sampling points in middle Mahakam water, Kutai Kartanegara, Indonesia

Parameter	Unit	Quality standard*)	Sampling point					
			1	2	3	4	5	6
Physical								
Temperature	°C	range ± 3°C	30.0	28.0	30.0	28.0	27.0	30.0
TDS	mg L^{-1}	1000	40	33	38	48	13	22
TSS	mg L^{-1}	50	32	12	20	24	8	11
Color	mg L^{-1} (PtCo)	180	164.442	102.341	172.542	142.842	234.643	245.444
Chemical								
pH	-	6 - 9	6.68	6.45	7.29	7.09	4.29	6,0
PO_4-P	mg L^{-1}	0.2	0.036	0.039	0.036	0.039	0.033	0.026
NO_2-N	mg L^{-1}	0.06	0.008	0.018	0.009	0.014	0.015	0.010
NO_3-N	mg L^{-1}	10	0.085	0.053	0.097	0.121	0.117	0.149
NH_3-N	mg L^{-1}	(-)	0.059	0.065	0.042	0.022	0.039	0.053
BOD	mg L^{-1}	3	1.75	1.15	2.02	1.67	1.21	1.55
COD	mg L^{-1}	25	27.830	23.562	26.496	21.961	43.300	63.039
DO	mg L^{-1}	4	5.88	4.72	4.07	5.88	5.41	5.11
Se	mg L^{-1}	0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cd	mg L^{-1}	0.01	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cu	mg L^{-1}	0.02	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Fe	mg L^{-1}	(-)	0.611	0.748	0.690	0.872	0.455	0.397
Pb	mg L^{-1}	0.03	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Mn	mg L^{-1}	(-)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hg	mg L^{-1}	0.002	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
Zn	mg L^{-1}	0.05	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Phenol	mg L^{-1}	0.001	<0.003	<0.003	<0.003	<0.003	0.003	0.004
Microbiological								
Fecal Coliform	MPN 100 mL^{-1}	1000	54	43	36	39	70	90

Note: 1. Pela River (Sangkuliman Village), 2. Pela Lama, 3. Middle Semayang Lake, 4. Mahakam River, 5. Enggelam Estuary; 6. Melintang Lake; (-): no limit given, *): East Kalimantan Provincial Government (2011)

TSS and TDS were physical parameters commonly used to measure water quality, namely the number of solid particles consisting of algae, organic materials, and inorganic materials (Khan et al. 2018). In the same sample, TDS and TSS were separated by filtration. The part that did not pass through the filter paper was called TSS, while the other passing through the filter paper was known as TDS (Adjovu et al. 2023). In adddition, total solids could affect water clarity. The higher the solids, the lower the penetration of light into water, which could affect the photosynthesis process in aquatic plants (Pagoray and Ghitarina 2024). Several studies had also shown the ability to accelerate water warming and retain more heat, which affected the life of aquatic organisms (APHA 2017). In this study, TSS and TDS concentrations at all sampling points were below the specified quality standards, hence, the parameters did not affect fish cultivation in the area.

Acidity or pH was a measure of the concentration of hydrogen ions, which determined whether water was acidic or alkaline. pH scale had a series of 0-14, and when it was 7, it indicated neutral and water was neither acidic nor alkaline. When pH value was below 7, this indicated acidic, and values above 7 showed alkaline (Swain et al. 2020). The toxicity of a chemical compound was also influenced by pH, and most aquatic biota were sensitive to changes. For freshwater species, the desired pH was around 6.5-9.0. At pH below 6.0 or above 9.0, most freshwater fish are likely to lose body weight. For barramundi fish (*Lates calcarifer*), the optimal pH was 7.24, and values less than 6.24 could decrease the performance (Fitriana et al. 2023).

In this study, there were two sampling points that had pH below 6.5, namely Enggelam Estuary (pH 4.29) and Melintang Lake (pH 6.0). Acidity in water was generally caused by high levels of carbon dioxide due to photosynthesis, respiration, and the decomposition of organic matter. The presence of phytoplankton also played a role in increasing or decreasing pH. Carbon dioxide in water reacted to become carbonic acid, where the carbonic acid released hydrogen, which contributed to lowering pH (Saalidong et al. 2022). The stream of Enggelam causes the low pH in the Enggelam estuary because the stream of Enggelam through the peat soil, so the water is dark in color. Water flowing through peat soil has a high level of acidity (low pH) (Cao et al. 2017; Suyatna et al. 2021).

Watercolor and COD had a similar pattern. Increasing watercolor is associated with increasing COD (Figure 2). The color of the water can be influenced by the presence of organic and inorganic materials, plankton, humus and metal ions such as iron (Fe) and manganese (Mn), as well as other materials that can color the waters. Watercolor can be grouped into true color, which is caused by dissolved materials, and apparent color, which is not only caused by dissolved materials but also by suspended materials (Awalliyah 2019). COD concentration is often used as a measure to assess water quality caused by pollution due to the presence of organic matter in waters (Cai et al. 2023), especially COD with a fraction > 0.7 µm (Lv et al. 2022). The results of this study showed that the COD concentration from the six sampling points varied from 21.961-63.09 mg L^{-1}. At several sampling points, namely

Pela River (Sangkuliman Village), Semayang Tengah Lake, Enggelam Estuary, and Melintang Lake, COD concentrations exceeded the water quality standard (25 mg L^{-1}).

