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Daily dynamics and structure of zooplankton communities as bioindicators in Merdada Lake, Dieng Plateau, Central Java, Indonesia

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Abstract

Prolonged anthropogenic disturbance contributes to the degradation of Merdada Lake. Tourism development, intensive water extraction, fertilizer and pesticide application, and the conversion of land into agricultural areas have accelerated soil erosion, sediment accumulation, nutrient loading, and siltation, which ultimately reduce water quality and influence zooplankton communities. This study assessed the suitability of zooplankton as a bioindicator by examining community composition, abundance, daily variation, ecological indices, and key environmental constraints as indicators of trophic conditions. Sampling was carried out randomly in May 2021 at five observation sites with three replicates, conducted during nighttime (7:00 PM), early morning (5:00 AM), and morning (9:00 AM). The zooplankton community consisted of several functional groups, including Cladocerans, Copepods, Nauplius, Protozoa, and Rotifers. Abundance ranged from 5.51 to 22.47 individuals per liter, with Rotifers, particularly Philodina sp., being the most dominant group. Peak abundance was recorded at night, reflecting diel movement patterns associated with vertical migration and food availability. Ecological index analysis revealed poor-moderate diversity (H' = 1.76–1.90), moderate -high evenness (E = 0.72–0.80), and high dominance (C = 0.79–0.82), which indicates an unstable community structure and ecological. Variations in zooplankton structure and daily dynamics were strongly associated with light intensity, nitrate concentration, dissolved oxygen, and alkalinity. Overall, the findings demonstrate that zooplankton communities are sensitive to environmental changes and can serve as effective bioindicators of water quality in Merdada Lake. Overall, zooplankton communities are responsive to water quality conditions in Merdada Lake.

Introduction

Lakes are classified as lentic freshwater ecosystems that contribute significantly to ecological stability, hydrological regulation, and socio-economic activities (Abd Ellah, 2020; Kusumawati et al., 2010; Sterner et al., 2020). Lakes serve as habitats for various aquatic organisms, buffer biodiversity, and deliver multiple ecosystem services that are essential to human life (Abd Ellah, 2020; Sterner et al., 2020; Sun et al., 2024). A hydrological perspective, lakes function as natural reservoirs that collect rainfall and surface runoff, helping to regulate water availability across seasons (Sudarmadji et al., 2019). Lakes play an important role in water storage, particularly for irrigation during dry periods, while also contributing to flood mitigation and the reduction of erosion caused by excessive runoff (Kusumawati et al., 2010; Sudarmadji et al., 2019).

Furthermore, lakes support agriculture, fisheries, and tourism, thereby contributing to human livelihoods and regional socio-economic development (Sterner et al., 2020).

Interactions among physical, chemical, and biological components shape dynamic lake ecosystems that are highly responsive to environmental changes. (Bhateria & Jain, 2016; Vasistha & Ganguly, 2020). These interactions make lakes an important habitat for various types of aquatic flora and fauna while also contributing to biodiversity conservation and germplasm (Kusumawati et al., 2010). Lake characteristics are strongly influenced by physical processes such as light distribution, water mass dynamics, and seasonal variations, which in turn influence water chemistry, including the distribution of nutrients and dissolved oxygen. High biogenic capacity makes lakes particularly sensitive to environmental change, as elevated nutrient inputs can trigger rapid eutrophication and result in a decline in the quality of lake waters (Domingues et al., 2017; Lennox et al., 2021; Vasistha & Ganguly, 2020).

The Dieng Plateau is a volcanic region home to several lakes with important ecological and hydrological functions for local communities. However, the lakes in the Dieng Plateau region are facing increasing anthropogenic pressures. Intensive water use for horticultural irrigation is one cause of ecological pressure on lake waters. Large-scale water withdrawals can reduce lake volume and water levels, especially during the dry season. This condition can also lead to increased concentrations of nutrients and dissolved materials in the water column, accelerating eutrophication and degrading water quality. The continued use of diesel-powered water pumps also has the potential to increase water pollution through runoff of fertilizer residues, pesticides, and fuel and oil (Sudarmadji et al., 2015).

Merdada Lake is located in Banjarnegara Regency, Central Java, at an elevation of approximately 2,043 mdpl. Merdada Lake is a volcanic lake on the Dieng Plateau. Merdada Lake has an area of 25 hectares and an average depth of 2 meters (Sudarmadji et al., 2015). Merdada Lake is experiencing significant environmental pressure. Over the past several decades, the condition of Merdada Lake has undergone substantial changes (Kusumawati et al., 2010). The natural beauty, soil fertility, and availability of water resources that were once characteristic of this area have declined due to various environmental interventions and pressures (Sudarmadji et al., 2015). Agricultural intensification, particularly potato cultivation with its extensive use of synthetic and organic fertilizers, has increased nutrient inputs into the waters through surface runoff and soil erosion. This increased nutrient load is reflected in the trophic status of Merdada Lake Waters, which are classified as eutrophic to hypertrophic based on nutrient content and water transparency, although this is not always accompanied by excessive algal growth (Kusumawati et al., 2010). In addition, high sedimentation due to soil erosion has caused shallowing and shrinking of the lake's water volume, so that Lake Merdada is categorized as critical (Sudarmadji et al., 2015).

Aquatic environmental pressures can be assessed through a biological approach using indicator organisms, such as plankton (Huang et al., 2023; Khan et al., 2025). Plankton are very small (microscopic) organisms with limited ability to move, so their distribution in a water body largely depends on currents and local environmental conditions (Majhi et al., 2024; Belgrano et al., 2013). Plankton, as a fundamental part of aquatic food webs, serve as a crucial element in supporting the stability and long-term health of water ecosystems (Sterner et al., 2020). Phytoplankton and zooplankton each play distinct roles in the functioning of aquatic ecosystems (Glandon et al., 2024; Tiberti et al., 2025; Yan et al., 2023). Being autotrophic, phytoplankton function as primary producers at the base of aquatic food webs (T-Krasznai et al., 2022). Zooplankton as heterotrophs in aquatic ecosystems (Ginatullina et al., 2023).

Zooplankton are capable indicators of aquatic ecosystem health (Krylov et al., 2020). Zooplankton remarkable ability to respond to environmental stressors and changes (Boldrocchi et al., 2023; Engdaw et al., 2025a; García-Avila et al., 2023; Goździejewska et al., 2024; Kahsay et al., 2022; Karpowicz et al., 2025; Kour et al., 2022; Musialik-Koszarowska et al., 2019; Ndah et al., 2022; Paquette et al., 2025; Xiong et al., 2020). Different groups of zooplankton can serve as biological indicators in aquatic environments. For example, rotifers can detect freshwater contaminants, including chemicals like ammonia, heavy metals, and engineered nanoparticles (Kuczyńska-Kippen et al., 2025; Phan et al., 2021; Xiong et al., 2020). Meanwhile, Copepods are often utilized to track environmental changes, including the effects of climate variability and predator activity in aquatic ecosystems (Boonmak & Sanoamuang, 2022; Musialik-Koszarowska et al., 2019; Oh et al., 2023).

