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Dynamics of the Zooplankton Community of Monastery Lake in Daloa (West-Central, Côte d'Ivoire)

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Abstract

Monastery Lake in Dalea (Côte d'Ivoire) represents an important aquatic ecosystem facing increasing anthropogenic pressures. Despite its ecological and economic importance as a fishing site, no previous study has documented the dynamics of its zooplankton community. The availability of fundamental scientific data is essential for developing appropriate management plans. This study examines the seasonal variation of zooplankton in Monastery Lake in Daloa (West-Central Côte d'Ivoire). Seasonal sampling was conducted from February to September 2024 at three stations. Physicochemical parameters (temperature, pH, dissolved oxygen, conductivity, transparency, depth) were measured in situ. Zooplankton was collected using a 50 µm mesh net, identified using standard taxonomic keys, and then enumerated. The data were used to calculate Shannon diversity and evenness indices, and to analyze correlations between environmental parameters and the zooplankton community. Seventy-one zooplankton taxa were identified, comprising 43 Rotifers, 4 Copepods, 19 Cladocerans and 5 other organisms. Rotifers showed qualitative dominance while Copepods dominated quantitatively across all seasons. Taxonomic richness and zooplankton abundance were higher during the rainy season compared to the dry season. Zooplankton distribution showed negative correlations with temperature, pH and transparency, and positive correlations with depth and dissolved oxygen. This study reveals that zooplankton organisms in Monastery Lake exhibit remarkable diversity and abundance, highlighting the ecological importance of this aquatic ecosystem.

Keywords: Zooplankton; Seasonal Variation; Diversity; Occurrence; Lake; Daloa

1. Introduction

Aquatic ecosystems host numerous diverse organisms that interact with each other and their environment [1]. Each organism, through its ecological niche and regardless of size, plays a specific role in ecosystem functioning and balance. In developing countries, the integrity of most water bodies is threatened by waste disposal from urban and industrial areas [2]. In Côte d'Ivoire, development requirements have led to activities that increasingly threaten aquatic environments [3], including the creation of hydroelectric and agro-pastoral reservoirs, and the discharge of domestic and industrial waste [4]. Aquatic ecosystems located within or near large urban centers are particularly affected by human activities. Monastery Lake in western Daloa is not spared from these threats, despite being a highly productive ecosystem and an important fishing site for the city [5].

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The lake therefore plays a crucial role in regional food security and livelihoods. However, no study has previously investigated the seasonal variation of zooplankton organisms in this water body. Yet these organisms play a central role in trophic networks, facilitating the transfer of matter and energy from primary resources to higher trophic levels [6]. Indeed, zooplankton serves as an important energy source for fish and other higher trophic level organisms in aquatic environments [7, 8]. Consequently, changes in zooplankton community structure and distribution significantly influence fisheries and fish communities due to their vital role in aquatic food webs. Understanding seasonal variations in zooplankton community structure and distribution patterns is therefore essential for developing sustainable fisheries management strategies. Numerous fish species depend on zooplankton as a food source and undertake seasonal migrations within aquatic environments.

Given zooplankton's important role in environmental monitoring, ecosystem management, and fisheries, the general objective of this study is to contribute to the understanding of the lake's biotic integrity through zooplankton structure in relation to environmental factors.

2. Material and methods

2.1. Study area

Daloa is a city in west-central Côte d'Ivoire. It is situated between 6°52' North latitude and 6°27' West longitude [9]. The city is located 383 km from Abidjan, the economic capital, and 141 km from Yamoussoukro, the political capital. It serves as the capital of the Sassandra-Marahoué district and is the regional headquarters of the Haut-Sassandra region [9]. The city of Daloa is bordered to the north by the departments of Vavoua and Zuénoula, to the south by the department of Issia, to the east by the department of Bouaflé, and to the west by the department of Zoukougbeu. The Daloa region experiences an Attiéen-type climate with a transitional pattern [10]. Two main seasons characterize the annual climate: a rainy season lasting from July to September and a dry season covering the period from October to June (Figure 1).

2.2. Sampling

Monthly sampling campaigns were conducted from February to September 2024 in Monastery Lake in the city of Daloa. Sampling took place between 7:00 AM and 9:00 AM at three points selected based on their accessibility and surrounding anthropogenic activities (Figure 7).

