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Current state of zooplankton diversity in the pelagic zone of Lake Tanganyika offshore of Bujumbura City

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Abstract
A study on the current state of zooplankton diversity in the pelagic zone of Lake Tanganyika along Bujumbura City was conducted from April to July 2020. The objective of the study was to assess zooplankton diversity for sustainable management of fishery resources and the conservation of this ecosystem. Two sampling sites were chosen. The first station was supposed to be polluted whereas the second one was considered as less polluted (or control). Zooplankton was collected with 50µm plankton net at different depths. The results obtained showed a total of 12 species identified in all the sampling stations among which, the copepods group was dominant while the rotifers group was found diversified with seven species (58.3%). The group of cladocerans represented by *Moina macrocopa* was identified for the first time in the pelagic zone. The calculation of the diversity index has reflected that the waters of Lake Tanganyika are classified into low level pollution category with a tolerable threshold. Therefore, the protection of Lake Tanganyika is necessary for sustainable fishery production and the future studies shall be carried out at several sites with annual sampling at a regular frequency to demonstrate the effect of seasons on the abundance of zooplankton communities.

Keywords: zooplankton, diversity index, Lake Tanganyika, freshwater

Introduction
Lake Tanganyika is located between Burundi, Democratic Republic of Congo, Tanzania, and Zambia. This lake is known for its high biodiversity and high fish production [1, 2, 3]. With more than 2000 species of aquatic flora and fauna, of which at least 700 are endemic [4], Lake Tanganyika is ranked among the richest freshwater ecosystems in the world [5].
The pelagic fauna of the Lake is mainly composed of commercial fish species, including six endemic species. These are two Clupeidae and four species belonging to the genus Lates [6] which occupy the pelagic zone where they feed on phytoplankton and zooplankton. Zooplankton, particularly copepods play a role in fisheries management and aquaculture [7]. It is an important food source for fish and plankton-like invertebrates [8, 9]. The zooplankton of freshwater ecosystems is composed mainly of protozoa, rotifers, cladocerans, copepods and ostracods [10].
Thus, the zooplankton found in Lake Tanganyika is dominated by three large groups, namely the rotifers and the two subclasses of crustaceans (cladocerans and copepods) of which only the copepods are truly pelagic. The only species representing the calanoids group in the pelagic zone is *Tropodiaptomus simplex* while the species *Mesocyclops aequatorialis* represents the Cyclopoid group [11]. The other species are rarely or occasionally found in the pelagic zone (Coulter, 1991) [6]. In the northern part of Lake Tanganyika, the zooplankton community is dominated by cyclopoids and jellyfish where increased stratification results in nutrient load decreasing. This process is favorable for smaller cyclopoid species. In the southern side, the amount of calanoids is greater than that one observed in the northern part due to higher concentration of diatoms which increases during ascent [11, 12].

Indeed, Lake Tanganyika ecosystem is threatened by several evils leading to degradation and loss of its biodiversity and biological richness [13, 14]. The increase of human population in the riparian countries in general and especially in Burundi exerts an increasing pressure on this resource capable of satisfying nutritional needs. The pollutants from the anthropogenic activities in Lake Tanganyika catchment have an impact on the development of zooplankton [15]. Zooplankton is considered to be very sensitive and very responsive to the variations of environmental conditions and climate change [16, 17]. Zooplankton species are also used as indicators of water pollution [18, 19, 20]. Certain species of zooplankton disappear in the presence of high concentration of pollutants and the disappearance of zooplankton leads to the destruction of the lake's aquatic ecosystem resulting in the extinction of certain species of carnivorous fish that feed on zooplankton [21].
The main objective of this study was to assess the current state of zooplankton diversity in the pelagic zone of Lake Tanganyika along Bujumbura City with a view to the sustainable management and conservation of this resource.