Zooplankton populations are affected by a wide range of factors, including human activity, hydrological conditions, climate change, seasons, interspecific competition, predator pressure, and food source (Conroy et al., 2020; Huang et al., 2023; Kahsay et al., 2022; Xiong et al., 2020). Other important influences include water of organic matter from human sources. Together, these factors shape the balance and stability of aquatic ecosystems (Gebrehiwot et al., 2017; Kahsay et al., 2022; Mequanent et al., 2022; Mohammed et al., 2023; Musialik-Koszarowska et al., 2019; Ndah et al., 2022; Xiong et al., 2020). Zooplankton exhibit unique daily vertical migration behavior to avoid predators and adapt to the intensity of sunlight Daily changes in environmental factors such as pH, dissolved oxygen, temperature, light intensity, and nutrient availability influence the dynamics of zooplankton communities in Telaga Meradda. These variations make zooplankton useful as bioindicators for monitoring the overall condition of the lake ecosystem.. This vertical migration behavior also explains differences in zooplankton composition between day and night (Conroy et al., 2020; Díaz-Astudillo et al., 2017; Huang et al., 2023; Ohshima et al., 2026).

Merdada Lake has been extensively studied in terms of water physicochemical aspects and trophic status, but studies that highlight the daily dynamics of zooplankton communities as bioindicators of water quality are still very limited. Previous research generally focused solely on nutrients and physical characteristics of the water, without linking the biological responses of zooplankton to daily and seasonal environmental changes (Kusumawati et al., 2010; Sudarmadji et al., 2015, 2019). Merdada Lake has been extensively studied in terms of water physicochemical aspects and trophic status, but studies that highlight the daily dynamics of zooplankton communities as bioindicators of water quality are still very limited. Previous research generally focused solely on nutrients and physical characteristics of the water, without linking the biological responses of zooplankton to daily and seasonal environmental changes.

Materials and methods

1. Time and Place of Research

Research on the daily dynamics and structure of zooplankton communities as bioindicators in the Merdada Lake was conducted at several locations. Sampling took place in May 2021 at Telaga Merdada, Dieng Plateau, Central Java. The Parasitology Laboratory served as the site for sample identification, measurement, and analysis. The Hydrology Laboratory, Faculty of Geography, Gadjah Mada University, served as the site for phosphate, sulfate, and nitrate levels.

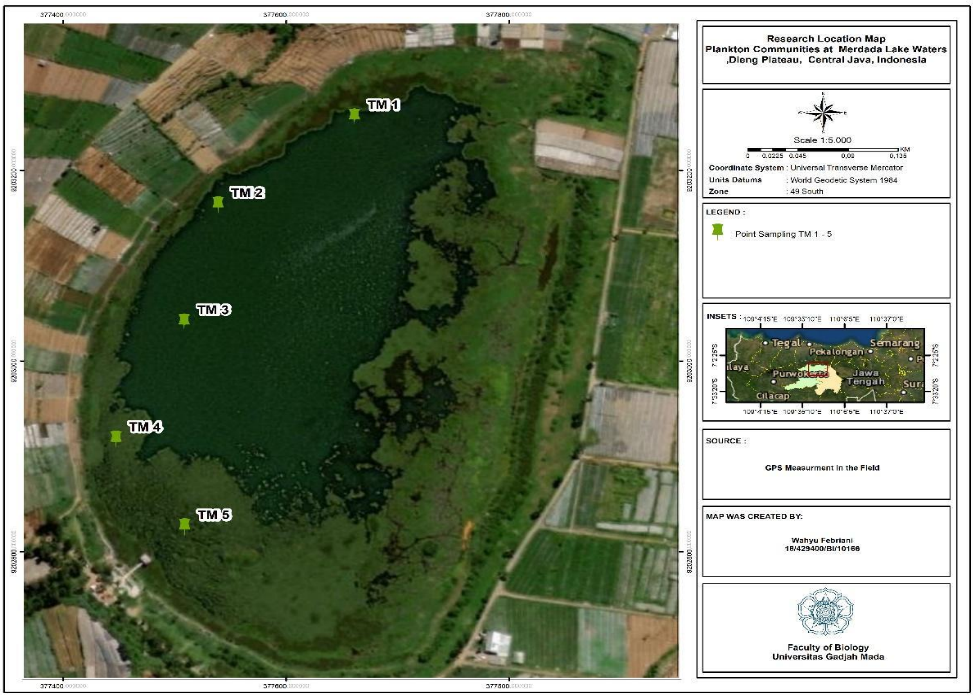


Figure 1. Research Map of Zooplankton Community as a Bioindicator of Merdada Lake

2. Equipments and Materials

Equipments used in the research of zooplankton community as bioindicator of Telaga Merdada waters include 1 Global Positioning System (GPS), 1 the modification of the Van Dorn water sampler (5 L), 1 Wisconsin 120μm plankton net, 2 10-liter buckets, 45 10 mL flacon bottles, 1 beaker, 1 dark pyrex bottle with a volume of 330 mL and 15 polyethylene bottles, 1 digital DO, 1 Lutron LX-107 lux meter, 1 alkalinity kit, 1 Secchi disc, 1 O-Haus ST20 pH meter, 2 thermometers, 1 Luffy hygrometer Model No. 4061, 2 dropper pipettes, 1 BM-180 light microscope with a magnification of 400, 2 Sedgwick Rafter Counting Cell (SRCC), and 1 hand counter. The materials used in the research on zooplankton communities as bioindicators of Telaga Merdada waters include Telaga Merdada water as the water sample used, 4% formaldehyde as a sample preservative, water samples for plankton identification under a microscope, distilled water and tissue, as well as HCl solution and PP indicator to measure the alkali content of the water.

