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Diversity of Zooplanktonic Crustaceans in a Soudano Guinean Crater Lake: Tison Lake (Adamawa, Cameroon)

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Abstract

This study investigated the diversity of zooplanktonic microcrustaceans in Lake Tison, a crater lake located in the High Guinean Savannah of Cameroon. Sampling was conducted on a fortnightly basis from November 2018 to January 2020. Physicochemical parameters were measured vertically at the center of the lake, from −0.5 m to −20 m. Organisms were collected from both the shoreline and the water column. During the dry season, the euphotic layer measured 7.07 ± 0.45 m, with cooler (23.46˚C ± 1.03˚C), more mineralized (880.13 ± 22.12 µS/cm), and well-oxygenated (7.34 ± 0.31 mg/L) water. In contrast, the metalimnetic waters were colder (20.05˚C ± 0.5˚C), less oxygenated (5.25 ± 1.26 mg/L), and highly mineralized (962.33 ± 22.5 µS/cm). A total of 15 species were identified, including a newly recorded species, *Camptocantus* sp. The littoral zone exhibited the highest species richness (15 species), with *Coronatella hardingi* being the dominant species (94 ind/L) during the dry season. In the water column, species richness was lower (4 species), with *Mesocyclops leuckarti* being the most abundant (12 ind/L) at a depth of −10 m during the dry season. Canonical Correspondence Analysis (CCA) distinguished periphytic from pelagic organisms, with their distribution influenced by factors such as temperature, salinity, conductivity, pH, and dissolved oxygen. These findings enhance our understanding of the diversity and dynamics of zooplanktonic microcrustaceans in crater lakes.

Subject Areas

Hydrobiology and Environment

Keywords

Cladocera, Copepods, Dynamics, Crater Lake, Sudano-Guinean Region

1. Introduction

Crater lakes of Cameroon are known for their small size, low nutrient content and low zooplankton species richness. The temperatures of these lakes lead to a small annual range of surface water temperatures, reducing deep convective mixing of the water column. Weak mixing aids the establishment of meromixis, a requisite condition for the gradual buildup of CO_2 in bottom waters [1]. These lakes provide a unique setting for studying zooplankton populations, particularly Cladocera's and Copepods. These aquatic organisms play a crucial role in food webs, acting as primary consumers of phytoplankton and serving as prey for fish larvae and benthic macroinvertebrates [2]-[4]. This action allows them to be intermediaries that connect primary producers to higher trophic levels. Also, by consuming phytoplankton and excreting waste, zooplankton microcrustaceans contribute to the reinjection of nutrients into the environment and therefore promote the carbon cycle for the health of lake ecosystems [5]-[7]. Additionally, they serve as bioindicators, signaling ecological changes within aquatic ecosystems [8] [9]. Indeed, the diversity and abundance of zooplankton crustaceans testify not only to the ecological health of aquatic ecosystems, but also to the effects of seasonality and climate change and anthropogenic activities on their habitat [10].