BOD is biological oxygen demand which reflects the need of oxygen for aerobic microbes to oxidize organic matter into carbon dioxide and water. In general, lower BOD values indicate better water quality (Quang and Giao 2023). Organic matter is the result of decomposing plants and animals or waste products from domestic and industrial waste (Effendi et al. 2016). The greater the BOD, the lower the amount of dissolved oxygen remaining in the water. The BOD measurements at the sampling points were in the range of 1.15-2.02 mg L^{-1}, where the highest BOD concentration was in the waters of Semayang Lake (2.02 mg L^{-1}). Areas that have higher human activity tend to have higher BOD concentrations than other areas. Community activity was high around the Pela River (Sangkuliman Village), Middle of Semayang Lake, Enggelam Estuary, and Melintang Lake sampling points. Factors that also influence BOD include various types of land use, domestic waste, industrial and agricultural activities (Universitas Mulawarman 2021).

DO concentration reflects the amount of dissolved oxygen in waters so that they can support the life of aquatic organisms that need oxygen (Ali et al. 2022). Fish, bacteria, phytoplankton, and zooplankton need oxygen to survive and reproduce; therefore, oxygen is an important component in aquaculture. If the DO concentration in freshwater is below 5-6 mg L^{-1}, many aquatic organisms will experience hypoxia, a lack of oxygen which can result in stress, decreased appetite, slow growth, susceptibility to disease, and death (Ali et al. al. 2022). DO concentrations can change over time, and allow the formation of stable areas where DO concentrations are below average, resulting in the death of aquatic organisms (Ito et al. 2017; Richardson and Bendtsen 2017) including plankton (Chowdhury et al. 2023). The DO concentration in this study ranged from 4.07-5.88 mg L^{-1}. In accordance with East Kalimantan Provincial Government (2011), the minimum DO concentration is 4 mg L^{-1}, so that the sampling points still met the specified quality standards.

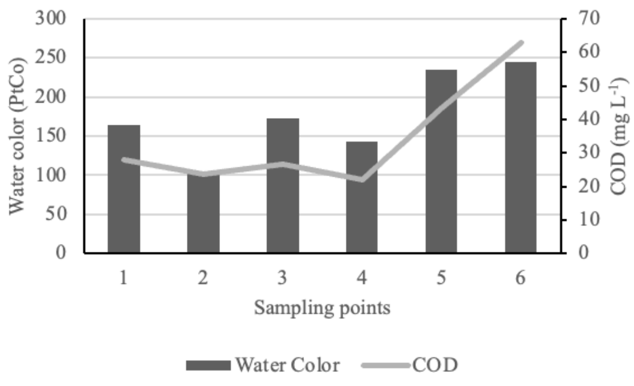

Figure 2. Watercolor and COD concentration at six sampling points in middle Mahakam water, Kutai Kartanegara, East Kalimantan, Indonesia. Note: 1. Pela River (Sangkuliman Village), 2. Pela Lama, 3. Middle Semayang Lake, 4. Mahakam River, 5. Enggelam Estuary; 6. Melintang Lake

All heavy metal concentrations analyzed, namely Se, Cd, Cu, Fe, Pb, Mn, Hg and Zn, were below the quality standards. These parameters are important to determine the safety of the waters in the observation area so that they can be used for aquaculture or capture fisheries. Some heavy metals are important elements needed by animals and plants, but if the amounts are excessive, they can be toxic. The main sources of heavy metals come from nature (source rock), agricultural activities (fertilizer, pesticides and compost), industry (mining, metal, textiles, paint, etc.), and domestic waste (Gavhane et al. 2021). Heavy metals dissolved in water will bind with free organic material and can have an impact on aquatic biota (Shara et al. 2021). In waters polluted by heavy metals, such as Pb, Zn, Cu, Ni, Fe, Mn, Cd, and Mg, there can be a very significant bioconcentration in plankton, where the ultrahigh bioconcentration of heavy metals is generally in Fe, Mg, and Mn, high bioconcentration in Ni, Zn, and Cu, and moderate bioconcentration in Pb and Cd (Nikolenko and Fedonenko 2020). Plankton play a large role in the food chain in the aquaculture environment. Plankton form the basis of the food chain for fish, so that if there is a high concentration of heavy metals in plankton, it can affect the health of humans who consume aquatic resources (Emmanuel and Ima-Owaji 2022).

Nitrogen in water was in the form of inorganic and organic nitrogen. Organic nitrogen consisted of ammonia (NH_3-N), ammonium (NH_4-N), nitrite (NO_2-N), and nitrate (NO_3-N). When water was contaminated by waste, specifically from anthropogenic sources, such as household waste, manure, nitrogen fertilizer, and industrial waste, most of the nitrogen was in organic form. The compound was then converted by microbes to form nitrites and nitrates (Hu et al. 2021; Omer et al. 2024). Nitrite was usually found in very small amounts in natural water. The results of nitrite measurements at sampling points were in the range of 0.008-0.015 mg L^{-1} (quality standard 0.06 mg L^{-1}), followed by nitrate (0.085-0.149 mg L^{-1}) (quality standard 10 mg L^{-1}), and ammonia (0.02-0.065 mg L^{-1}). This value was included in the category below the quality standard, hence, it was still safe and not toxic to aquatic organisms.