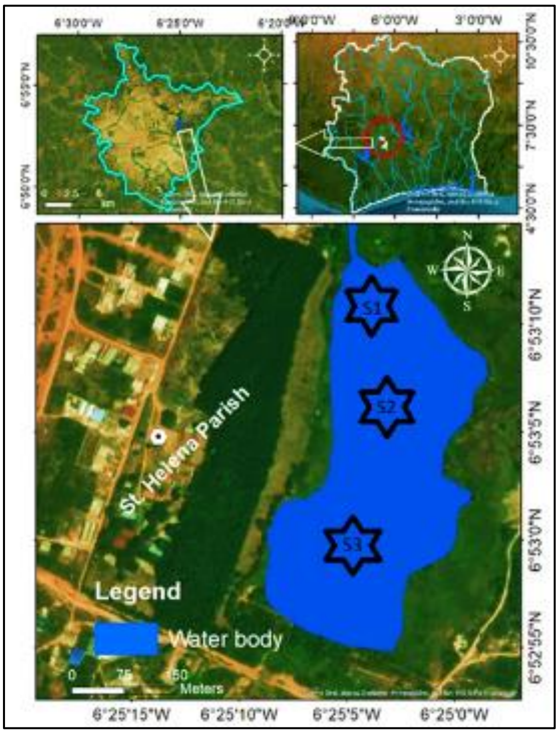

Figure 1 Distribution of selected sampling areas in Monastery Lake, Daloa municipality

2.2.1. Measurement of Physicochemical Parameters

pH, temperature, conductivity, and dissolved oxygen levels were measured using a HANNA HI 9828 multiparameter instrument. The device was switched on several minutes before use, and the probe was then immersed in the water column. Readings were taken after the device stabilized, and data were recorded from the screen. Regarding transparency, a Secchi disk was lowered into the water until it was no longer visible. It was then slowly raised using the graduated line held in hand until it reappeared. Transparency was determined by the length of the line from the water surface to the disk. A tape measure was used to assess depth. It was lowered into the water until it reached the bottom. The depth corresponded to the length of the submerged portion of the tape measure.

2.2.2. Zooplankton Collection and Sample Analysis

Water samples were obtained by collecting six (06) buckets of 10 L of water from the lake, which were then filtered through a 50 µm mesh plankton net. The filtrate collected in the net's cod-end was transferred to a sample vial. The collected samples were placed in vials and treated with 1 to 2 mg of sugar to prevent the carapace of Cladocerans from rupturing [11], 2 to 3 drops of neutral red stain to color the organisms for easier observation under magnification, and 1 to 2 drops of liquid soap to prevent clumping of organisms. Preservation of the zooplankton organisms required the addition of 5% concentration formaldehyde.

Subsamples were collected in a Dolfuss chamber at the laboratory and subsequently observed under a binocular microscope. Identification of zooplankton organisms was based on specific morphological characteristics observable using identification keys from several authors [12, 13 and 14].

For the total count (n), the 100 ml sample was concentrated to 80 ml. From this concentrated sample, two (2) subsamples of 3 ml each were extracted. These subsamples were examined under a microscope, where organisms were identified and counted. The resulting count was then extrapolated to the total volume of the original sample to estimate the total abundance of zooplankton.

2.3. Data analysis

2.3.1. Taxonomic Richness and Density of Zooplankton Taxa

Taxonomic richness (R), defined as the total number of taxa observed in an ecosystem [15], was estimated. The number of individuals belonging to a tax on present in the sample per unit volume of filtered water (Ind/m^3) was determined using the following formula

$$D = n / v$$

Where: D represents density (individuals per m^3); n is the number of individuals of a tax on present in the sample; v is the volume of filtered water expressed in m^3

2.4. Diversity Indices

Diversity indices reflect the degree of organization within a community. The Shannon-Weaver index was used to quantify the heterogeneity of the zooplankton community in our study area during the investigation period, using the following formula:

$$H' = -\sum[(n_i/N) \log_2(n_i/N)]$$

Where: H' represents specific diversity in bits/individual; $\sum$ denotes the sum of results obtained for each present species; n_i is the abundance of species i; N is the total number of individuals of all species- $\log_2$ is the base-2 logarithm

Regarding evenness, it was used to assess the regularity of zooplankton taxon distribution in Monastery Lake, Daloa during the study period according to the following formula

$$E = H'/H'max$$

Where: H'max represents the maximum value of H'; H'max = $\log_2$ Sobs; Sobs: number of taxa observed

2.5. Statistical Analyses

2.5.1. Mann-Whitney U Test

The Mann-Whitney U test was used to compare seasonal variations in zooplankton and diversity indices. When the p-value is below the significance threshold (0.05), the difference between the compared variables is considered statistically significant. If the p-value exceeds 0.05, the difference is not statistically significant. These comparisons were performed using the software PAST 4.02.