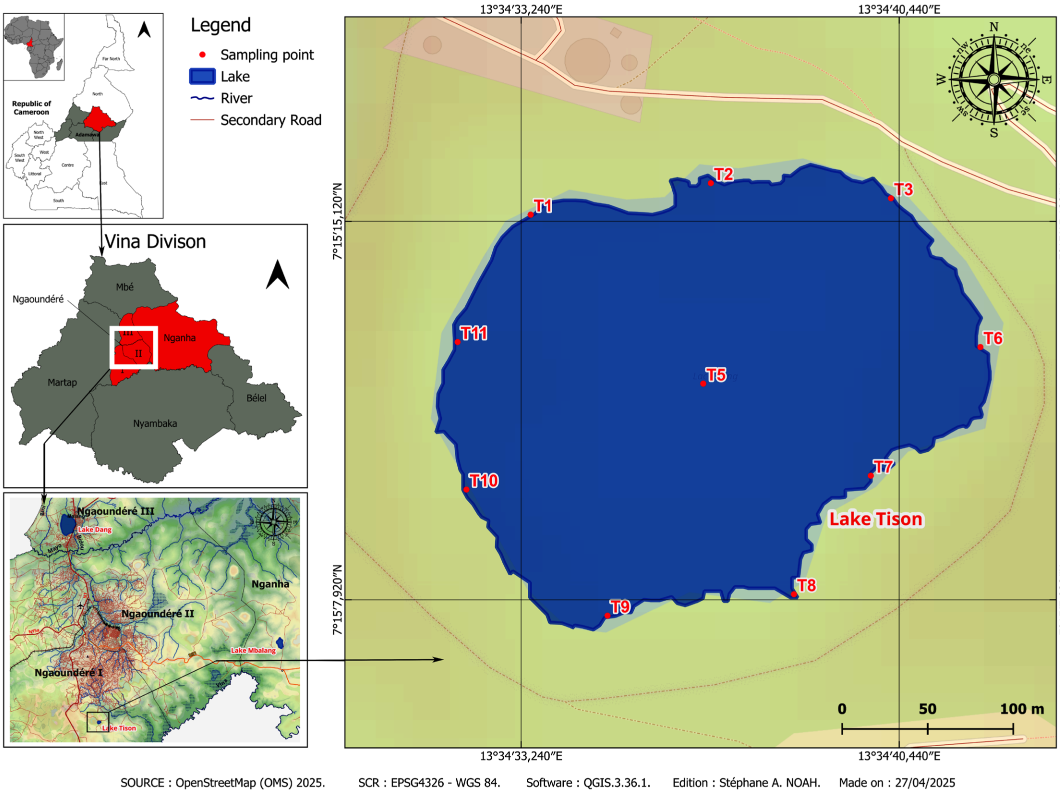
Beside Green (1995) [11] and Green and Kling (1988) [12] works on planktonic populations in high altitude, previous studies on the population dynamics of Cladocerans and Copepods in Cameroon have primarily focused on low-altitude lentic and lotic environments [4] [13]-[18]. Only the works of [4] [14] [18] and [3] specifically examined the horizontal and vertical dynamics of these organisms in both natural (Ossa and Mwèmbè) and artificial (Yaoundé Municipal Lake) dam lakes. However, the influence of depth on zooplanktonic microcrustacean populations in these long-isolated ecosystems remains largely unexplored.

This study aims to bridge that gap by examining the relationships between environmental conditions and zooplanktonic crustacean communities, with a focus on the unique ecological characteristics of a crater lake. Specifically, we hypothesisze that, the physico-chemical parameters of the lake will increase from the surface water towards the bottom; the microcrustacean population will be more structured at the shoreline than the water colon, and the will be high rate of interactions between these microcrustaceans and physico-chemical parameters at the lake banks.

2. Materials and Methods

2.1. Study Area

Lake Tison is a crater lake located on the Adamawa Plateau in Cameroon, situated at 7˚15'N, 13˚35'E, and at an altitude of 1154 meters (**Figure 1(a)**). The lake's climate is classified as humid tropical or Sudanian with a Sudano-Guinean influence, characterized by two distinct seasons [19]. The rainy season, extending from March to October, is marked by high rainfall (approximately 1500 mm) and cooler average temperatures of 25˚C. Conversely, the dry season, lasting from November to February, is characterized by warmer temperatures reaching 28˚C [20]. Lake Tison is formed within a crater resulting from post-cretaceous volcanism [21]. The lake covers an area of approximately 8 hectares and has a maximum depth of 48 meters [22] (**Figure 1(b)**).



(a)

(b)

Figure 1. Study site map showing Lake Tison. (a) Location of Lake Tison; (b) Overview of Lake Tison.

2.2. Sampling

Sampling was conducted every fortnightly from November 2018 to January 2020. Secchi disk readings were used to assess water transparency. A Palinset multiparameter device was employed to measure water temperature, pH, salinity, and conductivity *in situ* at one-meter depth increments, from the surface (−0.5 m) to the lake bottom. Dissolved oxygen was measured using a HACH HQ11d oximeter. Zooplanktonic microcrustaceans were sampled from both the aquatic vegetation (herbarium) and the water column. Herbarium samples were collected by filtering 90 liters of water through a 64 μm mesh size plankton net. Water column samples were collected at depths of −0.5 m, −5 m, −10 m, −15 m, and −20 m using a 6 L Van Dorn bottle, and then 90 L was filtered through the same plankton net. All filtered samples were immediately fixed in 5% formaldehyde and stored in cool conditions.

2.3. Euphotic Layer Thickness

The depth of the euphotic zone, the region where photosynthesis occurs, was determined using the following formula:

$$E_{zs} = E_0 e^{-Kz} \tag{1}$$

where:

- E_{zs} = Irradiance at the Secchi disk disappearance depth.
- E_0 = Incident surface irradiance (assuming 100% albedo).
- K = Vertical light extinction coefficient.

