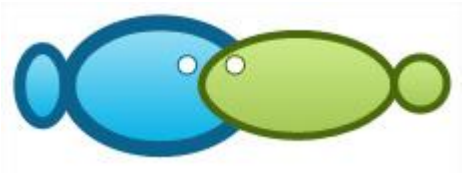

Zooplankton species diversity in Dau Tieng Lake, Vietnam

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Abstract. Zooplankton plays an important role in aquatic ecology. The study aimed to evaluate the diversity of zooplankton species composition in Dau Tieng Lake, Vietnam. The study was carried out with 20 sampling points that were divided into 3 areas (upstream, midstream, and downstream). Aquatic animal samples were collected by plankton net with a mesh size of 60 µm at many different sites in the water body. Quantitative samples of zooplankton were counted by Sedgwick-Rafter chamber. The results showed that a total of 90 zooplankton species were found in Dau Tieng Lake, of which rotifera had the highest species number with 48 species (53%), followed by protozoa with 17 species (19%), and the other groups varying from 6–10 species (7-11%). The zooplankton species number tended to increase through sampling periods, ranging from 40-72 species. The average densities of zooplankton varied from 147,718±129,759 ind m^{-3} to 582,815±314,656 ind m^{-3}. Zooplankton abundance in the upstream area was higher than that in the midstream and downstream areas. The Shannon-Weiner diversity index (H') ranged from 2.17 to 2.50, showing that the zooplankton species composition was moderately diverse. The zooplankton species diversity was influenced mainly by water quality parameters and chlorophyll-a content and the study areas showed a high similarity among their communities' composition.
Key Words: Dau Tieng Lake, zooplankton, species composition, biological indices.

Introduction. Dau Tieng Lake is one of the largest reservoirs in Vietnam, with a water surface area of about 270 km^2 and a capacity of 1.58 billion m^3 of water (Luyen 2020). The lake is responsible for regulating floods and controlling salinity downstream, storing freshwater, and providing irrigation water for the Tay Ninh, Binh Duong, and Binh Phuoc provinces and HCM City. In addition to providing irrigation water for agricultural production, Dau Tieng Lake has huge aquatic organism resources. In recent years, many land areas along the canals around the lake have been converted to aquaculture models. Aquatic resources in the lake have been quite high since the stocking of fingerlings. Aquatic exploitation output at Dau Tieng Lake has increased significantly from 2005 to present, with an average annual aquatic production of over 3,000 tons, reaching about 3,400 tons in 2016 (Ha 2017). Aquatic resources development depends on the food availability in the aquatic environment, mainly consisting of groups of organisms.

In water bodies, zooplankton plays a very important role in the food chain, therefore it is a topic of studies on animal biodiversity in aquatic ecosystems (Ut & Oanh 2013). Additionally, Santos-Wisniewski et al (2006) stated that zooplankton are considered one of the most important food sources for aquatic organisms, especially plankton-eating fish species. The distribution and abundance of zooplankton species are influenced by various environmental factors, such as water clarity and chlorophyll-a content (Ismail & Adnan 2016). Besides, aquatic animals are also indicators of the aquatic environment pollution, due to their sensitivity, ease of sampling in large quantities, and rapid response to environmental changes (Kangro et al 2005). Zooplankton could be used as a tool to monitor the trophic state of the lake. Zooplankton

species are always closely associated with the aquatic environment, so they are used as indicator organisms in water quality assessment and pollution levels of water bodies because they are strongly affected and respond quickly to changes in water quality parameters (Gannon & Stremberger 1978). In natural lakes, crustaceans and rotifers are the two dominant zooplankton groups in terms of productivity and biomass (Wetzel 2001). A change in the physical-chemical and biotic factors in aquatic systems results in a shift in the relative composition and quantity of creatures that thrive in water. The study of Whitman et al (2004) showed a strong correlation between nutrient levels and zooplankton population structure. In addition, Thao (2017) revealed that a study on zooplankton will serve as scientific data for ecological zoning and biodiversity assessment of water bodies. Therefore, this study aimed to determine the species composition, diversity, and density of zooplankton in the upstream, midstream, and downstream, thereby evaluating natural food sources and contributing to the protection and development of aquatic resources in Dau Tieng Lake.

Material and Method

Sampling time and locations. The research was conducted from October 2022 to May 2023 at Dau Tieng Lake, Tay Ninh Province. A total of 20 sampling points were divided into three areas and shown in detail in Table 1 and Figure 1. The study consisted of four sampling periods, corresponding to October 2022, December 2022, March 2023, and April 2023.

Table 1

Sampling sites in Dau Tieng Lake, Tay Ninh Province

No.	*Study area*	*Number of sampling locations*
1	Upstream	5
2	Midstream	6
3	Downstream	9

Figure 1. Study sites in Dau Tieng Lake, Tay Ninh Province.

Sampling and analysis methods. Qualitative samples of zooplankton were collected using a pyramidal plankton net with a mesh size of 60 μm. Sampling depth was from 10-50 cm from the surface layer. The filtration method was used to get zooplankton quantitative samples. The water volume passed through the plankton net at each point was 200 L. After being collected, samples were stored in plastic bottles of 180 mL and

fixed with formalin at a final concentration of 4-6%. The identification of the scientific names of zooplankton was performed using morphological methods based on published taxonomic documents such as: Shirota (1966), Thanh et al (1980), Boltovskoy (1999), and Phan et al (2015).

Zooplankton density was determined using a Sedgewick-Rafter counting chamber according to the method of Boyd & Tucker (1992). The formula for estimating zooplankton density is as follows:

$$X = \frac{T \times 1000 \times Vcon. \times 10^6}{A \times N \times Vsam.}$$

Where:
X - the zooplankton density (ind m^{-3});
T - the zooplankton count of individuals;
Vcon. - the concentrated volume (mL);
A - the area of one cell (mm^2);
N - the cell count;
Vsam. - the filtered sample's volume (mL).