The phosphate content (PO_4-P) in water indicated the level of water pollution in the environment. High concentration of phosphate could cause eutrophication and death of aquatic organisms (Velusamy et al. 2021). Phosphate content at all sampling points was below the quality standard, namely 0.2 mg L^{-1}, hence, it did not affect fisheries cultivation in the area.

Phenol and other polyphenolic compounds were organic compounds that were often found in aquatic areas. Phenolic compounds in water originated from waste from paper making, agriculture, pharmaceuticals, the petrochemical industry, coal processing, or municipal waste. This compound tended to be persistent in the aquatic environment for long periods and had toxic effects, hence, it was a concern in water use (Mainali 2020). The results of phenol measurements at sampling points ranged from <0.003-0.04 mg L^{-1}. These results exceeded the quality standard values as required by East Kalimantan Provincial

Government (2011) of 0.001 mg L^{-1}. Several studies showed that phenol was toxic to fish and plankton. Soliman et al. (2020) conducted an experiment on administering phenol at a concentration of 1.40 mg L^{-1} to tilapia (*Oreochromis niloticus* (Linnaeus, 1758)), leading to a decrease in growth, gonado-somatic index, relative fecundity, sperm density and sperm live. Similar results were obtained in the reduction of phytoplankton diversity and community structure at phenol concentrations higher than 0.05 mg L^{-1} (El-Naeb et al. 2022). Several methods can be used to reduce the problem of high phenol content in water, including microbiological methods involving bacteria, yeast and fungi (Anku et al. 2017).

The number of fecal coliform bacteria in water was a reference for environmental pollution, which indicated the presence of pathogenic bacteria, hence, it was often used as an indicator of water quality (Anisafitri et al. 2020; Puspitasari and Hadi 2022). In this study, the number of fecal coliform bacteria at all sampling points ranged from 36-90 MPN 100 mL^{-1}, indicating that it was below the established quality standard, namely 1000 MPN 100 mL^{-1}. When the number of bacteria found in water was below the quality standard, water quality was still good.

Plankton abundance

There were 52 species of plankton identified across the six sampling points. These 52 plankton species comprised 29 phytoplankton species and 23 zooplankton species. The plankton community composition was different at each sampling point (Tables 3 and 4). Images of each plankton are presented in Figures 5 and 6. In Figure 3, it can be seen that the most phytoplankton species were found in Middle of Semayang Lake and the most zooplankton were found in the Pela Lama and Mahakam River.

At each sampling point, there were more species of phytoplankton than zooplankton. This shows that phytoplankton diversity was higher than zooplankton diversity. The characteristics of plankton diversity reflect the occurrence of feeding events and the availability of nutrients to support the aquatic food chain. This condition is said to be stable if the phytoplankton population is greater than zooplankton, because phytoplankton act as producers and zooplankton as consumers (Yuan and Pollard 2018).

The types of phytoplankton identified came from the Bacillariophyceae, Cyanophyceae, Dinophyceae, Closteriaceae, Zygnematophyceae, and Chlorophyceae, while the zooplankton identified comprised Rotifera, Protozoa, Amoebozoa, Arthropoda, and Euglenaceae. The size of each phytoplankton and zooplankton taxonomic group is presented in Figure 4.

In phytoplankton, the group with the largest number was from Bacillariophyceae class (49%), while in zooplankton, the largest number was from Rotifera group (63%). Bacillariophyceae diatom group was phytoplankton that was sensitive to environmental changes. Therefore, the total biomass in phytoplankton population was often used as an indicator in aquatic habitat qualification (Gökçe 2016; Sukma and Takarina 2022). The high level of rotifers at the observation points indicated the good quality of water as a natural food source for fish larvae due to their role in the initial growth and development of fish (Wulur 2017). Rotifers were often cultured as a food source in fish hatcheries, specifically in biofloc technology (Hosain et al. 2024). According to Ramlee et al. (2022) in Papan River, Kenyir Lake (Malaysia) had the same pattern as this study where the most phytoplankton came from Bacillariophyta phylum (50.16%) and the most zooplankton was from Rotifera phylum (60%). Similar results were also obtained by Geng et al. (2022), where water was generally dominated by Bacillariophyta and Rotifera groups.

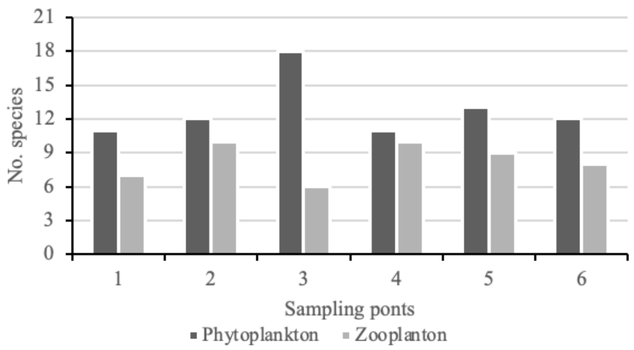

Figure 3. Number of plankton species at six sampling points in middle Mahakam water, Kutai Kartanegara, Indonesia. Note: 1. Pela River (Sangkuliman Village), 2. Pela Lama, 3. Middle Semayang Lake, 4. Mahakam River, 5. Enggelam Estuary; 6. Melintang Lake