Z_s = Depth of the euphotic zone (equivalent to the Secchi disk disappearance depth).

2.4. Identification and Counting

In the laboratory, microcrustaceans were identified down to the species level under, when possible, under a OPTIKA microscope using relevant taxonomic keys and guides of [14] [23]-[31] and they were enumerated under a stereoscopic microscope WILD M5. Counting was carried out until all samples were exhausted.

2.5. Diversity Index

Shannon-Weaver Diversity index (H'), Simpson's diversity index (D), and Pielou's evenness index (J) were calculated to assess zooplankton community structure. Shannon-Weaver Diversity Index (H') sensitive to rare species, measures community diversity and stability [32]. It was calculated as using the following formula:

$$H' = -\sum_{i=1}^{S} \left(p_i \log_2 p_i \right) \tag{2}$$

where:

- H' = Shannon-Weaver diversity index (bits/individual).
- p_i = Proportion of individuals belonging to species i.
- S = Total number of species or taxa.

Simpson's Diversity Index (D) quantifies the probability that two randomly selected individuals belong to the same species [33]. It was used to express dominance (values approaching 0) or codominance (values approaching 1). It was calculated as:

$$D = {}^{1}\!/_{H'} \tag{3}$$

where:

- D = Simpson's diversity index.
- H' = *Shannon-Weaver diversity index.*

Pielou's Evenness Index (J) measures the evenness of species distribution. It was calculated as:

$$J = H'/\log_2 S \tag{4}$$

where:

- J = Pielou's evenness index.
- H' = Shannon-Weaver diversity index.
- S = Total number of species.

These indices were calculated using Microsoft Excel 2016.

2.6. Data Analysis

The Mann-Whitney U test was used to assess significant differences in physicochemical parameters between seasons and sampling depths. Canonical Correspondence Analysis (CCA) was employed to explore relationships among environmental variables and zooplankton community composition, identifying groups of correlated variables [34]. Graphs were generated using GraphPad Prism 8, and statistical analyses were performed using R version 3.2.

3. Results

3.1. Physicochemistry

The physicochemistry results recorded in Lake Tison evolved in much the same direction as those recorded by Kling *et al.* (2015) in the same water body. The thickness of the euphotic layer averaged 7.07 ± 0.45 m in the dry season and 6.41 ± 0.08 m in the rainy season (**Figure 2**).

The vertical profile of the measured physicochemical parameters is recorded in **Figure 3**. On the surface, a maximum value was recorded during the dry season (24.8˚C) and a minimum value recorded during the rainy season (22.6˚C). At a depth of −20 m, an average of 19.125˚C ± 0.1˚C was recorded. The beginning of a thermocline can be observed from 8 m. At the surface, the suspended solids had a maximum value in the rainy season (7.14 mg/L) and a minimum value in the dry season (5 mg/L). At a depth of 20 m, an average value of 2.11 ± 0.38 mg/L has been recorded. Lake Tison is one of the most oxygenated in Cameroon's volcanic line. This parameter was present throughout the sampled column with a mean value of 8.08 ± 0.38 mg/L and a value of 3.58 ± 0.1 mg/L at a depth of 20 m. Lake Tison showed high conductivity values. At the surface, a maximum value was recorded in the dry season (857 µS/cm) and a minimum value in the rainy season (765 µS/cm). At a depth of 20 m, a value of 988.38 ± 0.92 µS/cm during the study period. Salinity was almost constant in the water body throughout the study period with an average value of 0.56 ± 0.026 ‰ in the dry season and an average value of 0.54 ± 0.03 ‰ in the rainy season (Figure 3).

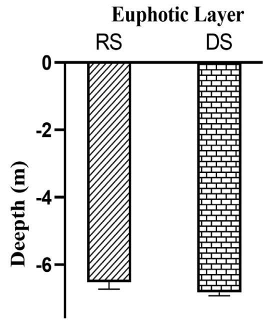


Figure 2. Seasonal variation of the euphotic layer thickness of Lake Tison (DS: Dry Season; RS: Rainy Season).