During sample analysis, the dominant zooplankton species at the sites were also recorded according to Liu et al (2017) as follows: 0-100,000 ind m^{-3} (+); 100,000-500,000 ind m^{-3} (++); 500,000-1,000,000 ind m^{-3} (+++); 1,000,000-5,000,000 ind m^{-3} (++++); 5,000,000-10,000,000 ind m^{-3} (+++++).

Biological indices. The biological indices calculated in this study are presented in Table 2.

Table 2

Biological indices of zooplankton

Indices	*Formulation*	*Note*
Shannon-Wiener diversity index (H') (Shannon & Wiener 1963)	H' = -∑ Pi x Ln (Pi)	Pi = n_i/N (ni is the number of individuals of species i, and N is the total number of individuals in the collected sample)
Margalef index (d) (Margalef 1958)	d = (S-1)/Ln(N)	S is the total number of species and N is the total number of individuals in the sample
Pielou's evenness index (J') (Pielou 1966)	J' = H'/ Ln(S)	H' is the Shannon-Wiener index and S is the total number of individuals in the sample
Simpson's index (D) (Simpson 1949)	$D=\sum(ni/N)^2$	n_i is the number of individuals in species i, N = total number of individuals of all species
Sorensen similarity index (S)	S = 2C/(A+B)	A is the species number present in area A, B is the species number present in area B, and C is the species number present in both areas A and B.

In addition, the study also measured water quality parameters including temperature, pH, dissolve oxygen (DO), alkalinity, total suspended solids (TSS), total ammonia nitrogen (TAN), nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{3-}) and chlorophyll-a in order to find out the correlation between water quality elements and species composition, density, and biodiversity indices of zooplankton in the study area.

Statistical analysis. Biological indices were calculated by the PRIMER 6.0 software. In addition, the research also used R 3.6 and R. Studio software to analyse the relationship between water quality parameters and species composition and density of zooplankton.

Results. Zooplankton species composition in Dau Tieng Lake, throughout the sampling periods, recorded a total of 90 species, including protozoa, rotifera, cladocera, and copepoda, and others also called meroplankton, which have both planktonic and benthic stages in their life cycles. Rotifera had the highest species composition with 48 species (53%), followed by protozoa (17 species, 19%), cladocera (10 species, 11%), copepoda (9 species, 10%), and others or meroplankton (6 species, 7%) (Figure 2).

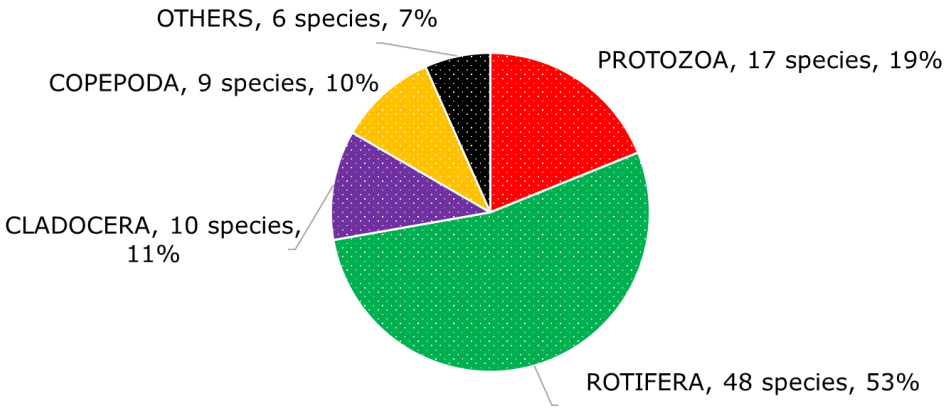


Figure 2. Structure and composition of zooplankton species in Dau Tieng Lake.

Variation in zooplankton species composition through the sampling periods. The aquatic animal species composition tended to decrease over the study periods. The zooplankton species number in Dau Tieng Lake fluctuated from 64-73 species. The species number was the highest in October 2022 with 73 species and the lowest in May 2023 with 64 species. Rotifera had a higher species number than other groups of zooplankton in most sampling areas, ranging from 33-43 species. Protozoa was relatively diverse and ranged from 8-13 species; common protozoa genera included mainly *Difflugia*, *Tintinnidium*, and *Tintinnopsis*. Cladocera ranged from 6-9 species, copepoda from 7-8 species, and meroplankton from 4-6 species (Figure 3).

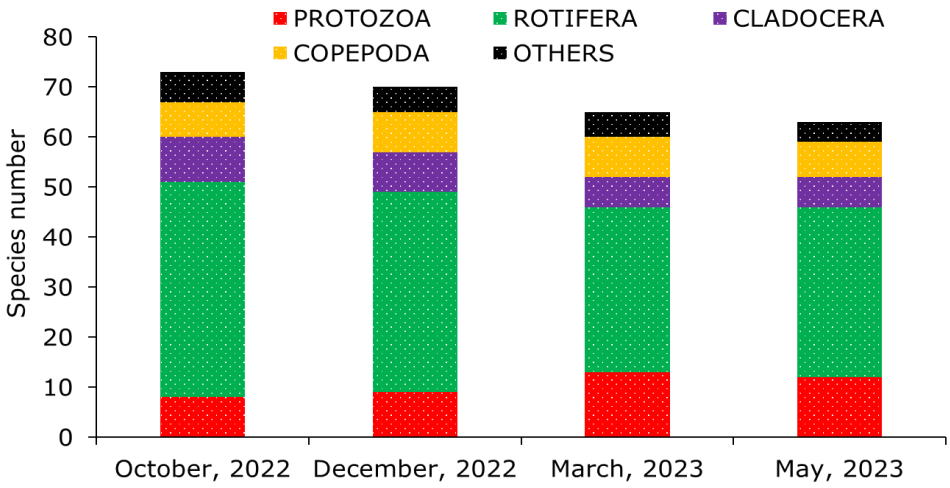


Figure 3. Total zooplankton species in Dau Tieng Lake throughout the sampling periods.