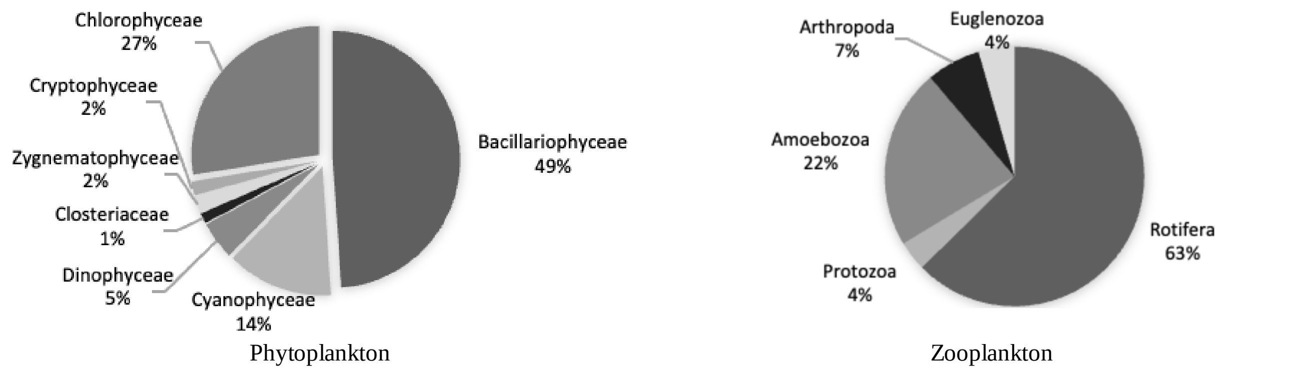

Figure 4. Proportion of phytoplankton and zooplankton groups for all sampling points in the middle Mahakam water combined, Kutai Kartanegara, East Kalimantan, Indonesia

Table 3. Phytoplankton taxa found at six sampling points in the middle Mahakam water, Kutai Kartanegara, East Kalimantan, Indonesia

Phytoplankton taxon	Sampling points					
	1	2	3	4	5	6
Bacillariophyceae						
Asterionella sp.	-	+	-	+	+	+
Climacosphenia moniligera	+	+	+	-	-	+
Cyclotella comta	-	-	+	-	-	-
Fragilaria sp.	-	-	-	+	-	-
Gomphonema sp.	-	-	-	+	-	-
Navicula sp.	+	+	-	-	-	-
Nitzschia sp.	+	-	+	-	-	-
Synedra ulna	-	-	+	+	+	+
Synedra tabulata	-	-	+	-	+	+
Tabellaria flocculosa	+	+	-	+	+	-
Cyanophyceae						
Gomphosphaeria aponina	-	-	-	-	-	+
Microcystis sp.	-	-	-	-	+	+
Oscillatoria sp.	+	+	+	+	+	+
Spirulina sp.	-	+	-	-	-	-
Dinophyceae						
Amphidinium sp.	-	-	+	+	+	+
Closteriaceae						
Closterium acerosum	-	+	-	-	-	-
Pachycladon umbrinus	-	+	+	-	-	-
Zygnematophyceae						
Zygnema sp.	+	-	+	+	-	-
Cryptophyceae						
Chilomonas sp.	-	+	+	-	-	-
Chlorophyceae						
Chlamydomonas sp.	+	-	-	-	+	-
Desmidium sp.	-	-	+	+	+	-
Lagerheimia citriformis	+	-	-	+	+	+
Microspore sp.	-	-	+	+	+	-
Oedogonium sp.	+	+	+	-	-	+
Palmella sp.	-	-	-	-	-	+
Stigeoclonium sp.	+	+	+	-	-	-
Staurastrum sp.	-	-	+	-	-	-
Spirogyra sp.	-	+	+	-	+	-
Ulothrix aequalis	+	-	+	-	+	-

Table 4. Zooplankton taxa found at six sampling points in the middle Mahakam water, Kutai Kartanegara, East Kalimantan, Indonesia

Zooplankton taxon	Sampling points					
	1	2	3	4	5	6
Rotifera						
Anuraeopsis sp.	-	-	-	-	+	-
Colurella adriatica	-	-	-	+	-	-
Euchlanis sp.	-	-	-	+	-	-
Lecane haliclysta	-	-	-	+	-	-
Lepocinclis salina	-	-	+	-	-	-
Monostyla sp.	-	-	-	-	+	-
Philodina sp.	+	+	+	+	+	+
Ploesoma sp.	-	-	-	-	+	-
Polyarthra sp.	+	+	-	+	+	-
Proales sp.	-	-	+	+	-	
Trichocerca rattus	-	-	+	+	+	+
Trichocerca longiseta	-	-	-	+	-	+
Tripyla sp.	+	+	-	-	-	+
Protozoa						
Difflugia bacillifera	+	-	-	-	-	-
Difflugia globulosa	-	+	-	-	-	-
Peranema sp.	-	+	-	-	-	-
Amoebozoa						
Arcella dentata	+	+	+	+	0	+
Arcella vulgaris	+	+	+	+	+	+
Arthropoda						
Alona affinis	-	+	-	-	-	-
Alona costata	+	-	-	-	+	-
Cyclopoid nauplius	-	-	-	-	-	+
Diaptomus sp.	-	+	-	-	-	+
Euglenozoa						
Trachelomonas armata	-	+	-	-	+	-