2.5.2. Spearman Correlation

In this study, Spearman's Rank Correlation Coefficient was applied to analyze the correlations between zooplankton and environmental variables.

3. Results

3.1. Physicochemical parameters

The results of the physicochemical parameters are shown in Table I.

The water temperature values for Lake Monastère range from 26.5°C to 30.1°C, with an average of 28.3 ± 2.08°C in the dry season, while in the rainy season the temperature is 26.6°C.

With regard to dissolved oxygen content, values (1.48 mg/L and 3.731 mg/L) with an average of 2.39 ± 1.05 mg/L were observed in the dry season, while in the rainy season, the dissolved oxygen content ranged from 3.3 mg/L to 3.72 mg/L, with an average of 3.51 ± 0.24 mg/L.

As for pH, values ranged from 8.65 to 9.19, with an average value of 8.92 ± 0.38 in the dry season. During the rainy season, pH values range from 6.79 to 6.84, with an average value of 6.81 ± 0.03.

Conductivity values varied between 235 µs/cm and 330.5 µs/cm, with an average of 282.75 ± 55.13 µs/cm during the dry season. During the rainy season, the values for this parameter fluctuated between 207 µs/cm and 237 µs/cm, with an average of 222 ± 17.41 µs/cm.

Water transparency values ranged from 60.5 cm to 61.2 cm with an average of 60.85 ± 0.57 cm during the dry season. In contrast, transparency values during the rainy season varied from 39.8 cm to 45.7 cm with a mean value of 43.5 ± 0.57 cm.

Regarding depth, values (60 cm and 61.2 cm) with an average of 60.6 ± 0.69 cm were recorded during the dry season. During the rainy season, depth values ranged between 76.1 cm and 89.8 cm with a mean of 82.95 ± 7.9 cm.

The physicochemical characteristics measured in Monastery Lake, Dalea showed a significant difference between dry and rainy seasons (Mann-Whitney U test, $p < 0.05$)

Table 1 Seasonal variations of physicochemical parameters measured in Monastery Lake, Dalea

	Values	**Temp (°c)**	**DO (mg/l)**	**pH**	**Cond (µs/cm)**	**Trans (cm)**	**Depth (cm)**
Dry Season	Min	26.5	1.48	8.65	235	60.5	60
	Max	30.1	3.31	9.19	330.5	61.2	61.2
	Average	28.3	2.39	8.92	282.75	60.85	60.6
	± SD	± 2.08	±1.05	± 0.38	± 55.13	± 0.57	± 0.69
Rainy Season	Min	26.6	3.3	6.79	207	39.8	76.1
	Max	26.6	3.72	6.84	237	45.7	89.8
	Average	26.6	3.51	6.81	222	42.75	82.95
	± SD	0	± 0.24	± 0.03	± 17.41	± 3.43	± 7.9

Temp: Temperature; DO: Dissolved oxygen; Cond: Conductivity; Trans: Transparency; SD: Standard Deviation; Min: Minimum; Max: Maximum

3.2. Zooplankton Community Structure

3.2.1. Taxonomic Composition

The zooplankton census in Monastery Lake during the study period revealed an overall taxonomic richness of 71 taxa (Table II). These taxa were distributed among the major zooplankton groups (43 Rotifers, 19 Cladocerans, 4 Copepods, and 5 other zooplankton organisms) and classified into 21 families. By season, 54 taxa were identified during the dry season, compared to 60 taxa during the rainy season. Rotifers were the most diverse group in both the dry season (30 taxa, 55.56%) and the rainy season (36 taxa, 60%).

Table 2 Seasonal Variation in Taxonomic Richness of Major Zooplankton Groups in Monastery Lake, Dalea

Zooplankton Groups	Specific Richness	Dry Season	Rainy Season
Rotifers	43	30	36
Cladocerans	19	16	17
Copepods	4	4	3
Others	5	4	5
Total	71	54	60

3.2.2. Density

The highest average total zooplankton abundance (28039.2 ind/m^3) was recorded during the rainy season, while the lowest (10279.32 ind/m^3) was observed during the dry season (Figure 2). Zooplankton was dominated by Copepods in both the dry and rainy seasons, accounting for over 50% of the total zooplankton abundance. They were followed by Rotifers, representing 13% and 20% during the dry and rainy seasons, respectively, and then by Cladocerans (11%) in both seasons (Figure 8).