Composition of zooplankton species in the study areas of Dau Tieng Lake. The composition of zooplankton species in the upstream, midstream, and downstream areas

ranged from 48-54 species. In particular, the highest species composition of zooplankton was found in December 2022 and the lowest in May 2023 belonging to the upstream area. The species composition of zooplankton in the downstream during surveys tended to be higher than that in the upstream and midstream areas (Figure 4). In the upstream area, zooplankton species' composition across the sampling periods varied from 48-70 species (Figure 4). The rotifera species number was higher among the recorded groups, ranging from 27 to 40 species. The rotifera species component was the highest in December 2022 and the lowest in May 2023. Protozoa tended to increase in species composition in December 2022, March 2023, and May 2023 and ranged from 4–9 species. Cladocera and copepoda groups had insignificant changes in species composition between sampling periods. Cladocera and copepoda ranged from 6–8 species and 5-8 species, respectively. The meroplankton group had a relatively low number of species, with only 2-3 species found.

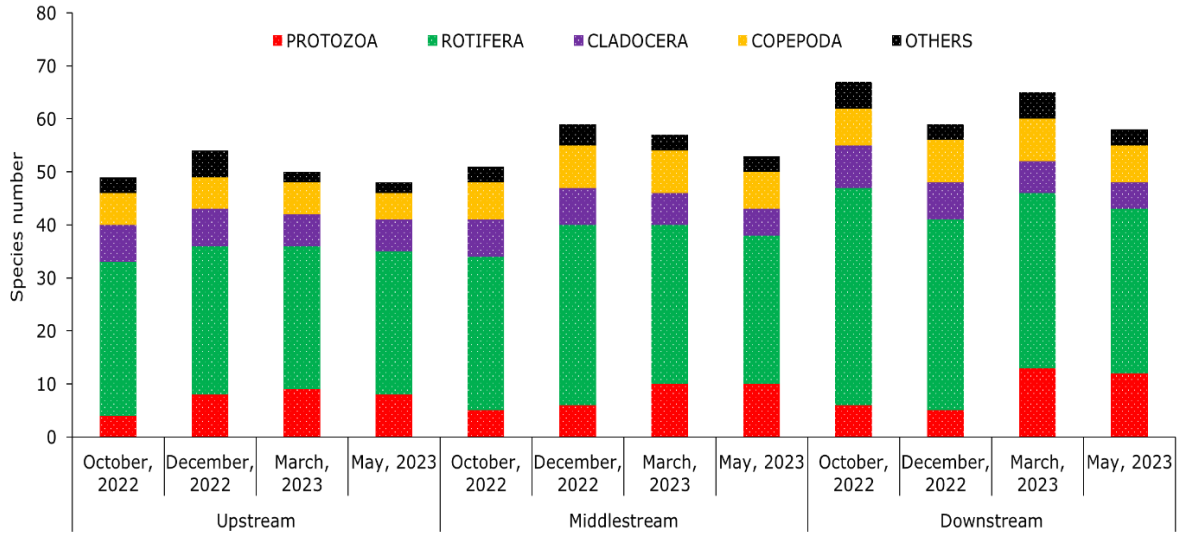


Figure 4. Composition of zooplankton species in the study area.

Similarly, the zooplankton species composition in the midstream zone fluctuated between 51 and 59 species over the study periods (Figure 4). The largest concentration of aquatic animal species was reported in December 2022, and the lowest in October 2022. Rotifera also had the highest number of species, ranging from 28 to 34 species. This research demonstrated that the rotifera species number did not change significantly when compared to the species number in the upstream area. Protozoa tended to rise throughout the sampling period, oscillating between 5 and 10 species, but copepoda and cladocera species number dropped during the sampling periods, ranging between 7-8 and 5-7 species, respectively. The meroplankton group had the fewest number of species, ranging from 3-4 species.

The species makeup of zooplankton in the downstream area ranged from 58 to 67 species as observed during the surveys. The number of species peaked in October 2022 and dropped in May 2023 (Figure 4). Rotifera had the highest species' composition, ranging from 31 to 41 species and decreasing across the sample periods. Protozoa, on the other hand, tended to rise across the study periods, with the number of species ranging from 5-13 species. Copepoda, cladocera, and meroplankton had recorded species numbers of 7-8 species, 5-8 species, and 3-5 species, respectively.

Density of zooplankton in the study areas. The zooplankton density in the studied sites varied significantly, ranging from 139,125±114,005 ind m^{-3} to 569,267±274,178 ind m^{-3}. The upstream region had the highest zooplankton abundance in March 2023 and the lowest in December 2022. The zooplankton content in the upstream area was low in October and December 2022, but high in March and May 2023. In contrast, in the downstream area, the zooplankton concentration was high in October 2022, and

December 2022, but low in March 2023 and May 2023 (Figure 5). Some common species of zooplankton were found in Dau Tieng Lake, as shown in Figure 6.