Note for Tables 3 and 4: 1. Pela River (Sangkuliman Village); 2. Pela Lama; 3. Semayang Tengah Lake; 4. Mahakam River; 5. Enggelam Estuary; 6. Melintang Lake. +: present; -: absent

The individual plankton counts from each sampling point ranged from 2772 to 5985 individual per liter. Phytoplankton as primary producers act as a proxy for the fertility of water bodies. The abundance of phytoplankton in a water body has a positive impact on productivity, as the composition and specific abundance of phytoplankton in a water body play a role as natural food for higher trophic levels, and also acts as a provider of oxygen in the water. In this case, phytoplankton are the main food source for the zooplankton present. Figure 7.A shows that the dynamics of the number of zooplankton individuals follow the movement of the phytoplankton population, while Figure 7.B shows the Rotifer population following the movement of the Bacillariophyceae. The greater number and variety of phytoplankton caused the biota to increase to a higher trophic level to ensure an increase in aquatic productivity. The results showed that there were more phytoplankton as producers than zooplankton as consumers, indicating the stability of aquatic ecosystem (Yuan and Pollard 2018).

The high population of plankton in water of Mahakam and Pela River was thought to be related to the relatively higher DO content compared to other sampling points (Figure 8). Although East Kalimantan Provincial Government (2011) stipulated that the minimum DO concentration in water was 4 mg L^{-1}, there was a decrease in DO from 5.88 to 4.07 mg L^{-1} (a decrease of 30.78%), which had an impact on decreasing plankton population. Oxygen in water was obtained from two sources, namely from the atmosphere and aquatic plants, including phytoplankton. Apart from the ability to produce oxygen, phytoplankton, plankton population also needed oxygen (Takarina et al. 2017). When water DO decreased, plankton population also experienced a decline (Weinstock et al. 2022) and when the decrease was below 2 mg L^{-1}, hypoxia occurred (Karpowicz et al. 2020; Keister et al. 2020). Apart from the decline in plankton populations, the distribution of fish abundance had also decreased due to the decrease in DO (Suyatna et al. 2021).

Diversity, evenness, and dominance

Results of calculating diversity index, evenness index, and dominance index of plankton at sampling points are presented in Table 5. Phytoplankton diversity index varied from H' = 0.8011 (Pela River) to H' = 1.1891 (middle Semayang Lake), while zooplankton diversity index varied from H' = 0.2631 (Melintang Lake) to H' = 0.9457 (Pela Lama). The low diversity index reflected pressure in water quality both physically and chemically. In this study, the population was in an unstable to moderate position. The study of Hossain et al. (2017) in Meghna River of Bangladesh showed that diversity index for phytoplankton ranged from 0.5387-0.6874 and zooplankton from 0.4506-0.6931. This condition shows the changing distribution of the water surface where certain types of zooplankton benefited from the changing environment.