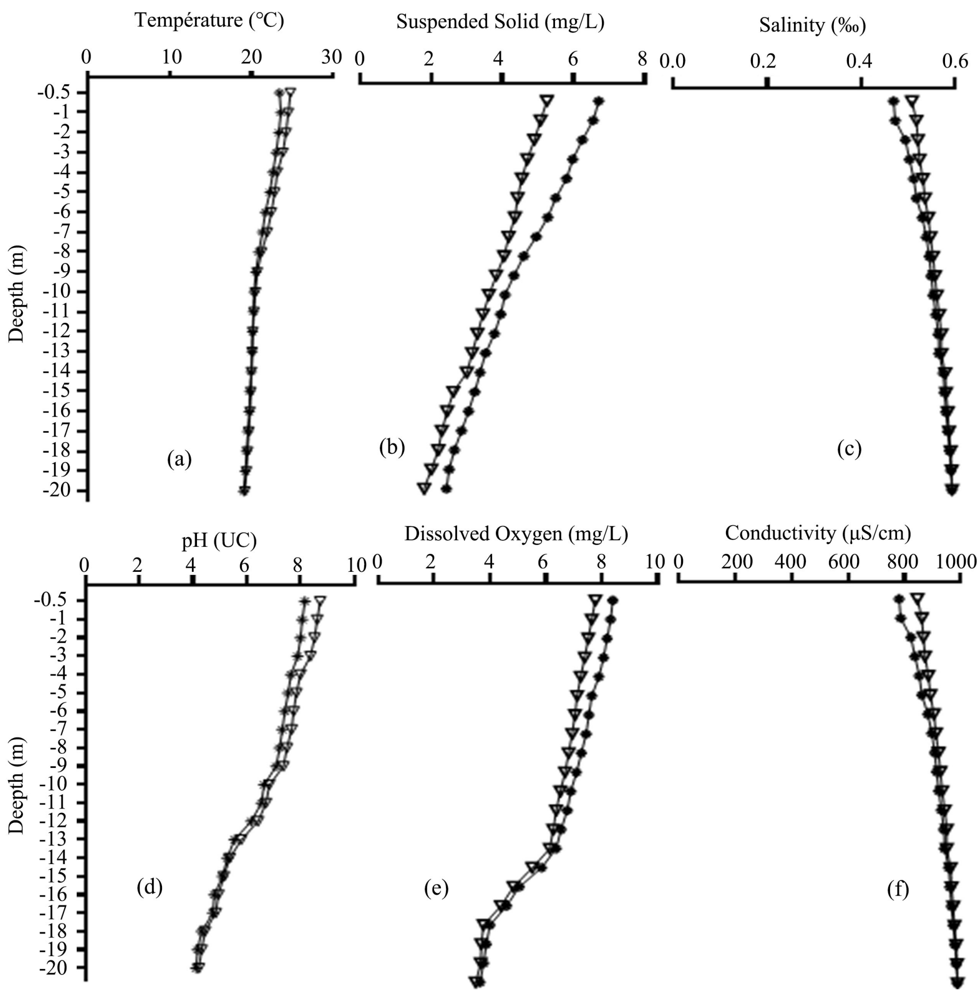


Figure 3. Vertical profiles of physicochemical parameters: Temperature (a), Total suspended solids (b), Salinity (c), pH (d), Dissolved oxygen (e) and Conductivity (f).

3.2. Species Richness

The microcrustaceans community of Lake Tison was represented by two groups in which the most abundant was the Cladocerans Sub Order (78%) and the less abundant was the Copepods Order (22%) (**Figure 4**) dry and rainy seasons (**Figure 4**). Five families where identified (Chydoridae, Daphniidae, Moinidae, Macrothricidae and Ilyocryptidae) belonging to the Sub Order of Cladocerans. The family Chydoridae dominated the microcrustaceans community counting 86% of the total Cladocerans abundance and 66.6% of the total microcrustaceans abundance. This was followed by the family Daphniidae 6% of the total Cladocerans abundance and 4.7% of the total microcrusta-ceans abundance. The Order of Copepods was made by two families (Cyclopidae and Canthocamptidae).

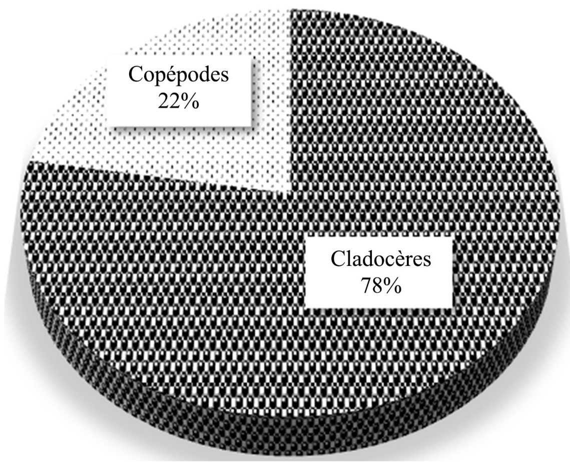


Figure 4. Zooplanktonic microcrustacean species richness in Lake Tison.