3. Methods

The research on the daily dynamics and structure of zooplankton communities as bioindicators of quality waters at Merdada Lake has been conducted in several stages, including research site surveys, physicochemical parameter measurements, sample sampling, and sample observation and identification. The research site survey was conducted in April 2021. A site survey is important before the research process as an initial step. The site survey serves as an introduction to the location and to determine the sampling points to be used, so that it is expected that these sampling points have the potential to contain zooplankton communities. Measurements of physicochemical parameters, including water transparency, water and air temperature, dissolved oxygen levels, alkalinity, water transparency, water pH, and air humidity, were carried out in situ at the research site. Nitrate, sulfate, and phosphate concentrations were analyzed ex situ at the Hydrology Laboratory, Faculty of Geography, Universitas Gadjah Mada. Nitrate levels were measured and analyzed using the Brusin method using spectrophotometry (IKM/5.4.11/BLK-Y). Phosphate levels were used according to the APHA method 22 edition, 4500 P-D, 2012. Sulfate levels were measured using the APHA method. 4500- SO4 2- E, 2012.

Plankton sampling at each sampling point of the study location was carried out using a Van Dorn water sampler (5 L). Filtration was carried out using the Wisconsin 120 µm plankton net, which was first opened, and the filtered water samples were placed into 10 ml flasks. After filtering the water samples, each water sample was preserved with 4-5 drops of 4% formaldehyde using a dropper. The 4% formaldehyde was used to ensure the samples would last and be preserved during identification in the laboratory. One flask of water sample from each sampling point and replicate was marked with a paper label, and the flask was tightly closed. Plankton samples were observed and identified at the Parasitology Laboratory, Faculty of Biology, Universitas Gadjah Mada, using a BM-180 light microscope at 10x40 magnification, a Sedgewick Rafter Cell Counting (SRCC), and a hand counter. The plankton observation process uses the strip counting method, and the identification process uses the Plankton of South Vietnam identification book and Freshwater Biology.

4. Data Analysis

The collected data were tabulated using Microsoft Excel and analyzed descriptively using PAST (Paleontological Statistics) software. The analysis focused on describing the structure of the zooplankton community across sampling stations. Zooplankton community structure was evaluated using ecological indices, including the Shannon–Wiener diversity index (H'), Pielou's evenness index (E), and Simpson's dominance index (C). In addition, abundance (ind/L) and density (ind/m³) were calculated based on the number of individuals per unit volume. Differences in zooplankton composition among sampling stations were interpreted descriptively through comparison of index values, abundance, and species composition, without applying inferential statistical tests. Data visualization was presented using histograms, tables, and Venn diagrams to illustrate distribution patterns and community similarities.

Plankton abundance (N) was determined to quantify the number of plankton individuals per unit volume (ind/L). The calculation of abundance followed the standard method proposed by APHA (2017), using the relationship between the filtered water volume, sample volume, and the number of individuals counted.

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

Description:

N = plankton abundance (ind/L)

n = number of observed individuals
V = volume of filtered water (L)
Vt = total concentrated sample volume (mL)
Vs = volume of subsample observed (mL)

The diversity of the plankton community was analyzed using the Shannon–Wiener index developed by (Shannon & Weaver, 1949):

$$H' = -\sum p_i \ln\, p_i$$

Description:

H'= diversity index
p_i= proportion of species i (n_i/N)
n_i= number of individuals of species i
N= total number of individuals

The diversity values were interpreted based on commonly used ecological criteria (Odum, 1971):

- $H' < 1$= low diversity
- $1 \leq H' \leq 3$= moderate diversity
- $H' > 3$= high diversity

In addition, the calculated Shannon–Wiener index values were then classified to assess the ecological condition of the water body based on the criteria proposed by Reiss & Kröncke (2005) as cited in Adebayo et al. (2021). The classification divides ecosystem conditions into five categories: high, good, moderate, poor, and bad.

Table 1. Classification of the Shannon–Wiener Index (H')

Shannon–Wiener Index (H')	Ecological Condition
H' > 4	High
3 < H' ≤ 4	Good
2 < H' ≤ 3	Moderate
1 < H' ≤ 2	Poor
H' ≤ 1	Bad

Evenness was calculated to evaluate the uniformity of individual distribution among species using the formula proposed by Evelyn C. Pielou (1966):

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

Description:

- E = evenness index
- H'= diversity index
- S= number of species

The evenness values were categorized as follows (Odum, 1993):

- $E < 0.5$= low evenness
- $0.5 \leq E \leq 0.75$= moderate evenness
- $0{,}75 < E \leq 1{,}0$:= high evenness

The dominance of plankton species was analyzed using Simpson's index developed by Edward H. Simpson (1949):

$$C = \sum \left(\frac{n_i}{N}\right)^2$$

Description:

- C= dominance index

- n_i= number of individuals of species i
- N= total number of individuals

The dominance values were interpreted as (Odum, 1993):

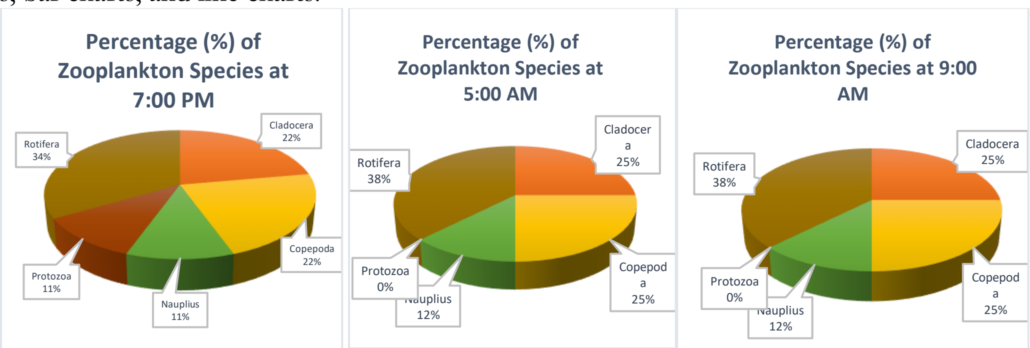
- $C < 0.5$= low dominance
- $0.5 \leq C \leq 0.75$= moderate dominance
- $0{,}75 < C \leq 1{,}0$ = high dominance

Results and discussion

Zooplankton communities are becoming increasingly important to study in Merdada Lake because nutrient input from surrounding agricultural activities can affect aquatic productivity and trophic interactions. This section presents the results of research on zooplankton communities in Telaga Merdada waters, including the structure of community composition and abundance, daily zooplankton dynamics at three observation times, and analysis of ecological indices used to evaluate the level of water stability and quality.