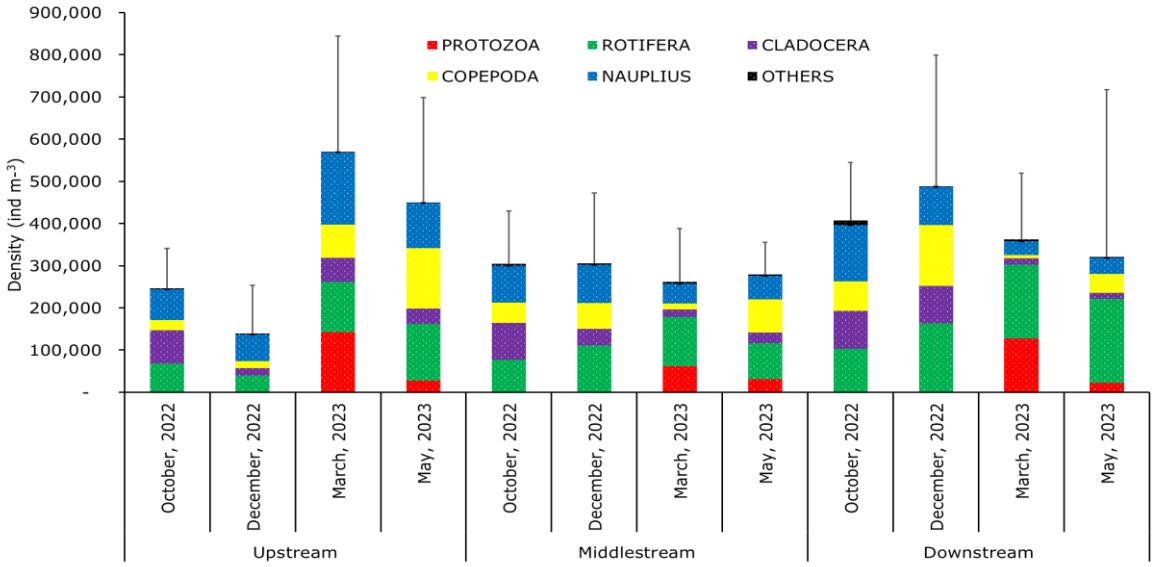
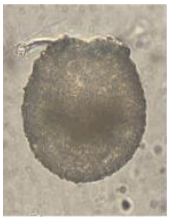


Figure 5. Variation in zooplankton density in Dau Tieng Lake.

In the upstream area, the average aquatic animal density ranged from 139,125±114,005 ind m^{-3} to 569,267±274,178 ind m^{-3} (Figure 5). In March and May 2023, the upstream zooplankton abundance was higher than that in other stages. Copepoda, which included both adult copepods and larvae, had the largest density. Rotifera density increased during sampling periods, from 39,522±22,061 ind m^{-3} to 133,983±86,641 ind m^{-3}. Protozoa density increased between March and May 2023, from 28,128±26,366 ind m^{-3} to 142,544±121,649 ind m^{-3}. The dominating Protozoa species was *Difflugia lebes*, which indicates organically polluted settings. Cladocera and meroplankton densities were lower, ranging from 17,043±17,825 ind m^{-3} to 78,545±76,523 ind m^{-3} and 255±311 ind m^{-3} to 2,149±2,586 ind m^{-3}, respectively.

In the midstream zone, zooplankton abundance ranged from 154,528±59,726 ind m^{-3} to 305,681±166,018 ind m^{-3}, with the greatest recorded in December 2022 and the lowest in March 2023. This zone has a lower zooplankton density than the upstream and downstream zones (Figure 5). Furthermore, the density of Nauplius (copepoda) larvae varied between 46,906±44,297 ind m^{-3} and 89,998±53,115 ind m^{-3}. Cladocera, copepoda, and meroplankton showed densities ranging from 17,652±19,085 ind m^{-3} to 87,161±651,609 ind m^{-3}, 14,057±14,226 ind m^{-3} to 78,302±41,495 ind m^{-3}, and 3,766±5,181 ind m^{-3} to 4,800±7,302 ind m^{-3}, respectively.

In the downstream area, zooplankton density ranged from 320,605±396,618 ind m^{-3} to 488,476±310,837 ind m^{-3} (Figure 5). Rotifera density surged with the appearance of several dominant species and indicators of organically polluted water habitats, such as *Brachionus falcatus*, *B. angularis*, *B. forficula*, and *Polyarthra vulgaris*. Copepoda and nauplius larvae (copepoda) density varied from 7,031±9,398 ind m^{-3} to 144,422±198,275 ind m^{-3} and 33,325±10,159 ind m^{-3} to 133,680±42,362 ind m^{-3}, respectively, with *Mongolodiaptomus mekongensis* species (Figure 6) outperforming the others. Protozoa densities ranged from 446±493 ind m^{-3} to 127,087±111,762 ind m^{-3}, with *Difflugia lebes* (Figure 6) being the most prevalent. Cladocera density ranged from 13,612±10,661 ind m^{-3} to 89,915±46,655 ind m^{-3}, with the *Moina* dominating as a natural food source for many freshwater fish species due to its high nutritional value.



Difflugia lebes

Brachionus angularis

Lecane curvicornis

Anuraeopsis fissa

Polyarthra vulgaris

Diaphanosoma brachyurum

Bosmina longirostris

Nauplius (Copepoda)

Mongolodiaptomus mekongensis

Figure 6. Images of zooplankton observed at Dau Tieng Lake.

Biological indices. The diversity index H' of zooplankton species composition in the examined areas ranged between 2.17 and 2.85 (Figure 7). The average H' index in the upstream, midstream, and downstream areas was 2.17±0.35 to 2.50±0.17; 2.43±0.25 to 2.85±0.09; and 2.41±0.22 to 2.55±0.11, respectively.