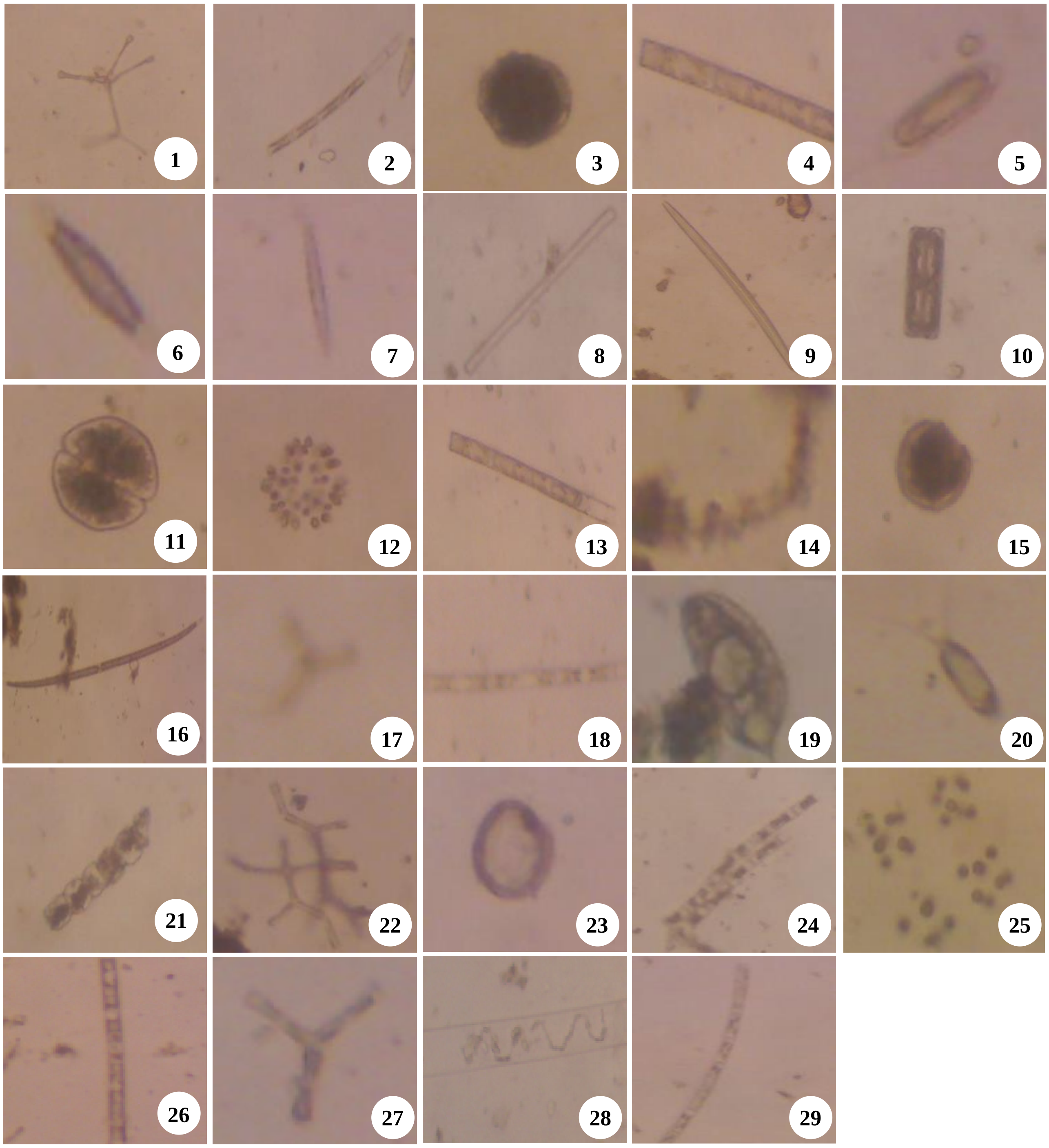

Figure 5. Phytoplankton found at six sampling points in the middle Mahakam water, Kutai Kartanegara, East Kalimantan, Indonesia: 1. *Asterionella* sp.; 2. *Climacosphenia moniligera; 3. Cyclotella comta;* 4. *Fragilaria* sp.; 5. *Ghophonema* sp.; 6. *Navicula* sp.; 7. *Nitzschia* sp.; 8. *Synedra ulna;* 9. *Synedra tabulate;* 10. *Tabellaria flocculosa;* 11. *Gomphosphaeria aponina;* 12. *Microcystis* sp.; 13. *Spirulina* sp.; 14. *Oscillatoria* sp.; 15. *Amphidinium* sp.; 16. *Closterium acerosum;* 17. *Pachycladon umbrinus;* 18. *Zygnema* sp.; 19. *Chilomonas* sp.; 20. *Chlamydomonas* sp.; 21. *Desmidium* sp.; 22. *Lagerheimia citriformis;* 23. *Microspore* sp.; 24. *Oedogonium* sp.; 25. *Palmella* sp.; 26. *Stigeoclonium* sp.; 27. *Staurastrum* sp.; 28. *Spirogyra* sp.; 29. *Ulothrix aequalis*