1. Zooplankton Communities: Structure, Composition, and Abundance

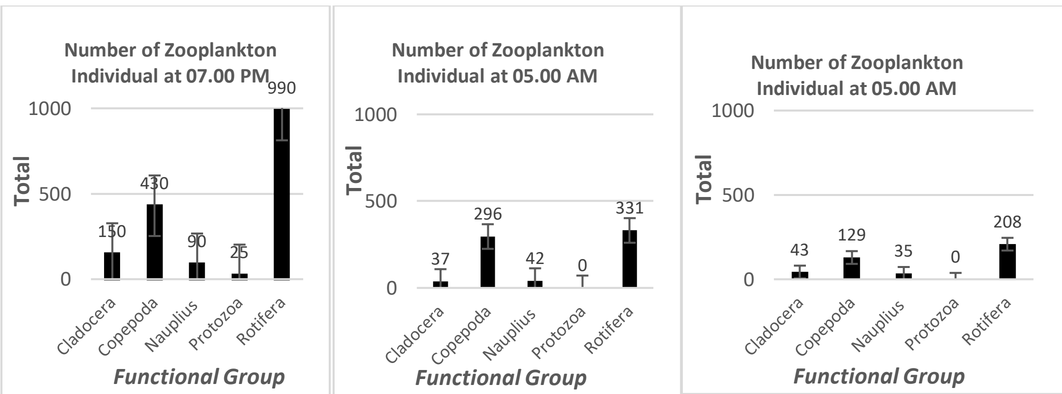
Zooplankton composition structure found in Merdada Lake consists of 5 functional groups with 8 species in the morning and afternoon, while at night it consists of 5 functional groups with 9 zooplankton species. The composition and abundance vary throughout the day, reflecting the zooplankton's responses to daily changes in the aquatic environment. The composition structure and reflecting zooplankton in Merdada Lake waters have been analyzed and visualized in the form of pie charts, bar charts, and line charts.



(a)

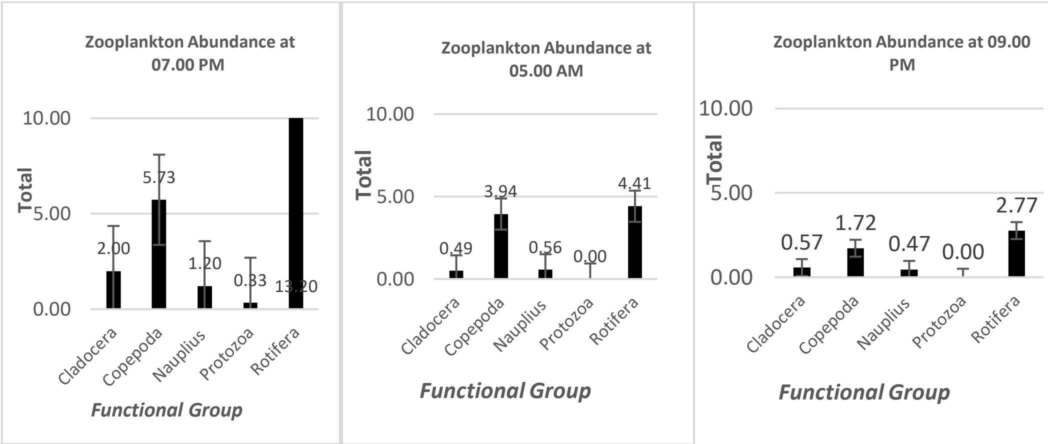
(b) (c)

Figure 2. Distribution of percentageof zooplankton species among functional groups at different sampling times (a) 07:00 PM, (b) 05:00 AM, and (c) 09:00 AM in Merdada Lake, Dieng Plateau, Central Java, Indonesia (2021)



(a) (b) (c)

Figure 3. Number of individuals in zooplankton functional groups at different sampling times (a) 07:00 PM, (b) 05:00 AM, and (c) 09:00 AM in Merdada Lake, Dieng Plateau, Central Java, Indonesia (2021).



(a) (b) (c)

Figure 4. Zooplankton functional group Abundance (ind. L⁻¹) at different sampling times (a) 07:00 PM, (b) 05:00 AM, and (c) 09:00 AM in Merdada Lake, Dieng Plateau, Central Java, Indonesia (2021).

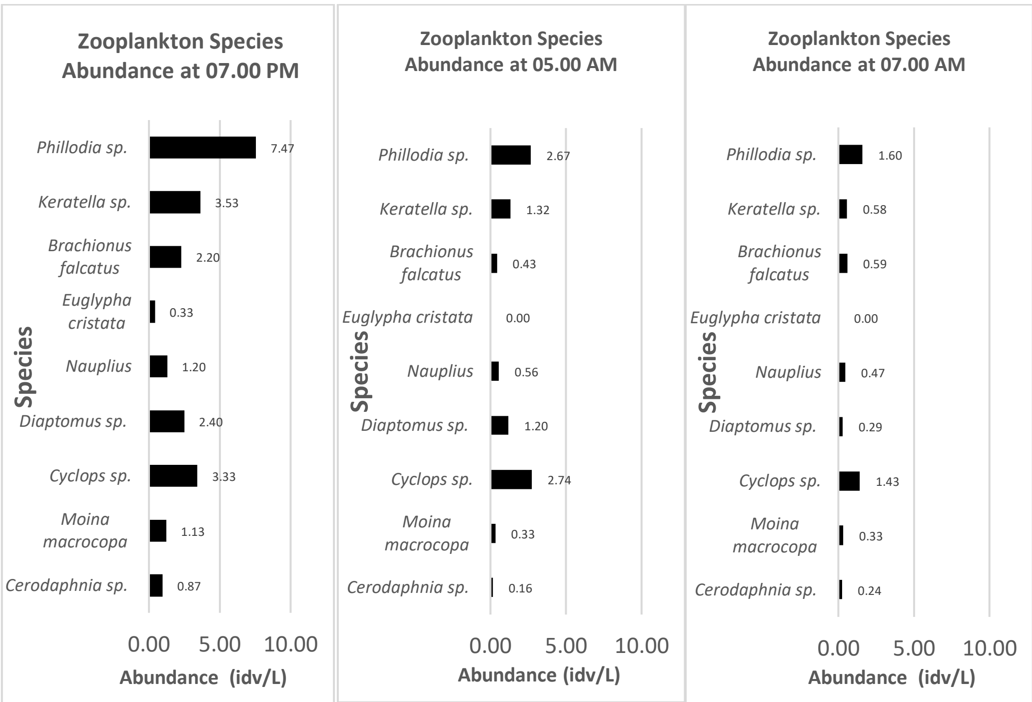
The zooplankton communities in Merdada Lake are composed of five main taxonomic groups, with a consistent dominance of Rotifera across all observation times. This dominance is reflected in species composition, individual abundance, and density, indicating that Rotifera plays a key ecological role in the lake ecosystem. In contrast, protozoa contribute minimally and are absent during certain periods, suggesting limited adaptability under the prevailing environmental conditions. The observed higher zooplankton abundance at night suggests the influence of diel vertical migration and feeding activity, which regulate temporal distribution patterns within the water column. Overall, the zooplankton community structure, characterized by the dominance of Rotifera and low representation of other groups, reflects ecological conditions that may be associated with environmental stress or nutrient dynamics in the lake.(Engdaw et al., 2025; Krylov et al., 2020).