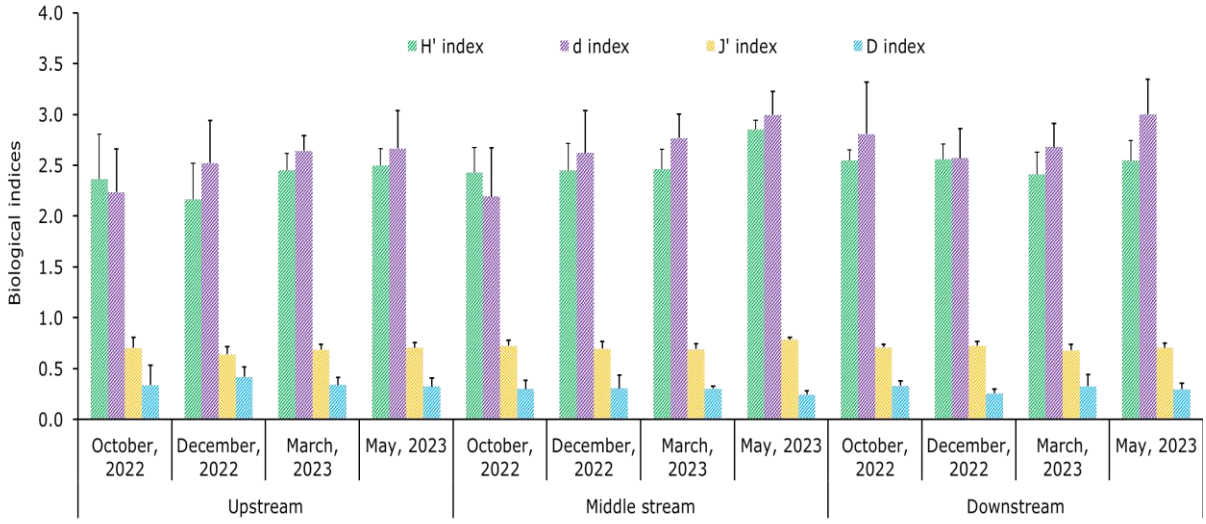


Figure 7. Biological indices of zooplankton in Dau Tieng Lake.

The d index in the studied locations ranged from 2.19±0.48 to 3.00±0.34. The J' index varied between 0.64±0.08 to 0.71±0.05, 0.69±0.05 to 0.79±0.02, and 0.68±0.06 to 0.73±0.04 for the upstream, midstream, and downstream regions, respectively. The dominance index (D) in the studied areas ranged from 0.25±0.04 to 0.42±0.10 (Figure 7). The Sorensen similarity score revealed a high degree of similarity in zooplankton

species composition between upstream, midstream, and downstream regions during the sampling stages. In this investigation, the similarity index ranged from 68-95% (Figure 8).

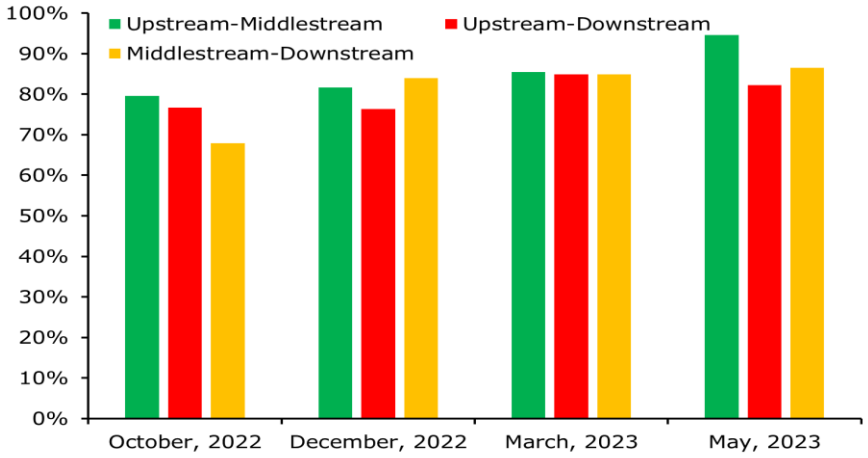


Figure 8. Similarity index between the study areas.

Correlation between zooplankton component and water environment parameters in Dau Tieng Lake. The correlations between species composition, density, and diversity of zooplankton with water environmental factors are shown in Figure 9. In this study, temperature and alkalinity were positively correlated with the species composition (number) and density of protozoa. On the other hand, these parameters were inversely influenced by the species composition of cladocera and copepoda. In addition, the densities of the genera *Difflugia* (Protozoa), *Anuraeopsis* (Rotifera), and *Bosmiopsis* (Cladocera) increased with increasing temperature and alkalinity. In addition, water quality factors, including TSS, TAN, NO_2^-, NO_3^- were positively associated with the species composition and density of cladocera and copepoda. The abundance of copepoda and Cladocera increased under conditions of high DO, pH, and chlorophyll-a contents in the study area. Similar results were also recorded for the genera *Mongolodiaptomus* (Copepoda) and *Bosmina* (Cladocera). Furthermore, rotifera genera consisted of *Keratella*, *Brachionus*, *Filinia*, and *Polyarthra* and were related to the highest values of DO, pH and chlorophyll-a. The biological indices like H', d, J', and D had a negative relationship with pH, DO, and chlorophyll-a contents, indicating that the diversity of zooplankton species composition depended mainly on these parameters.

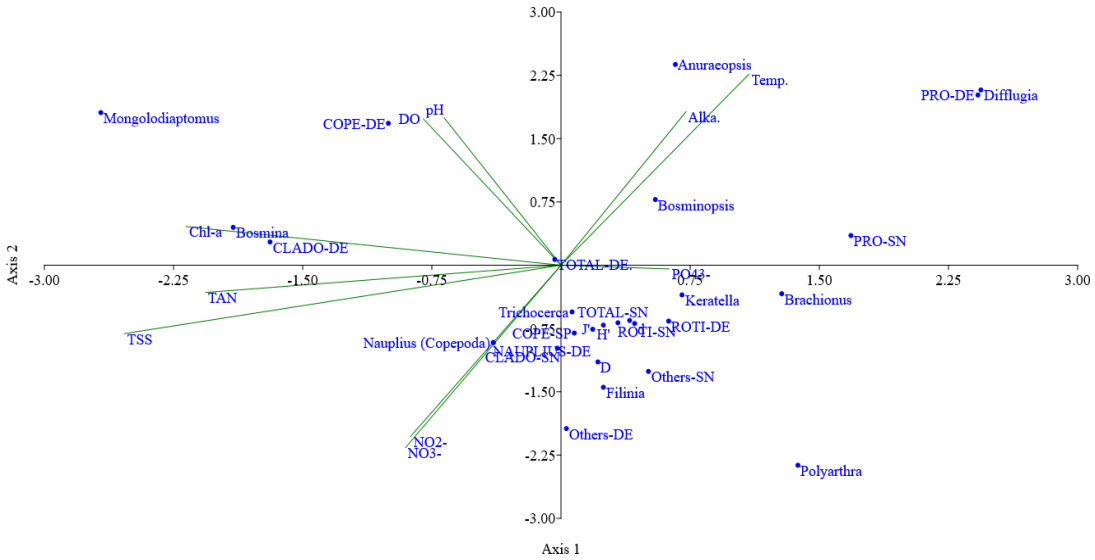


Figure 9. Relation of the water environment parameters with the species' composition and density of zooplankton.