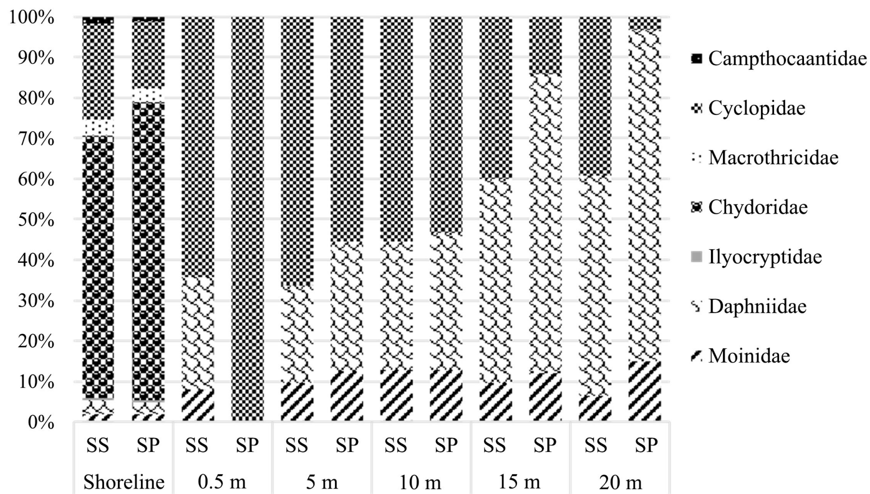


Figure 5. Relative abundance of Cladocerans and Copepods taxa in Lake Tison.

This Order was dominated by the Cyclopidae family counting 94% of the total Copepods abundance and 21% of the total microcrus-taceans abundance as shown on **Figure 5**. During the study, the most diversified sampling point was the shoreline, in which five families where identified. Here, the family Chydoridae was the most abundant during the dry season (64.93%) followed by the Cyclopidae family (23.86%) and Macrothricidae family (3.87%) (**Figure 5**).

A total of fifteen (15) microcrustacean species were identified into three orders and seven families in Lake Tison. Twelve species of these were Cladocerans, represented by five families (Daphniidae, Moinidae, Macrothricidae, Ilyocryptidae, and Chydoridae) belonging to the order Anomopoda. Three species of Copepods, belonging to two families Cyclopidae and Harpacticoidae of the orders Cyclopoida and Harpacticoida respectively, were identified (**Table 1**).

The total zooplankton density in Lake Tison was 615 ind/L. Horizontally, the aquatic vegetation (shoreline) exhibited the highest density (524 ind/L), with a peak in the dry season (321 ind/L) where species such as *Coronatella hardingi* (94 ind/L) dominated the community, followed by *Ectocyclops rubescens* (43 ind/L) (**Table 2**), *Alona guttata* (42 ind/L) and *Mesocyclops leuckarti* (33 ind/L) in the dry season (**Table 2**). In the water column, the highest density (35 ind/L) was registered at 10 m depth and the species *Mesocyclops leuckarti* (12 ind/L) dominated the community during the dry season (**Table 2**). While, the lowest density was registered at 0.5 m depth (0 ind/L) in the rainy season throughout the study period (**Table 1** and **Table 2**).

Table 1. Cladocerans species density (ind/L) in Lake Tison.

Super Order: Cladocera				**Shoreline**		**Epilimnia**				**Mesolimnia**					
						−0.5 m		**−5 m**		**−10 m**		**−15 m**		**−20 m**	
Order	**Subfamily**	**Family**	**Species**	**DS**	**RS**	**DS**	**RS**	**DS**	**RS**	**DS**	**RS**	**DS**	**RS**	**DS**	**RS**
Anomopoda	Aradopoda	Daphniidae	*Simocephalus latirostris*	5	3	0	0	2	1	3	2	4	3	1	1
			Ceriodaphnia cornuta	7	3	1	0	3	1	4	3	5	5	1	1
		Moinidae	*Moinodaphnia macleayi*	6	4	0	0	2	1	3	2	2	1	0	1
	Radopoda	Ilyocriptidae	*llyocryptus spinifer*	1	1	0	0	0	0	0	0	0	0	0	0
		Chydoridae	*Chydorus eurynotus*	18	12	0	0	0	0	0	0	0	0	0	0
			C. cf. *sphaericus*	16	10	0	0	0	0	0	0	0	0	0	0
			Pseudochydorus. Bopingi	6	3	0	0	0	0	0	0	0	0	0	0
			Pleuroxus trigonelus	9	5	0	0	0	0	0	0	0	0	0	0
			Alona guttata	42	30	0	0	0	0	0	0	0	0	0	0
			Coronatella. Hardingi	94	70	0	0	0	0	0	0	0	0	0	0
			Oxyurella singalensis	24	19	0	0	0	0	0	0	0	0	0	0
		Macrothricidae	*Macrothrix laticornis*	12	7	0		0		0		0		0	
Total 1		**5**	**12**	**240**	**167**	**1**	**0**	**7**	**3**	**8**	**7**	**11**	**9**	**2**	**3**