Rotifers showed a higher abundance contribution compared to other zooplankton groups throughout the observation period. Rotifers have ecological characteristics with a wide habitat range and good adaptability to various water conditions, and utilize a variety of food sources (Kuczyńska-Kippen & Joniak, 2016; Phan et al., 2021). Rotifers use diverse feeding strategies depending on species and environmental conditions (Kuczyńska-Kippen et al., 2025). Most rotifers function as filter feeders, consuming microalgae, bacteria, and suspended organic particles from the surrounding water. Some species are also capable of collecting food particles directly from the water surface. The relatively high abundance of Rotifers is also thought to be related to their biological characteristics, which include a rapid life cycle, short development time, high reproductive rate, and high tolerance, enabling them to respond quickly to environmental changes, making them useful as bioindicators of ecological conditions and water fertility levels Phan et al., 2021). These characteristics allow Rotifers to persist and dominate zooplankton communities, allowing them to be consistently found in various types of lentic waters, including lakes like Merdada Lake (Engdaw et al., 2025; Phan et al., 2021).

Copepods are highly diverse microcrustaceans that inhabit a wide variety of aquatic environments, reflecting their strong ecological adaptability (Boonmak & Sanoamuang, 2022). Copepods constituted the second most dominant functional feeding group in Merdada Lake. The daily dynamics of copepod abundance showed values of 5.73 individuals L^{-1} at night, 3.94 individuals L^{-1} in the morning, and 1.72 individuals L^{-1} in the afternoon. This pattern suggests that copepods exhibit diel variations in activity and distribution, which may be associated with predator avoidance and the optimization of food acquisition (Díaz-Astudillo et al., 2017; Huang et al., 2023). Copepods abundance is also thought to be influenced by the structure of the aquatic habitat, particularly the presence of aquatic vegetation (macrophytes) that provide shelter from predators, food sources in the form of detritus and microalgae, and microhabitats that support feeding and reproductive activities (Engdaw et al., 2025b; Kuczyńska-Kippen et al., 2025; Phan et al., 2021). Copepods also have a high protein content, making them a favorite food and preferred by fish, especially planktivorous fish (Boonmak & Sanoamuang, 2022).

Cladocerans feed on algae, detritus, and other small organisms, helping to regulate the food web (Adamczuk, 2024). Cladocerans have relatively slow swimming abilities, making them more vulnerable to predation. Cladocerans contribute to nutrient recycling, which supports overall water productivity (Berta et al., 2019). Research results in the Merdada Lake also indicate Cladocerans as the third most abundant functional group. The relatively high abundance of Cladocerans in Merdada Lake Waters is closely related to the macrophyte-dominated waters (Adamczuk, 2022; Geraldes & Boavida, 2004). Shallow water conditions with abundant vegetation are known to support the development of Cladoceran communities because they provide protection from predators and increase food availability (Adamczuk, 2022). The high presence of Cladocerans may point to their important role in sustaining ecosystem balance in waters affected by human activities, providing insights into the water's ecological state, including nutrient richness and environmental pressures (Adamczuk, 2024; Berta et al., 2019).

Nauplius larvae and protozoans were also observed ascomponents zooplankton communities in Merdada Lake. Nauplius larvae are juvenile stage of crustaceans that contribute to nutrient cycling and to sustaining interactions among different trophic levels in aquatic habitats. The abundance of Nauplius Larvae in Merdada Lake is thought to be related to limited swimming ability and its dependence on the stability of the water column, so that its presence is greatly influenced by the hydrodynamic conditions of the waters. Protozoa are part of the zooplankton community that is tolerant and responsive to environmental pressure (Yuan et al., 2024). Protozoa can be analyzed as part of the entire zooplankton community and not separated as a single indicator, but their role is important in describing the general ecological conditions of the waters. Protozoa found in waters with sufficient availability of organic matter (El-Tohamy et al., 2024; Madoni, 2011; Yuan et al., 2024).



(a) (b) (c)

Figure 5. Abundance (ind. L⁻¹) of zooplankton species at different sampling times (a) 07:00 PM, (b) 05:00 AM, and (c) 09:00 AM in Merdada Lake, Dieng Plateau, Central Java, Indonesia (2021).

The abundance of these species of zooplankton is thought to be due to the high nutrient content of the Merdada Lake waters, as well as agricultural waste around the lake. Fertilizer and pesticide residues that are not absorbed by plants from agricultural land are carried into the water body through surface runoff (Sudarmadji et al., 2019). *Philodina* sp. was identified as the most abundant zooplankton species recorded in Merdada Lake and belongs to the functional group Rotifera (Moreira et al., 2016; Parysek & Pietrzak, 2021). Its abundance reached 7.47 individuals L^{-1} at night, decreasing to 2.67 individuals L^{-1} in the morning and 1.60 individuals L^{-1} during the day. This genus has a cosmopolitan distribution and is widely reported in freshwater ecosystems, particularly in habitats associated with aquatic vegetation (Kuczyńska-Kippen et al., 2025). The elevated abundance recorded in this study may be linked to the presence of macrophytes and nutrient-rich conditions that promote higher primary productivity(Gebrehiwot et al., 2017; Kuczyńska-Kippen & Joniak, 2016). Aquatic vegetation can create structurally complex habitats that provide protection from predators and supply abundant food resources, supporting greater rotifer populations (Gebrehiwot et al., 2017). Furthermore, the higher density detected at night suggests possible diel fluctuations in zooplankton distribution, which may be influenced by predator avoidance strategies or shifts in environmental conditions (Huang et al., 2023).

Cyclops sp. was identified as the species with the second-highest abundance. *Cyclops* sp. is classified within the copepod functional group. Its abundance reached 3.33 individuals/L at night, decreased to 2.74 individuals/L in the morning, and further declined to 1.40 individuals/L during the day. The strong presence of this species may be attributed to its high ecological tolerance and rapid reproductive capacity, which enable it to persist and develop successfully under varying environmental conditions. In addition, as a predator of smaller plankton, *Cyclops* sp. regulates prey populations and maintains trophic balance in the aquatic ecosystem.