Discusions. The number of zooplankton species detected in this study was significantly higher than that found by Nga & Dang (2019); the zooplankton fauna in Tuyen Lam Lake, Lam Dong province, Vietnam recorded 33 species. Rotifera had the highest species number (16 species), followed by cladocera (7 species), copepoda (5 species), protozoa (4 species) and 1 species belonging to aquatic insects. This showed that rotifera is mainly distributed in freshwater environments, it has a higher species composition than other groups and is an indicator organism for nutrient-rich water environments (Berzins & Pejler 1987). Rotifera has a small size and short life cycle, but is an essential qualitative and quantitative component of zooplankton in the aquatic ecosystem (Sharma 2010). In addition, rotifers are important organisms of freshwater ecosystems and play an integral role in the aquatic food chains due to their qualitative and quantitative occurrence (Vanjare & Pai 2013). Besides, rotifera is a group of organisms with a typical distribution in freshwater environments, adapted to water environments with high nutrient levels, and the rotifera dominance depends on the nutrient level of the water body (Ismail & Adnan 2016). They often account for more than 60% of the zooplankton population in freshwater bodies (Armengol et al 1998), including species like *Brachionus angularis*, *B. falcatus*, *Filinia terminalis*, and *Polyarthra vulgaris*. Similarly, Cladocera varied from 6-9 species in the study areas. They are also an important group in freshwater ecosystems and are a food source for pelagic fish and invertebrates, playing an important role in the nutrient cycle of aquatic ecosystems and are indicators of aquatic environments with moderate nutrient levels (Hall et al 1997). The present cladoceran fauna is characterized by having rich epiphytic and benthic forms. It can be associated with the shallow and vegetation-rich habitats of the study sites (Tanaka & Ohtaka 2010). Common species belonging to cladocera were *Bosmina longirostris*, *Bosminopsis deitersi*, and *Moina macrocopa*, which were found at most of the sampling sites.

Copepoda and Meroplankton had a relatively low species number, ranging from 4-8 species. Copepoda often have a more diverse species composition in saline-brackish water environments, so the recorded species number was lower than in the other groups. In addition, according to Ding et al (2024), freshwater copepods belong to three main orders: calanoida, cyclopoida, and harpacticoida. Among these, calanoids are the dominant group in freshwater ecosystems and fisheries, thriving in the pelagic zones of lakes, estuaries, and ponds. The species composition of protozoa found in this study was higher than in Lien et al (2019), who conducted a research study on the species' composition of zooplankton in Bun Xang Lake in Can Tho City, Vietnam, and discovered 11 species. Protozoa efficiently gather microorganisms for food and are small enough to have generation patterns similar to the food particles they feed on. They are, quantitatively, the most important microbial grazers in aquatic environments, and they most likely govern bacterial abundance (Finlay & Esteban 1998). Furthermore, Xu et al (2005) investigated water quality assessment employing protozoa as indicator organisms in high organic matter and contaminated areas. Pollution did not affect species diversity, but it did enhance the community's instability (Tang 2001). When the aquatic environment was nutrient-rich, zooplankton species composition and density increased (Golmarvi et al 2017).

In the upstream area, nutrient concentrations in the water were quite high. This provided favorable conditions for rotifera to increase in species number in the study areas. In addition, according to Lien et al (2013), some genera of rotifera are distributed in the rainy season, including *Keratella*, *Platyias*, *Polyarthra*, and *Filinia*, and in the dry season, like *Lecane* and *Trichocerca*. The present study also documented the presence of these genera. An increase in zooplankton density in the upstream area was associated with an increase in phytoplankton abundance (estimated as chlorophyll-a content). Increased algal density had supplied food for zooplankton to thrive. The Jucazinho reservoir in Brazil, significant correlations between phytoplankton and zooplankton have been reported (Mélo-Júnior et al 2007). The composition of zooplankton species identified in the midstream area tended to be higher than that in the upstream area during the observation periods, but not significantly. The species number of aquatic animals across sampling periods in downstream areas was higher than that in upstream and midstream areas. In general, the structure of zooplankton species was relatively similar in the three

survey areas. Among them, rotifera always has the highest number of species at sampling locations.

Zooplankton abundance upstream was the highest among sampling periods in Dau Tieng Lake in March 2022, when the density of Protozoa was 142,544±121,649 ind m^{-3} (25%), indicating an organic pollution environment. Additionally, the high density of nauplius larvae (copepoda), copepoda, and rotifera in the upstream area indicated a nutrient-rich water environment. The zooplankton density in the midstream was lower than that in the upstream because the nutrient content in the water was lower, as shown by the contents of TAN (0.011–0.056 mg L^{-1}), NO_3^- (0.065-0.123 mg L^{-1}), PO_4^{3-} (0.046-0.061 mg L^{-1}), which limited the zooplankton growth. Protozoa had a high density in March 2023 period (61,632±44,433 ind m^{-3}), indicating that the water environment had a high content of organic matter. Rotifera density was recorded from 77,002±55,925 ind m^{-3} to 117,035±60,508 ind m^{-3}. Some rotifera species found in the study area, such as *Brachionus rubens*, *B. calyciflorus*, and *B. angularis*, are currently also being cultured as biomass for the larval or fry stages of many freshwater aquatic species (Út & Oanh 2013). The research performed by Lien et al (2020) revealed that the higher the H' index, the more diverse the species and the less polluted the water. Besides, Ren et al (2011) used zooplankton as an indicator organism to measure water quality using the H' index. The index ranges from 0-1 for heavy pollution, 1-2 for moderate-α pollution, 2-3 for moderate-β pollution, and >3 for light pollution or no pollution. According to the H' diversity index, the research locations had moderate species diversity and moderate water quality (α pollution level).