Table 2. Copepods density (Ind/L) in Lake Tison.

Superclass: Copepods			Species	Shoreline		−0.5 m		−5 m		−10 m		−15 m		−20 m	
Super Order	**Order**	**Family**		DS	RS	DS	RS	DS	RS	DS	RS	DS	RS	DS	RS
Podoplea	Cyclopoida	Cyclopidae	*Ectocyclops rubescens*	43	19	0	0	0	0	0	0	0	0	0	0
			Mesocyclops leuckarti	33	14	0	0	5	4	12	8	8	2	1	0
	Harpacticoida	Canthocamptidae	*Canthoocamptus* sp.	5	2	0	0	0	0	0	0	0	0	0	0
Total 2	**2**	**2**	**3**	**81**	**36**	**0**	**0**	**5**	**4**	**12**	**8**	**8**	**2**	**1**	**0**
Total 1 + 2	**4**	**7**	**15**	**321**	**203**	**1**	**0**	**12**	**7**	**20**	**15**	**19**	**11**	**3**	**3**

Horizontally, the aquatic vegetation exhibited the highest species diversity (*H′* = 3.26 bits/ind) and evenness (*J* = 0.79 ± 0.03). Vertically, species diversity was generally lower, with the sampling depths (−0.5 m, −5 m, −10 m, −15 m, and −20 m) showing lower Shannon-Weaver index (*H′*) values (1, 2, 2, 1.77, and 1, respectively) and an evenness (*J* = 0.73 ± 0.27) of species distribution. The −0.5 m depth exhibited the lowest diversity, dominated by *M. leuckarti* (*H′* = 0.69 ± 0.7 bits/ind) (**Figure 6**).

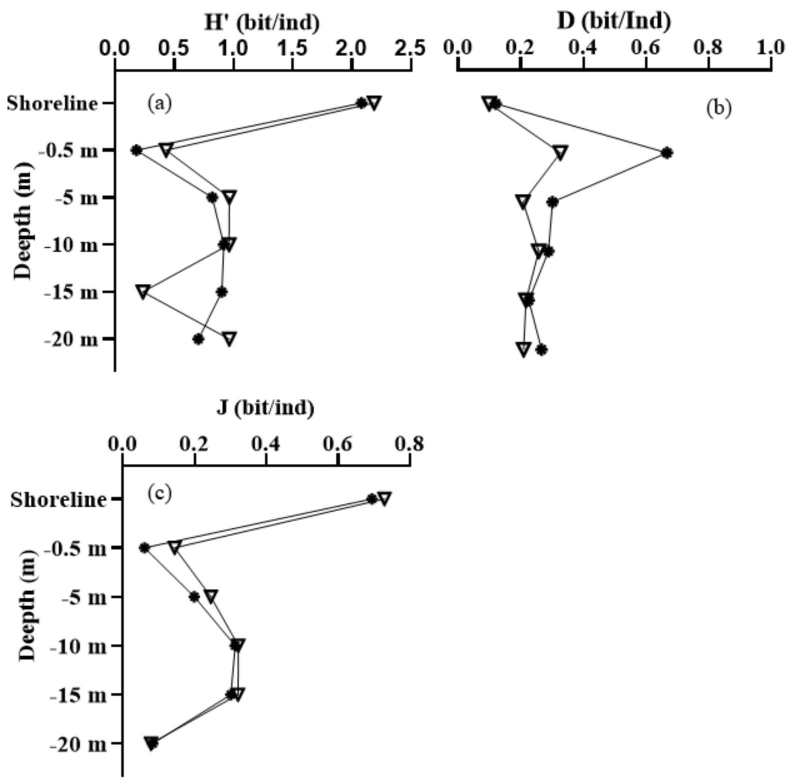


Figure 6. Spatial variation in microcrustacean community indices in Lake Tison. (a) Shannon & Weaver Index; (b) Simpson index and (c) Pielou's equitability index.