Keratella sp. is included in the functional feeding group Rotifers. *Keratella* sp. in the waters of Telaga Merdada has a relatively high abundance, ranking third after Philodina sp. and Cyclops sp. Research results in Merdada Lake waters showed the abundance of *Keratella* sp. at night is 3.53 individuals/L, then decreases in the morning (1.32 individuals/L) and during the day (0.58 individuals/L). The high abundance of Keratella sp. is thought to be related to its good ability to adapt to various environmental conditions, including waters with unfavorable conditions. Ecologically, *Keratella* sp. has a broad tolerance to environmental fluctuations, so it can survive and thrive in waters with changing physical and chemical conditions (Cieplinski et al., 2017; Devkota et al., 2025)

Diaptomus sp. has an abundance ranked fourth in Merdada Lake. The results showed 3.53 individuals/L at night, 1.32 individuals/L in the morning, and 0.58 individuals/L during the day. This pattern suggests that temporal variation may influence its distribution. The relatively high occurrence of Diaptomus sp. can be associated with its ecological adaptability. As a member of the family Diaptomidae within the copepod functional group, this genus exhibits a well-defined distribution pattern despite inhabiting regions characterized by environmental heterogeneity and complex biogeographic history. Such distribution patterns reflect long-term diversification processes that occurred before the establishment of connections between the Nearctic and Neotropical regions during the Pliocene. In addition, climatic factors play a significant role in shaping Diaptomidae species richness across different ecoregions. This indicates that *Diaptomus* sp., which possesses relatively broad environmental tolerance, has a greater capacity to persist and potentially dominate zooplankton communities under varying ecological conditions (Perbiche-Neves et al., 2014).

Brachionus falcatus exhibited an abundance of 2.20 individuals/L (night), which declined to 0.43 individuals/L (morning) and slightly increased to 0.59 individuals/ L (afternoon) in Merdada Lake. *Brachionus falcatus* is a member of the family Brachionidae within the rotifer group. *Brachionus falcatus* is recognized for its high tolerance to environmental fluctuations(Houssou et al., 2018). *Brachionus falcatus* is frequently associated with nutrient-enriched waters and elevated organic inputs, and it is often regarded as an indicator of eutrophic conditions (Houssou et al., 2018). Therefore, its presence and relative abundance in the lake may reflect the quality of aquatic ecosystem (Houssou, et al., 2017; Houssou, et al., 2017).

2. Zooplankton Communities Ecology Index

The results of the ecological index analysis are presented in the following line chart:

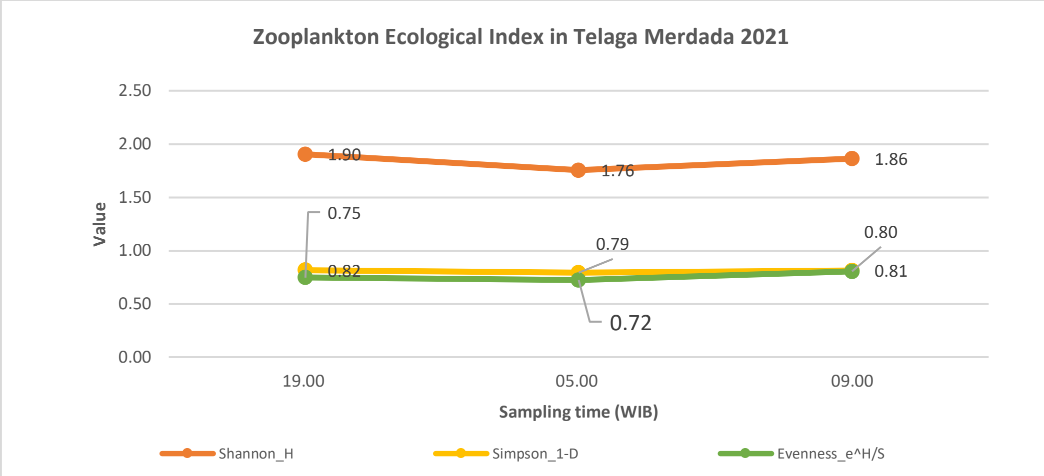


Figure 6. Zooplankton ecological index at different sampling times (a) 07:00 PM, (b) 05:00 AM, and (c) 09:00 AM in Merdada Lake, Dieng Plateau, Central Java, Indonesia (2021).

The complexity and stability of aquatic biota, particularly the plankton community structure, can be evaluated using the Shannon–Wiener diversity index (Shannon & Weaver, 1949). In this study, the zooplankton diversity index in Merdada Lake showed variation across sampling periods (night, morning, and day), with values ranging from 1.76 to 1.90. Based on the Shannon–Wiener diversity classification (Odum, 1971), these values fall within the moderate diversity category (1 ≤ H' ≤ 3). Although categorized as moderate, the values are close to the lower boundary of the category, indicating relatively limited species diversity and reduced community stability. In addition, according to the ecological condition classification proposed by Reiss & Kröncke (2005) as cited in Adebayo et al. (2021), Shannon–Wiener index values can be used to assess ecosystem health ranging from high to bad conditions. Based on this classification, the obtained values (1.76–1.90) indicate a poor ecological condition (1 < H' ≤ 2), suggesting that the aquatic ecosystem is experiencing environmental stress. This condition suggests that the zooplankton community structure is under environmental pressure, which may be related to habitat degradation such as lake sedimentation and increased nutrient input from surrounding agricultural activities. These factors can influence water quality and reduce habitat suitability for diverse plankton communities. Shannon–Wiener diversity values tend to decrease with increasing eutrophication levels, reflecting a decline in ecosystem stability and changes in community structure (Kour et al., 2022).

The evenness index is commonly used to determine the balance of a plankton community in aquatic ecosystems. When the individual number is relatively similar across species, the community is considered more balanced. Research in the Telaga Merdada waters revealed that the evenness index exhibited a fluctuating and dynamic trend across three time periods. The zooplankton evenness index ranged from 0.72 to 0.80. This moderate - high evenness index indicates a fairly even distribution of individuals across species, with no particular species dominating (Kour et al., 2022). The dominance of certain zooplankton within a zooplankton community in an aquatic ecosystem can be determined using a dominance index calculation. One method that can be used is Simpson's dominance index formula. A greater value of the dominance index, approaching 1, indicates a dominant species. Conversely, a smaller value indicates a dominant species in the waters. Research in the waters of Merdada Lake on May 2021 showed a fluctuating and dynamic trend in the Simpson dominance index of the plankton community at three different times: night, morning, and afternoon. The Simpson dominance index for zooplankton varied between 0.79 and 0.82, indicating the presence of dominance species and suggesting an imbalance in the zooplankton community structure in Merdada Lake.