The d index correlated with zooplankton richness. The results from Figure 7 showed that the dominance of zooplankton species tended to increase through the survey periods. The low d index was recorded in the upstream area in May 2023, and the total number of zooplankton species was 48 species at the same time, lower than the middle and downstream areas. On the contrary, the zooplankton density in the upstream area tended to increase; this result was consistent with the dominance rule of the variation in species composition and density of aquatic organisms in the water body. For J' index, the evenness index was in the range of 0-1. When the J’ value was closer to 1, the individuals within communities were more evenly distributed (Pielou 1966). In the present study, the results indicated that zooplankton abundance in the population in these areas was quite evenly distributed and had high species diversity. Furthermore, the D index in the upstream area was high, indicating that species diversity was lower than in the other locations. As a result, water pollution levels in the upstream area were often higher than those in the middle and downstream sections. Overall, the studies revealed a significant degree of consistency in the species composition of aquatic creatures between upstream, midstream, and downstream locations. This was because Dau Tieng Lake had water supply and drainage to support agricultural production activities; water was exchanged on a regular basis between the areas. As a result, the species composition of aquatic creatures did not differ significantly between the studied sites.

Variation in species composition and density of aquatic animals is influenced by water quality factors and interactions of biotic factors (Wetzel 2001). Besides, seasonal variability and the water environment are the two most important factors that affect aquatic biological community structures (Jiang et al 2007). The occurrence of rotifers is affected by the complex interaction of various physical, chemical, geographical, biological, and ecological parameters. All these factors play an individual role in the formation of rotifer assemblages and their seasonal occurrence, but the ultimate effect is produced due to the interplay and interaction of all these factors (Hulyal & Kaliwal 2008). In addition, small-sized species such as rotifers have a close relationship with the nutrient content in water. They act as biological filters by using nutrients as food sources. In this study, some genera such as *Bosminopsis*, *Anuraeopsis* (rotifera), and *Difflugia* (protozoa) were negatively correlated with levels of TAN, NO_3^-, NO_2^-, and TSS. The study by Martin-Cereceda et al (2002) revealed that certain genera of protozoa and some dominant species could be employed as biological indicators because there is a strong positive correlation between the abundance of some protozoa and chemical parameters in freshwater systems. Furthermore, according to Lansac-Tôha et al (2005) registered high

abundances of small young forms of cyclopoida in Iraí Reservoir, and associated with chlorophyll-a. In general, water quality elements and chlorophyll-a are affected by the zooplankton growth and diversity.

Conclusions. The zooplankton population of Dau Tieng Lake, Vietnam, was highly diversified. The survey found a total of 90 species, with rotifera having a more diversified species makeup than the other groupings. Zooplankton density increased across studies, ranging from 139,125±114,005 ind m^{-3} to 569,267±274,178 ind m^{-3}. The upstream area had a higher concentration of aquatic animals than the midstream and downstream areas. In March 2023, protozoa abundance increased in most research zones. The biological indices of H', J', d, and D demonstrated a moderately diverse zooplankton species composition in Dau Tieng Lake. The abundance of zooplankton species in the communities was very uniform across the research sites, with significant similarities between locations. Aquatic animal species diversity was mostly influenced by water quality parameters and chlorophyll-a content. Continuous research on the variety of zooplankton species by season should be done in the study regions. This allows for the evaluation of natural food supplies to ensure the long-term development of aquaculture in Dau Tieng Lake, Vietnam.

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References

Armengol X., Esparcia A., Miracle M. R., 1998 Rotifer vertical distribution in a strongly stratied lake a multivariate analysis. Hydrobiologia 387:161-170.

Berzins B., Pejler B., 1987 Rotifera occurrence in relation to pH. Hydrobiologia 182:171-182.

Boltovskoy D., 1999 South Atlantic zooplankton. Backhuys Publishers, Leiden, The Netherlands, 1705 p.

Boyd C. E., Tucker C. S., 1992 Water quality and pond soil analysis for aquaculture. Agricultural Experiment Station, Alabama, 188 p.

Ding R., Liu L., Shu S., Li Y., Chen F., 2024 Diversity of freshwater calanoid copepods (Crustacea: Copepoda: Calanoida) in North-Eastern China. Diversity 16:288.

Finlay B. J., Esteban G. F., 1998 Freshwater protozoa: biodiversity and ecological function. Biodiversity and Conservation 7:1163-1186.

Gannon J. E., Stemberger R. S., 1978 Zooplankton (especially crustaceans and rotifers) as indicators of water quality. Transactions of the American Microscopical Society 97(1):16-35.

Golmarvi D., Kapourchali M. F., Moradi A. M., Fatemi M., Nadoshan R. M., 2017 Influence of physico-chemical factors, zooplankton species biodiversity and seasonal abundance in Anzali International Wetland, Iran. Open Journal of Marine Science 7:91-99.

Ha G., 2017 [Tay Ninh: Enhance aquatic resources in Dau Tieng Lake]. Available at: http://nguoinuoitom.vn/tay-ninh-tang-cuong-nguon-loi-thuy-san-o-ho-dau-tieng/. [In Vietnamese].

Hall B. D., Bodaly R. A., Fudge R. J. P., Rudd J. W. M., Rosenberg D. M., 1997 Food as the dominant pathway of methylmercury uptake by fish. Water, Air and Soil Pollution 100:13-24.

Hulyal S. B., Kaliwal B. B., 2008 Water quality assessment of Almatti Reservoir of Bijapur (Karnataka State, India) with special reference to zooplankton. Environmental Monitoring and Assessment 139(1-3):299-306.