Among Rotifers, Testudinella patina was dominant during the rainy season (48%). For Cladocerans, Macrothrix rosea dominated in both the dry and rainy seasons (31% in the dry season and 38% in the rainy season). Among Copepods, nauplii were the most abundant in both seasons (over 50% in each season). Other zooplankton organisms were primarily composed of other insect larvae (53% in the rainy season and 33% in the dry season) and Ostracods (29% in the rainy season and 35% in the dry season) during both dry and rainy seasons (Figure 3).

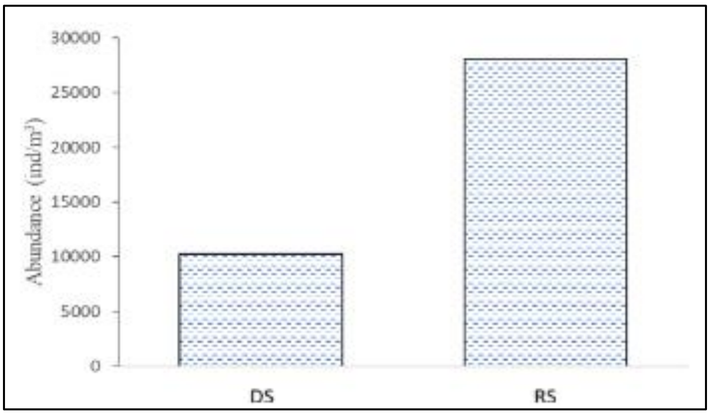

Figure 2 Seasonal variation in the mean density of zooplankton in Monastery Lake, Dalea. DS: dry season; RS: rainy season

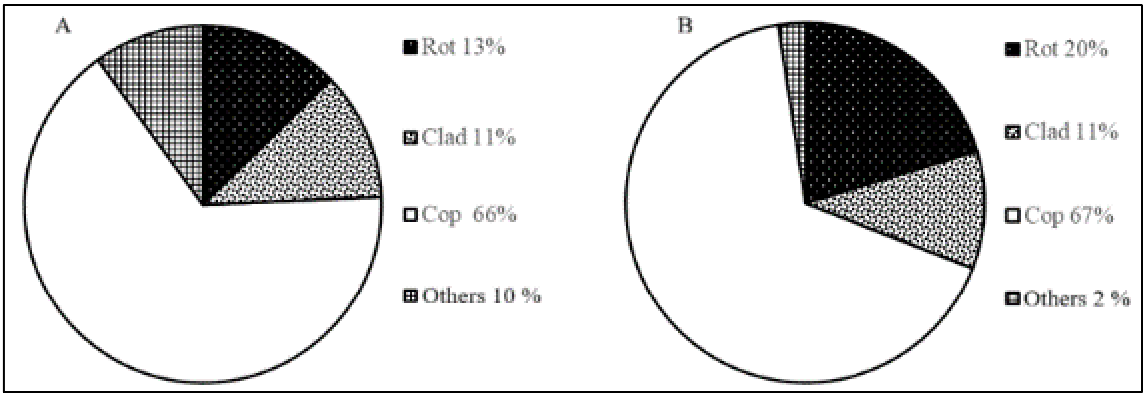

Figure 3 Seasonal variation in the relative density of major zooplankton groups in Monastery Lake, Daloa. A: dry season; B: rainy season. Rot: Rotifers; Clad: Cladocerans; Cop: Copepods; Others: insect larvae and Ostracods

3.2.3. Diversity Index

The highest values for the Shannon index (2.178 ± 0.26 bits/in) and Equitability (0.76 ± 0.14) were recorded during the dry season, in contrast to the lowest values observed (2.055 ± 0.14 bits/in and 0.76 ± 0.14, respectively) during the rainy season (Figure 4). However, the Mann-Whitney U test showed no significant seasonal variation for these indices ($p > 0.05$)