3. Zooplankton Daily Dynamics

Temporal variation within a 24-hour cycle contributes substantially to changes in zooplankton distribution and abundance. This is related to the organisms' adaptation strategies to changing environmental conditions, food source availability, and predation pressure. Sampling was conducted in Merdada Lake at five observation points, with three replicates at each point, at three different times of the day. These differences in sampling times reflect variations in ecological conditions that influence energy transfer processes, trophic interactions, and the relationships between plankton communities and the aquatic environment, as well as their limiting factors. Thus, changes in zooplankton abundance observed at each observation point can be explained through the ecological dynamics that occur on a daily scale.

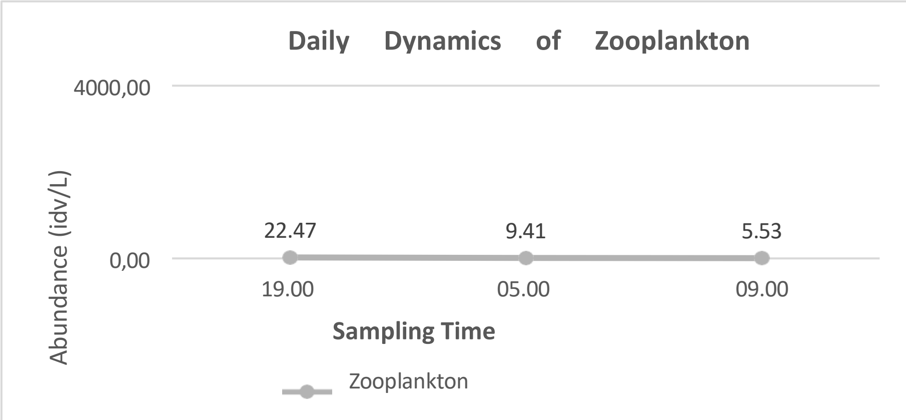


Figure 7. Daily dynamics of zooplankton communities in the Dieng Plateau, Central Java, Indonesia, 2021

Zooplankton at night were more abundant in the surface layer, while from morning to afternoon, their numbers in the upper layers tend to decrease. Differences in zooplankton abundance are related to daily zooplankton dynamics, particularly vertical migration behavior and grazing activity, so that at night (7:00 PM) their abundance is higher than during the day (9:00 AM). Vertical zooplankton migration is indicated by movement to the water surface at night and movement to deeper layers when sunlight intensity increases. Towards morning and afternoon, when sunlight is maximum, zooplankton are generally at deeper depths and therefore rarely seen at the surface. Vertical migration by zooplankton aims to avoid predators, increase production, and as an effort to conserve energy. Vertical migration is used as a strategy to change position in the water column. Food availability, water depth, light penetration, and bottom topography are factors that cause differences in zooplankton vertical migration behavior. Zooplankton perform vertical migration at night to access food resources (Huang et al., 2023). This movement allows it to feed more effectively on phytoplankton and smaller zooplankton. Night-time feeding also affects their vertical distribution in the water column (Díaz-Astudillo et al., 2017). As a result, this behavior contributes to observed patterns in zooplankton abundance throughout the day. Therefore, there is a decrease in phytoplankton abundance at night and an increase in zooplankton abundance. The theory of phytoplankton and zooplankton predation states that if the zooplankton population in a body of water tends to be high, the phytoplankton population will tend to decline due to predation by heterotrophic zooplankton. Zooplankton predation events in aquatic ecosystems can also be used to control phytoplankton populations (Conroy et al., 2020; Ohshima et al., 2026).

4. The Influence of Physicochemical Parameters on Zooplankton Communities

The physicochemical conditions of Telaga Merdada waters during three different observation periods indicate environmental dynamics that can influence the abundance and structure of the plankton community. Physicochemical parameter measurements were conducted simultaneously with plankton sampling at three times: evening (7:00 PM WIB), morning (5:00 AM WIB), and afternoon (9:00 AM WIB). Observed parameters included alkalinity, pH, dissolved oxygen (DO), light intensity, water temperature, turbidity, water transparency, sulfate, and nitrate.

Table 1. Diel variation of physicochemical parameters in Merdada Lake waters

Parameter	Units	Night	Morning	Afternoon
pH	-	6.28	6.61	6.70
Alkalinity	mg/L	15.60	11.20	11.20
Dissolved Oxygen (DO)	mg/L	17.70	7.65	6.65
Light Intensity	lux	0	2,560.67	49,673.33
Water Temperature	°C	18.07	17.60	18.03

Parameter	Units	Night	Morning	Afternoon
Turbidity	NTU	15.60	14.93	19.43
Water Transparency	mg/L	0.21	0.73	0.86
Sulfate	mg/L	16.86	19.66	17.58
Nitrate	mg/L	2.87	3.41	3.52

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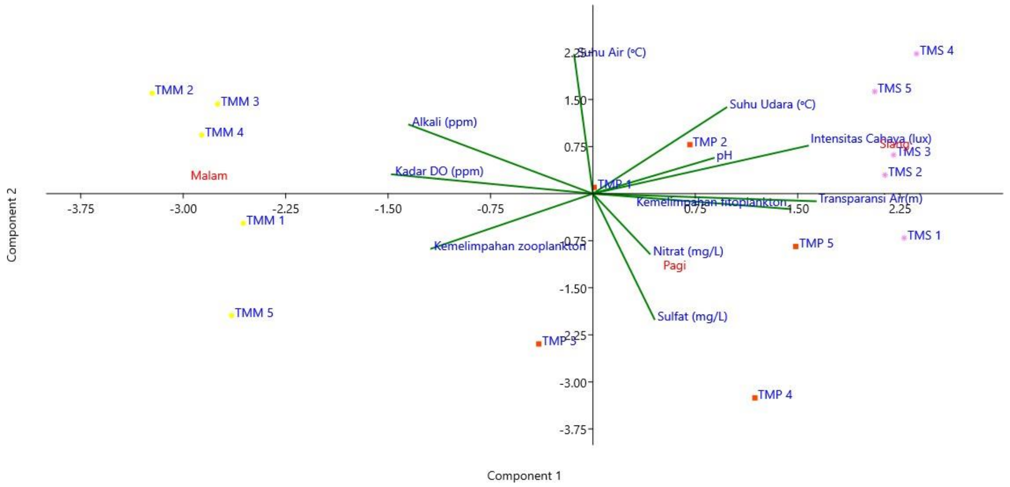

Figure 8. Correlation between zooplankton abundance (individuals per liter) and the physicochemical parameters in Merdada Lake Waters.