Following the Canonical Correspondence Analysis (CCA), the first two axes (74.7% of the cumulative variance) show a strong positive correlation between TSS and species such as: *Coronatella hardingi* (r = 0.27), *Alona guttata* (r = 0.26), *Pleuroxus trigonellus* (r = 0.21), *Ectocyclops rubescens* (r = 0.17) and *Ilyocryptus spinifer* (r = 0.15) on axis 2. Whereas on axe 1, we noticed a positive correlation between electrical conductivity and species such as: *Simocephalus latirostris* (r = 0.35), *Ceriodaphnia cornuta* (r = 0.28), *Moinodaphnia maclayi* (r = 0.21) and *Mesocyclops leuckarti* (r = 0.2). The CCA plot (Figure 7) showed two distinct groups of organisms. Group I, located on the positive side of axis 1, which represents the water column, characterized by pelagic species. These species prefer warmer waters, low oxygen concentration low total suspended solids (TSS) and pH contents. As for Group II organisms, located on the negative side of axis 1, prefers the littoral zone. Sampling points in this zone were characterized by warmer waters, rich in oxygen concentration, low turbidity, slightly basic with high electrical conductivity. These conditions favored the growth of periphytic and eurytopic species such as *Chydorus. eurynotus*, *Chydorus. cf. sphaericus*, *Pseudochydorus bopingi*, *Pleuroxus. trigonellus*, *Ilyocryptus spinifer*, *Alona. guttata*, *Coronatella hardingi*, *Macrothrix laticornis*, *Ectocyclops rubescens*, and *Canthocamptus* sp., *E. rubescens*, *C. hardingi C. eurynotus*, *M. laticornis*, *P. trigonellus. Alona guttata*, *O. singalensis*, *I. spinifer*, and *P. bopingi* which are highly tolerance to saline waters.

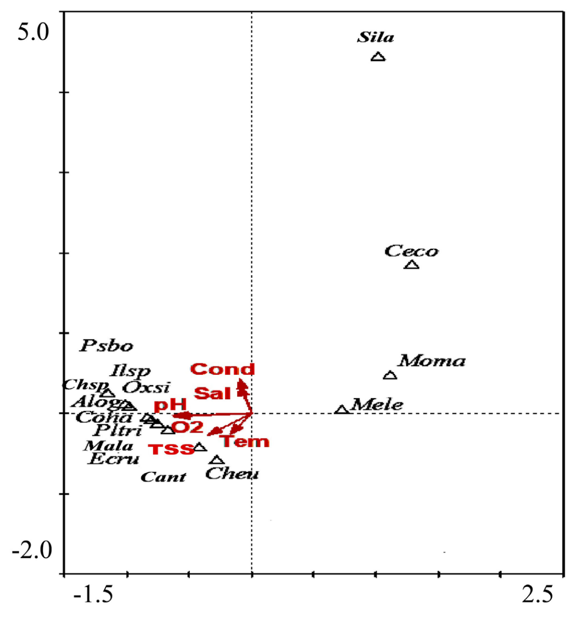


Figure 7. Canonical correspondence analysis of Lake Tison water samples (Tem: Temperature; Sal: Salinity; TSS: Total Suspended Solids; O_2: Dissolved Oxygen; pH Hydrogen potential; Cond: Conductivity; *Alog*: *Alona guttata*; *Cheu*: *Chydorus eurynotus*; *Coha*: *Coronatella ardingi*; *Psbo*: *Pseudochydorus bopingi*; *Moma*: *Moinodaphnia macleayi*; *Cant*: *Cantocamptus* sp.; *Mele*: *Mesocyclops leukarti*; *Ecru*: *Ectocyclops rubescens*; *Pltri*: *Pleuroxus trigonelus*; *Ceco*: *Ceriodaphnia cornuta*; *Sila*: *Simocephalus latirostris*; *Oxsi*: *Oxyurella singalesnsis*; *Ilsp*: *Ilyocryptus spinifer*; *Chsp*: *Chydorus cf. sphaericus and Mala*: *Macrothrix laticornis*.