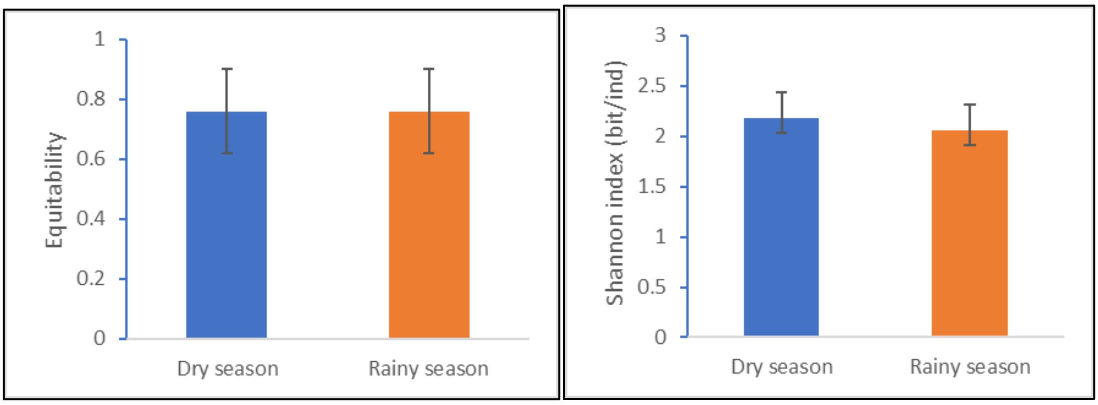

Figure 4 Seasonal variation of Shannon diversity and Equitability indices in Monastery Lake, Dalea

3.2.4. Influence of environmental factors on Zooplankton Community distribution

The correlations between environmental variables and the different zooplankton groups show that temperature, pH, and transparency are negatively correlated with all zooplankton groups, while depth and oxygen are positively correlated with these organisms. Conductivity is positively correlated only with rotifers and negatively correlated with the other zooplankton organisms (Table V).

Table 3 Spearman's rank correlation between zooplankton groups and environmental variables

Taxons	Cond (µS/cm)	Temp (°C)	DO (mg/L)	pH	Trans (cm)	Depth (m)
Rotifers	0.024	- 0.47	0.08	-0.6	- 0.22	0.34
Cladocerans	-0.12	- 0.58	0.55	-0.6	- 0.37	0.73
Copepods	-0.61	- 0.67	0.37	- 0.71	- 0.623	0.63
Others	-0.05	- 0.29	0.66	- 0.43	- 0.45	0.88

Temp: Temperature; DO: Dissolved Oxygen; Cond: Conductivity; Trans: Transparency

4. Discussion

Physicochemical variables of water determine the distribution and abundance of zooplankton organisms in aquatic ecosystems [16, 3 and 17]. Overall, the physicochemical characteristics assessed in Monastery Lake in the city of Daloa differ significantly between the dry and rainy seasons. In this lake, the highest values of conductivity, temperature, transparency, and pH were recorded during the dry season, while dissolved oxygen and depth reached their lowest values during this same season.

The temperatures recorded in this study varied on average between 26.9°C in the rainy season and 28.3°C in the dry season. These data align with the observations of [18], who noted that it is rare for Ivorian water bodies to be below 25°C. Temperature values are higher during the dry season, which could be explained by the direct impact of solar radiation on the water surface, leading to a homogeneous warming of the water body [19]. During the dry season, air temperature related to solar radiation is expected to be at its maximum. Indeed, during the dry season, dry and hot air, water velocity, and the absence of canopy cover in lacustrine environments would contribute to water warming.

During the dry season, conductivity records higher values than in the rainy season. Indeed, a higher concentration of dissolved elements in the water would be favored by the low water volume in the dry season. [20] further emphasize that during the dry season, evaporation combined with the lack of water input leads to an accumulation of ions that would increase conductivity. This could explain the rise in conductivity observed during the dry season and the low conductivity recorded during the rainy season in Monastery Lake.

The mean pH values recorded in Monastery Lake (6.84 during the rainy season and 8.92 during the dry season) are relatively close to those measured in Lake Ayamé I, which range from 7.1 to 7.8 [21], and comparable to those from Lake Bakré (southern Côte d'Ivoire), varying from 6.6 to 8.8 [22]. This indicates a near-neutral pH during the rainy season and alkaline conditions during the dry season.