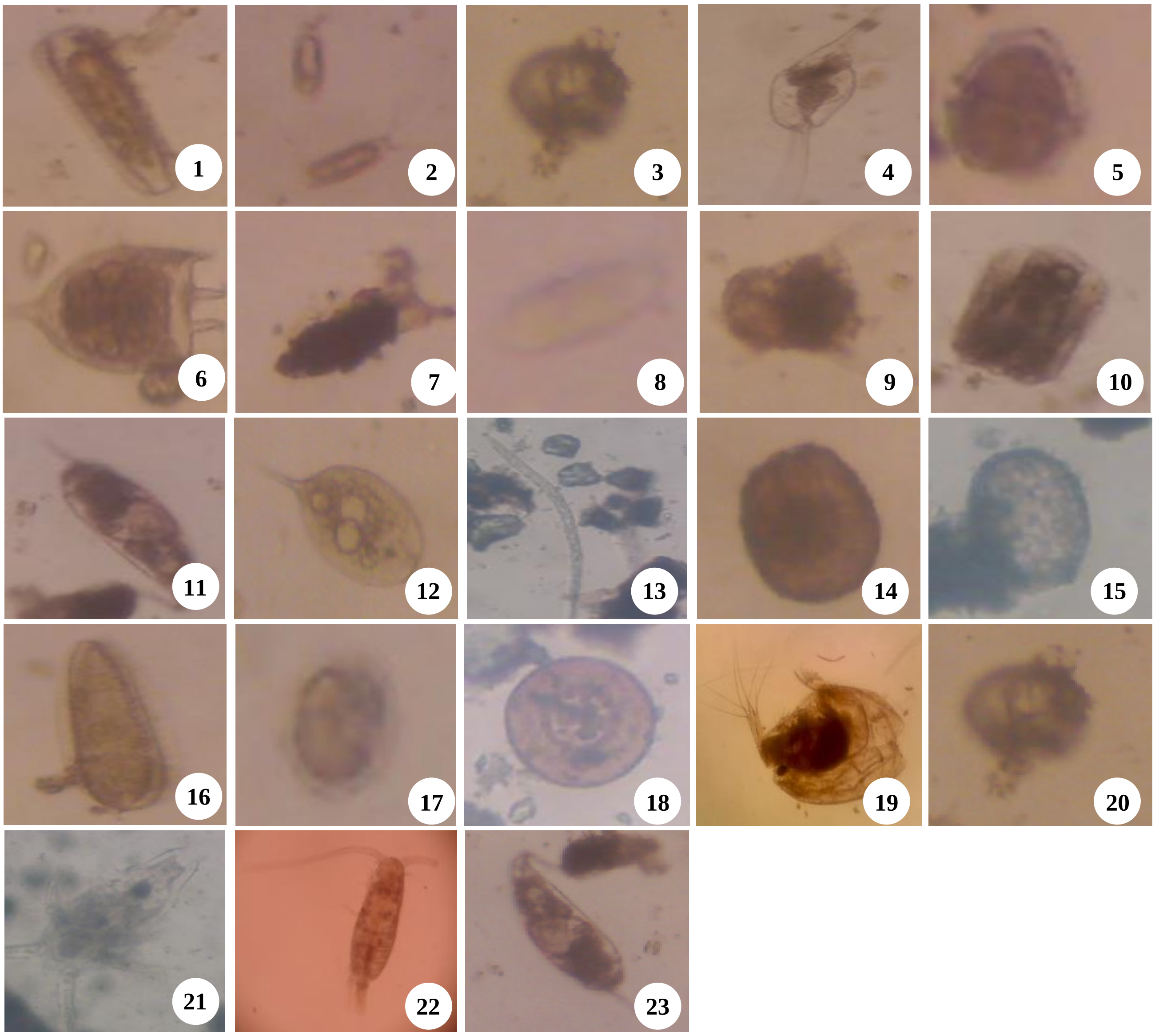

Figure 6. Zooplankton found at six sampling points in the middle Mahakam water, Kutai Kartanegara, East Kalimantan, Indonesia: 1. *Anuraeopsis* sp.; 2. *Colurella adriatica; 3*. *Euchlanis* sp; 4. *Lecane haliclysta*.; 5. *Lepocinclis salina*.; 6. *Monostyla* sp.; 7. *Philodina* sp.; 8. *Ploesoma* sp.; 9. *Polyarthra* sp.; 10. *Proales* sp.; 11. *Trichocerca rattus;* 12. *Trichocerca longiseta*.; 13. *Tripyla* sp.; 14. *Difflugia bacillifera*; 15. *Difflugia globulosa*; 16. *Peranema* sp.; 17. *Arcella dentata;* 18. *Arcella vulgaris*; 19. *Alona affinis*.; 20. *Alona costata*; 21. *Cyclopoid nauplius*; 22. *Diaptomus* sp.; 23. *Trachelomonas armata*

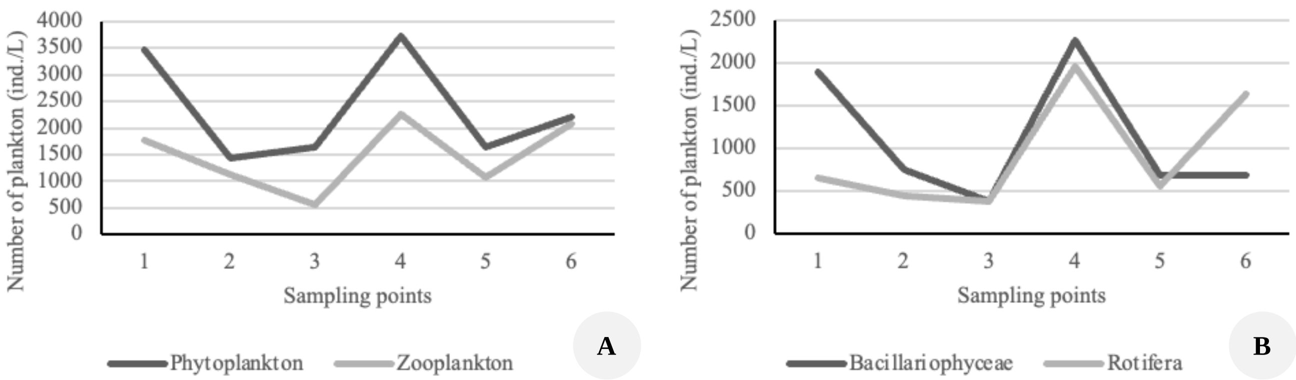

Figure 7. A. Abundance of phytoplankton and zooplankton and B. Bacillariophyceae and Rotifera at six sampling points in the middle Mahakam water, Kutai Kartanegara, East Kalimantan, Indonesia. Note: 1. Pela River (Sangkuliman Village), 2. Pela Lama, 3. Middle Semayang Lake, 4. Mahakam River, 5. Enggelam Estuary; 6. Melintang Lake

Table 5. Diversity index, evenness index, and dominance index of phytoplankton and zooplankton at six sampling points in the middle Mahakam water, Kutai Kartanegara, East Kalimantan, Indonesia