Ismail A. H., Adnan A. A., 2016 Zooplankton composition and abundance as indicators of eutrophication in two small man-made lakes. Tropical Life Sciences Research 27:31-38.
Jiang J-G., Wu S-G., Shen Y-F., 2007 Effects of seasonal succession and water pollution on the protozoan community structure in a eutrophic lake. Chemosphere 66:523–532.
Kangro K., Langaste R., Peter N., Ott I., 2005 Long-term changes and seasonal development of phytoplankton in a strongly stratified, hypertrophic lake. Hydrobiologia 547:91-103.
Lansac-Tôha F. A., Bonecker C. C., Velho L. F. M., 2005 [Establishment of the zooplankton community in our reserves.] In: Biocenoses in reserves: spaced and temporally protected. Rodrigues L., Thomaz S. M., Agostinho A. A., Gomes L. C. (eds), pp. 115-127, Rima, Sao Carlos. [In Portuguese].
Lien N. T. K., Hoa A. V., Tri N. V., Giang H. T., Phu T. Q., Glenn S., Ut V. N., 2020 [Potential use of zooplankton in biomonitoring on Hau River]. Can Tho University Journal of Science 56:149-160. [In Vietnamese].
Lien N. T. K., Trang L. T. T., Son V. N., 2019 [Zooplankton composition in Bun Xang Canal of Can Tho City]. VNU Journal of Science: Natural Sciences and Technology 36(2):31-40. [In Vietnamese].
Lien N. T. K., Ut V. N., Giang H. T., 2013 [Zooplankton community biodiversity in the Cu Lao Dung mangrove, Soc Trang province]. Can Tho University Journal of Science 25*:*149-157. [In Vietnamese].
Liu Q., Borong L., Xue S., Yan L., Yu G., Huifang L., Min W., Hongbing S., Alan W., Xiangrui C., Yong J., Zhihua L., 2017 Recovery of ciliated protozoan communities in response to environmental change in a shrimp-farming pond in southern China. Journal of the Marine Biological Association of the United Kingdom 98(6):1263-1272.
Luyen N., 2020 [Dau Tieng Lake - the largest artificial lake in Vietnam]. Available at: https://www.vntrip.vn/cam-nang/ho-dau-tieng-tay-ninh-67540. [In Vietnamese].
Margalef R., 1958 Information theory in ecology. General Systems 3:36–71.
Martin-Cereceda M., Zazmora J., Perez-Uz B., Guine A., 2002 Ciliate communities of rotating biological contactor biofilms: A multivariate approach. Systematic and Applied Microbiology 25:301–313.
Mélo-Júnior M., Santos-Almeida V. L., Nogueira-Paranaguá M., Nascimento-Moura A., 2007 [Planktonic crusts from an oligotrophic reserve in Northeast of Brazil.] Revista Brasileira de Zoociências 9(1):19-30. [In Portuguese].
Nga L. T. N., Dang P. D., 2019 [Zooplankton fauna in Tuyen Lam lake, Da Lat city, Lam Dong province]. Ho Chi Minh city University of Education Journal of Science 16: 178-189. [In Vietnamese].
Phan D. D., Nguyen V. K., Le T. N. N., Dang N. T., Ho T. H., 2015 Identification handbook of freshwater zooplankton of the Mekong River and its tributaries. Mekong River Commission, Vientiane, 207 p.
Pielou E. C., 1966 The measurement of diversity in different types of biological collections. Journal of Theoretical Biology 13:131-144.
Ren L., Zhang Z., Zeng X., Ma Y., Zeng Y., Zhou C., 2011 Community structure of zooplankton and water quality assessment of Jialing River in NanChong. Procedia Journal of Environmental Sciences 10:1321-1326.
Santos-Wisniewski M., Rocha O., Guntzel A., Matsumura-Tundisi T., 2006 Aspects of the life cycle of *Chydorus pubescens* Sars, 1901 (Cladocera, Chydoridae). Acta Limnologica Brasiliensia 18(3):305-310.
Shannon C. E., Wiener W., 1963 The mathematical theory of communication. University of Illinois Press, Urbana, 127 p.
Sharma B. K., 2010 Rotifer communities of Deepor Beel, Assam, India richness, abundance and ecology. Journal of Threatened Taxa 2:1077-1086.
Shirota A., 1966 The plankton of South Vietnam, freshwater and marine plankton. Oversea Technical Cooperation Agency, Japan, 489 p.
Simpson E. H., 1949 Measurement of diversity. Nature 163:688.

Sorenson T., 1948 A method of establishing groups of equal amplitudes in plant sociology based on similarity of species content and its application to analyses of the vegetation on danish commons. Kongelige Danske Videnskabernes Selskab Biologiske Skrifter 5:1-34.
Tanaka S., Ohtaka A., 2010 Freshwater Cladocera (Crustacea, Branchiopoda) in Lake Tonle Sap and its adjacent waters in Cambodia. Limnology 11:171–178.
Tang V. T., 2001 [Ecological basis]. Viet Nam Education Publishing House, 264 p. [In Vietnamese].
Thanh D. N., Bai T. T., Mien P. V., 1980 [Identification of freshwater invertebrates in North Vietnam]. Science and Technology Publishing House, Hanoi, 573 p. [In Vietnamese].
Thạo N. D., 2017 [Zooplankton and pelagic fish resources in the southwest sea of Vietnam]. Fisheries Magazine 6:32-34. [In Vietnamese].
Ut V. N., Oanh D. T. H., 2013 [Textbook of aquatic plants and animals]. Can Tho University Publishing House, 342 p. [In Vietnamese].
Vanjare A. I., Pai K., 2013 Ecology of freshwater rotifera in a seasonal pond of the University of Pune (Maharashtra, India). Applied Ecology and Environmental Research 11(4):525-539.
Wetzel R. G., 2001 Limnology Lake and river ecosystems UK. Academic Press, London, 1024 p.
Whitman R., Nevers B. M., Goodrich L. M., Murphy C. P., Davis M. B., 2004 Characterization of lake Michigan coastal lakes using zooplankton assemblages. Ecological Indicators 4(4):277-286.
Xu M., Cao H., Xie P., Deng D., Feng W., Xu J., 2005 The temporal and spatial distribution, composition and abundance of Protozoa in Chaohu Lake, China Relationship with eutrophication. European Journal of Protistology 41:183-192.

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