Dissolved oxygen levels are higher during the rainy season than in the dry season. This could be explained by the fact that runoff water entering Monastery Lake is rich in organic matter. Additionally, temperature also impacts the water's capacity to hold dissolved oxygen, as an increase in temperature leads to a reduction in dissolved oxygen in more exposed waters [23], which could account for the low dissolved oxygen content during the dry season.

In Monastery Lake, the water is clearer during the dry season than in the rainy season. During the dry season, the lentic environment allows debris in the water column to settle by gravity and accumulate at the bottom of the lake. Furthermore, the same result was observed by [17] in the waters of the Upper Bandama. The higher depth values recorded during the rainy season in Monastery Lake in the city of Daloa are due to intense runoff during this period, which raises the water level of this hydrosystem.

This study collected 71 zooplankton taxa. This number of species is higher than those obtained by [4] in the Bia River basin (64 taxa), [4] in the Agnéby River (30 taxa), and [24] in the Comoé River national park (20 taxa), even though the nets used in those studies had smaller mesh sizes (20 µm compared to 50 µm in this study). Indeed, lentic environments are well known to be more favorable for zooplankton development than lotic environments. However, in Lake Kaby, [25] obtained a lower number of species (31) using a 60 µm net, compared to 71 species in this study with a 50 µm net. The mesh size of the net used could explain this difference, as smaller mesh nets would retain organisms that larger mesh nets would allow to pass through.

The qualitative preponderance of Rotifers (53.70-56.67%) indicates a high organic matter load in this environment across all seasons [26]. Indeed, these organisms feed on small particles such as bacteria, detritus, and diatoms, which are abundant in this environment [27].

The high abundance of Copepods (65-66%) observed in this environment could be explained by the fishing pressure on planktivorous fish populations. The reduction of these predators decreases predation on zooplankton, thereby promoting the proliferation of Copepods. This dominance reflects relatively stable trophic conditions but could also indicate an ecological imbalance related to fisheries exploitation.

In Monastery Lake, taxonomic richness was higher during the rainy season (60 taxa) than during the dry season (54 taxa). The significant concentration of zooplankton observed during the rainy season in this study could be attributed to increased availability of food resources and the migration of new species. Variations in flow can indirectly cause variations in zooplankton populations; indeed, an increase in flow leads to greater food availability for local communities [28]. The transport and flooding of zooplankton egg banks during flow events can largely explain the increases in zooplankton density during the rainy season [29]. This accounts for the presence of species such as Cephalodella llagibba, Lecane curvicornis, Trichocerca biden, and Cephalodella tantilloides, which were only observed during the rainy season.

Among Copepods, copepod nauplii were the most abundant in both the dry and rainy seasons (64% in the dry season versus 62% in the rainy season). These copepod nauplii are frequently used as food for many fish species and are often employed as live prey in aquaculture as a replacement for Artemia salina and rotifers of the genus Brachionus [30]. Indeed, copepod nauplii possess biochemical and physical properties that make them an excellent substitute and/or nutritional supplement for fish larvae [31]. Due to the abundant presence of copepod nauplii in both dry and rainy seasons, this lake provides a permanent food source for organisms at higher trophic levels, such as fish. It serves as a privileged feeding and nursery ground for many fish species, which explains the significant fishing activity in the area. Under these circumstances, this study could serve as an important decision-making tool for the protection of this environment.

5. Conclusion

This study provides the first information on the seasonal variation of zooplankton in Monastery Lake. Regarding the measured physicochemical parameters, temperature, pH, and transparency values were higher during the dry season, while dissolved oxygen and depth values were higher during the rainy season.

Concerning the zooplankton organisms in this lake, 71 taxa were recorded, comprising 43 rotifers, 19 cladocerans, 4 copepods, and 5 other organisms, distributed across 21 families. This community is characterized by the consistent qualitative dominance of Rotifers and quantitative dominance of Copepods across all seasons.

The distribution of zooplankton organisms showed negative correlations with parameters such as temperature, pH, and transparency, while being positively correlated with depth and oxygen. Species such as Cephalodella gibba, Lecane curvicornis, Trichocerca biden, and Cephalodella tantilloides were exclusively present during the rainy season, unlike copepod nauplii, which were highly abundant throughout all seasons.

Given the high richness and abundance of zooplankton in this lake, an assessment of the impact of zooplankton availability on the structure of higher trophic level organisms, through trophic relationships between compartments, would provide a better understanding of their effects on the lake's food web. The establishment of a water protection program for this lake is therefore urgently needed.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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