Types of plankton	Sampling points					
	1	2	3	4	5	6
Phytoplankton						
Diversity index (H')	0.8011	0.9905	1.1891	0.9356	1.0270	0.9630
Evenness index (E)	0.3341	0.3986	0.4114	0.3902	0.4004	0.3875
Dominance index (D)	0.2350	0.1229	0.0769	0.1399	0.1154	0.1478
Zooplankton						
Diversity index (H')	0.6992	0.9457	0.7536	0.8258	0.8698	0.2631
Evenness index (E)	0.3593	0.4107	0.4206	0.3586	0.3959	0.1265
Dominance index (D)	0.2734	0.1247	0.1852	0.2191	0.1626	0.3627

Note: 1. Pela River (Sangkuliman Village), 2. Pela Lama, 3. Middle Semayang Lake, 4. Mahakam River, 5. Enggelam Estuary; 6. Melintang Lake

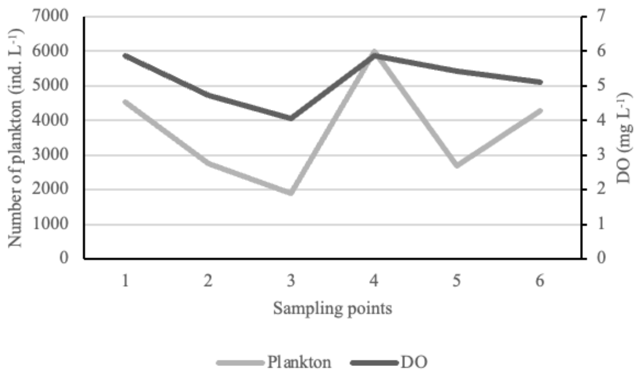

Figure 8. Dissolved Oxygen (DO) and plankton abundance at six sampling points in the middle Mahakam water, Kutai Kartanegara, East Kalimantan, Indonesia. Note: 1. Pela River (Sangkuliman Village), 2. Pela Lama, 3. Middle Semayang Lake, 4. Mahakam River, 5. Enggelam Estuary; 6. Melintang Lake

Plankton diversity was often used as an indicator of water quality because plankton had a high sensitivity to changes in the aquatic environment. Plankton diversity was influenced by various chemical and physical factors. Dissolved Oxygen (DO) and nutrients played an important role in plankton diversity, which indirectly affected temperature (Rombouts et al. 2019; Aravinth et al. 2023). Eutrophication caused by an abundance of nutrients could lead to an excessive increase in phytoplankton populations, which affected zooplankton predation both in quantity and quality (Znachor et al. 2020). Therefore, this condition played an essential role in the stability of plankton diversity in middle Mahakam water.

The observations at six sampling points showed that the value of the phytoplankton Evenness index (E) ranged between 0.3341 (Pela River) and 0.4114 (middle of Semayang Lake). The phytoplankton evenness index values indicate that the middle Mahakam phytoplankton population is quite diverse. Similarly, for zooplankton the lowest evenness index was 0.1265 (Melintang Lake) and the highest was 0.4206 (middle of Semayang Lake). Under such conditions, pollution and eutrophication may occur, because the evenness index can also be used as an indicator of the level of pollution of water bodies. An evenness index value in the range of 0-0.3 indicates heavy pollution, a range of 0.3-0.5 indicates it is in the mesosaprobic area (moderate pollution), and if the index is > 0.5 it indicates light pollution or no pollution (Islam et al. 2022; Palupi et al. 2022).

Plankton dominance index indicated that in a water area, there was a type of plankton that dominated. When dominance index value was close to one, there were certain organisms that dominated the body of water. In addition, values close to zero indicated that there was no dominant organism. Based on Table 5, phytoplankton dominance index ranged from 0.0769 (middle Semayang Lake) to 0.2350 (Pela River). Zooplankton dominance index ranged from 0.1247 (Pela Lama) to 0.3627 (Melintang Lake). Dominance index value of 0-0.5 indicated that plankton population was at low dominance (Martins et al. 2024). This was in line with a low evenness index, which indicated the absence of a dominant species.

In conclusion, almost all water quality components observed at the six sampling points in the middle Mahakam watershed are within the water quality standards based on East Kalimantan Provincial Government (2011), except for pH (at the Enggelam Estuary), watercolor (Enggelam Estuary and transverse lake), COD (all observation locations, except Pela Lama and the Mahakam River), and phenol (at all observation locations). The number of phytoplankton and zooplankton species found at each sampling point is different, but the number of phytoplankton species is always higher than zooplankton, so the diversity of phytoplankton is higher than zooplankton. The identified phytoplankton came from the Bacillariophyceae, Cyanophyceae, Dinophyceae, Closteriaceae, Zygnematophyceae, and Chlorophyceae groups, while the zooplankton came from the Rotifera, Protozoa, Amoebozoa, Arthropoda, and Euglenaceae groups. At all sampling points the phytoplankton Diversity index (H') ranged from 0.8011 to 1.1891, while zooplankton ranged from 0.2631 to 0.9457. Phytoplankton Evenness index (E) ranges between 0.3341 to 0.4114, while zooplankton ranges from 0.1265 to 0.4206. Phytoplankton dominance index ranges from 0.0769 to 0.2350, and for zooplankton it ranges from 0.1247 to

0.3627. The abundance of zooplankton populations in aquatic areas was highly dependent on the density of phytoplankton, which coordinated the food chain between fish and plankton. Various aspects related to plankton must be considered due to their ability to estimate the potential for future fish productivity.

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