Figure 8 presents PCA findings that highlight zooplankton abundance tends to be higher at night, while phytoplankton are more abundant from morning to afternoon. This pattern indicates a difference in biological responses to changes in daily environmental conditions, where zooplankton show a tendency to increase as light intensity decreases. Environmental parameters show that zooplankton abundance is positively correlated with dissolved oxygen (DO) and alkalinity levels, and inversely with light intensity and water transparency. This indicates that zooplankton in Merdada Lake tend to be more abundant in water conditions with lower light levels, which may be associated with daily vertical migration behavior to avoid visual predators and high light radiation. Conversely, phytoplankton abundance is positively correlated with light intensity, water transparency, pH, and nitrate and sulfate concentrations, reflecting the role of light and nutrients in supporting photosynthesis. The negative correlation between zooplankton abundance and parameters that support phytoplankton growth indicates a close trophic relationship between the two communities. Zooplankton utilize phytoplankton as a food source, so their abundance dynamics are influenced not only by direct physicochemical factors but also by the availability of food in the water. Thus, the distribution of zooplankton in Telaga Merdada reflects an ecological response to a combination of light, water chemistry, and trophic interactions, confirming their role as bioindicators of water conditions.

Acidity (pH) maintains the stability of aquatic ecosystems. Fluctuations of pH can impact aquatic life because each organism has a different tolerance to changes in acidity. Changes in pH can affect metabolic rates, reproduction, and survival of organisms, ultimately impacting the structure of zooplankton communities. Measurements in May 2021 showed that the pH of Telaga Merdada waters ranged from 6.19–6.34 at night (average 6.28), 6.38–7.13 in the morning (average 6.61), and 6.31–7.34 during the day (average 6.70). This range is still considered safe for aquatic life. Odum (1971) stated that water pH in the range of 6.5–8 still supports the life of aquatic organisms. This relatively stable pH value indicates that the waters can still support the existence of zooplankton.

The stability of pH in water is greatly influenced by alkalinity, which functions as a buffer system. Alkalinity describes the capacity of water to withstand changes in pH due to acid input. The concentration of this parameter depends on HCO_3^-, CO_3^{2-}, and OH^- ions, which act to buffer changes in water chemistry (Tahraoui et al., 2021, 2024, 2025). The measurement results showed that the alkalinity value of Telaga Merdada at night ranges from 11.33–18.00 mg/L with an average of 15.60 mg/L, while in the morning and afternoon it ranges from 9.33–13.33 mg/L with an average of 11.20 mg/L. These values are categorized as low so that the buffer capacity of the water is relatively limited. This condition makes the water more susceptible to pH changes that can affect the stability of the zooplankton habitat.

Dissolved oxygen (DO) contributes for respiration & metabolism of zooplankton. The measurements showed that DO levels ranged from 8.17 to 21.33 mg/L (night) with an average of 17.70 mg/L. DO values were between 7.17 and 8.23 mg/L (morning) with an average of 7.65 mg/L, and 6.13 to 6.80 mg/L (afternoon) with an average of 6.65 mg/L. These relatively high DO concentrations suggest that the water conditions remain suitable for supporting aquatic life. Very high DO values at night are thought to be related to oxygen supersaturation conditions due to photosynthesis during the previous day or the influence of water turbulence. In general, DO levels above 2 mg/L are still able to support the life of aquatic organisms, so these conditions still support the existence of zooplankton. Light intensity influences the daily vertical migration patterns of zooplankton. The highest light intensity in Telaga Merdada occurs during the day, ranging from 28,000–57,900 lux (average 49,673 lux), while in the morning it ranges from 5,450–51,800 lux (average 25,681 lux) and at night it is 0 lux. Increasing light intensity has the potential to increase phytoplankton biomass, which can indirectly support an increase in the abundance of zooplankton, the primary consumers.

Water temperature affects metabolism, respiration, and plankton growth. Temperatures that are too high or too low can disrupt the physiological activities of organisms. The water temperature of Lake Merdada ranges from 17.33–18.67°C at night, 17.33–18.00°C in the morning, and 17.67–18.33°C during the day. This temperature range is still within the tolerance range for zooplankton growth, which is 15–35°C. Increased temperature can reduce oxygen solubility in water, thereby affecting the availability of DO for organisms. Water transparency is related to light penetration into the water column and affects primary productivity. The transparency value in Lake Merdada ranges from 0.13–0.36 m at night, 0.63–0.86 m in the morning, and 0.63–0.98 m during the day. Higher transparency allows deeper light penetration, increases phytoplankton photosynthesis, and indirectly supports food availability for zooplankton.

Nutrient concentrations, such as sulfate and nitrate, regulate aquatic productivity& zooplankton dynamics. In Merdada Lake, sulfate levels were 15.60–18.10 mg/L (night), 17.00–22.30 mg/L (morning), and 14.20–21.70 mg/L (afternoon), while nitrate concentrations ranged from 1.59–3.70 mg/L (night), 1.34–5.49 mg/L (morning), and 1.00–5.63 mg/L (afternoon). Previous study in Merdada Lake reported nitrate levels of 1.1–2.1 mg/L (Sudarmadji et al., 2019). These nutrients can stimulate phytoplankton growth, providing essential food for zooplankton. However, excessive nutrient inputs may lead to eutrophication, causing fluctuations in dissolved oxygen that can negatively affect zooplankton habitat quality. Overall, the physicochemical conditions of the lake remain suitable for sustaining zooplankton populations. Therefore, variations in these parameters highlight the value of zooplankton as bioindicators for monitoring the ecological status of Merdada Lake (Melese & Debella, 2025; Xiong et al., 2020).

Conclusion

The zooplankton community in Merdada Lake consists of five main functional groups; Cladocerans, Copepods, microcrustacean larvae, protozoa, and rotifers with a clear dominance of rotifers, particularly *Philodina* sp., indicating a community structure shaped by opportunistic and environmentally tolerant taxa. The daily dynamics of zooplankton abundance with higher densities observed at night, reflects the influence of vertical migration and grazing activity as key ecological processes regulating temporal distribution. The overall community structure, characterized by poor-moderate diversity, moderate-high evenness, and strong dominance, suggests an ecological imbalance likely associated with environmental stressors within the lake. These findings demonstrate that zooplankton dynamics in Merdada Lake are closely linked to both physicochemical conditions and biological interactions, reinforcing their role as reliable bioindicators for assessing water quality and ecosystem health in tropical highland lake systems.

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Author's contributions: Wahyu Febriani: Conceptualization, Methodology, Investigation (including fieldwork and sampling), Data Curation, Formal Analysis, Writing – Original Draft. Suwarno Hadisusanto: Conceptualization, Supervision, Validation, Writing – Review & Editing. All authors reviewed and approved the final version of the manuscript.

Generative AI: Generative artificial intelligence (AI) tools were used to assist in language editing and improving the clarity of the manuscript. All content was reviewed and validated by the authors.

Data availability: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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