4. Discussion

Comparative analysis with Kling *et al.* (2015) [35] revealed consistent transparency and euphotic zone depths in Lake Tison, indicating stable water clarity. In contrast, conductivity and salinity values were approximately three times higher than previously recorded by Kling *et al.* (2015) [35]. This elevation is attributed to the lake's extended water residence time, originating from its pre-holocene formation [21]. The long residence period, influenced solely by evaporation and lateral infiltration [36] [37], promotes rock hydrolysis, resulting in the depth-dependent accumulation of chloride ions [38], a process described as auto-mineralization. The presence of a thermocline at −8 m confirms thermal stratification, a common characteristic of tropical crater lakes within the Cameroon Volcanic Line [35]. Surface waters were more susceptible to seasonal variations, while deeper waters exhibited greater stability. Notably, Lake Tison's littoral zone displays greater species richness in Chydoridae (7 species) and Daphniidae (2 species) than several East African crater lakes [39]: Lake Elgon (4 species), Lake Aberdares (2 species) and Lake Bujuku (2 species) for Chydorids and for Daphniids, lakes Mahoma and Bujuku which each harbored only one species. Furthermore, Lake Tison harbors a more diverse Copepod population (2 Cyclopidae, 1 Haparticoidae) compared to Lake Wonchi (single species) as recorded by [1]. A new harpacticoid copepod, *Canthocamptus* sp. was recorded in Lake Tison. This species' presence could be linked to the lake's gradual increase in conductivity (917.88 ± 56.79 µS/cm) and salinity (0.55 ± 0.03 ‰) over time. Wells (2007) noted that species of the *Camptocamptus* genus are eurybiontic, meaning they can tolerate a broad range of environmental conditions such as salinity [40] and conductivity [41]. This discovery marks the first record of this genus not only in Cameroon but also in a crater lake, suggesting that *Canthocamptus* sp. could be endemic to Lake Tison.

The application of Canonical Correspondence Analysis (CCA) successfully delineated the zooplanktonic microcrustacean assemblages into littoral/periphytic and pelagic ecological groups with higher specific richness a (3.12 ± 0.12 bit/ind) and density (321 ind/L) at the herbarium during the dry season. A prominent feature of the dry season was the elevated specific richness, evidenced by both high species diversity (3.12 ± 0.12 bit/ind) and population density (321 ind/L) at the shoreline attributable to increased food resource availability during this season [42] [43].

Statistical analysis revealed significant seasonal variations in zooplanktonic microcrustacean densities at the lake's surface ($p = 0.000$, $\alpha = 0.05$), but not at depth ($p = 0.36$, $\alpha = 0.05$). This disparity suggests a gradient of environmental influence, with surface waters being more dynamically responsive to seasonal changes. Indeed, if temperature continues to rise, the grazing activities of the population located at the surface will slow down, their growth and their maturity size will be consequently reduced the reproductive success of the organisms. This will ultimately affect their generation time [44]. In the same time, changes that have a significant impact on the patterns that govern the stratification of the lake also influence the nutrient regime leading to an algal bloom in which cyanobacteria proliferate. These are very toxic to zooplanktonic microcrustaceans leading to the disappearance of certain species such as *S. latirostris*, which could be an alarm bell for disturbances that would arise [45] in lake Tison. Nevertheless, according to the depth, the non-volcanic nature of Lake Tison minimizes the potential for perturbations associated with volcanic gas emissions and underlying magmatic activity [46], explaining the stability of species located in the column.

5. Conclusion

The aim of this study was to assess the microcrustacean diversity and the contribution of the relationships between environmental conditions and zooplankton crustacean communities in Lake Tison. The results show that the thickness of the epilimnic layer of Lake Tison is greater in the dry season and characterized by waters that are less warm, low in suspended solids, basic and well oxygenated. The mesolimnia was less oxygenated and highly mineralized. The waters of Lake Tison are more stable at depth and have a thermocline from 8 m, a chemocline from 12 m, an oxycline from 15 m and a pycnocline from 17 m, proof of a stratification of Lake Tison. The diversity indices of Shannon and Weaver and of Simpson showed that the littoral zone is more diverse than the column with 15 species of zooplankton microcrustaceans (12 Cladocerans and 3 Copepods) with one newly recorded species (*Canthocamptus* sp.) The physicochemical parameters distribution reflecting paleogeological pollution. In view of the physicochemical dynamics observed in Lake Tison, it is important to carry out permanent monitoring in this water body to prevent a possible environmental disaster.

Conflicts of Interest

The authors declare no conflicts of interest.

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