Material and Methods
Study Area and Sampling Stations
In the present study, two stations were selected. The first station with GPS coordinates (S:3 ° 28 ’, E: 29 ° 17’) is located at 13.5km from the shore of Lake Tanganyika, along Nyamugari beach, in the commune of Kabezi, Bujumbura Province. The second one with GPS coordinates (S:3 ° 22 ’, E:29 ° 19’) is located at 3.5 km

from the shore of Lake Tanganyika nearby REGIDESO water catchment point and off the port of Bujumbura. The two stations have different characteristics (Figure 1). The one along Nyamugari beach was taken in the pelagic zone and served as control station since it is less impacted by anthropogenic activities. The other one located very close to the water catchment area, north of the lake, was subject to be threatened by human activities as it is receiving regularly the waters from both Mutimbuzi and Kinyankonge Rivers which are tributaries of Lake Tanganyika carrying the alkaline soils from the plain. Kinyankonge River is an outlet for Buterere wastewaters treatment plant. This second site is also affected by the Ntahangwa River and to some extent by Rusizi River.

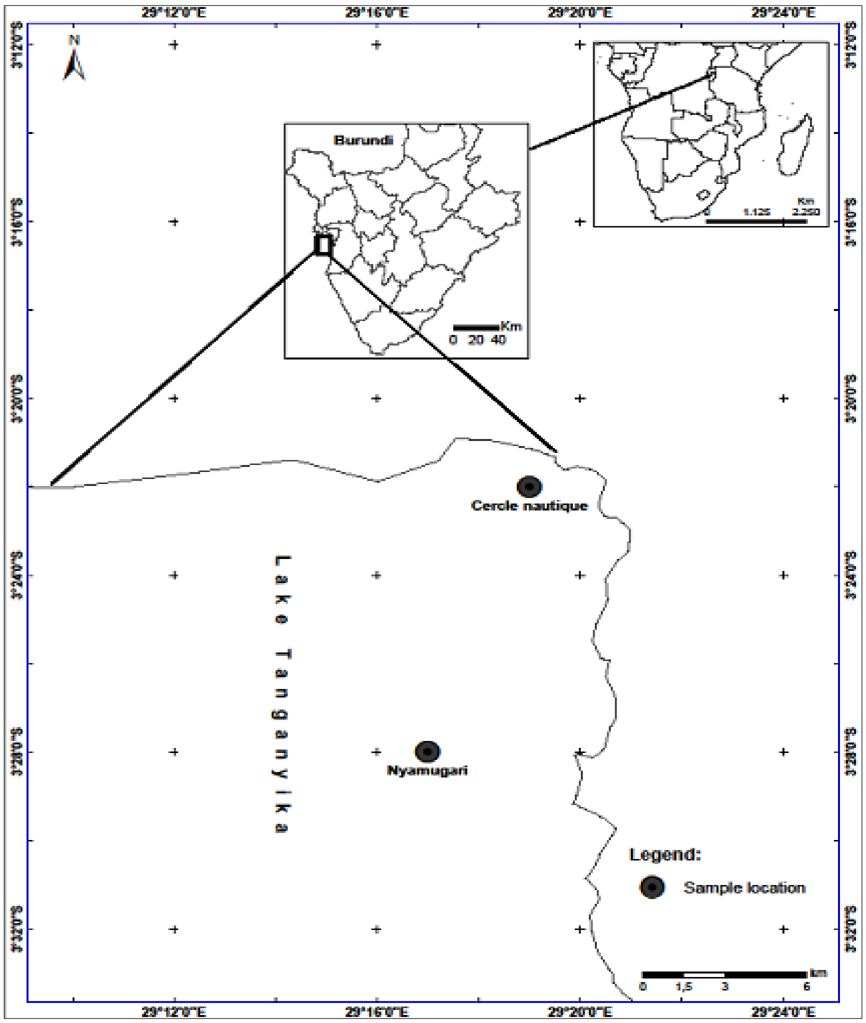

Fig 1: Geographical location of the study area and sampling stations

Sampling

The samples for zooplankton study were collected during four months from April to July 2020. This period covers part of the rainy season (April to May) and the dry season (June to July). Zooplankton was collected using plankton net of 50 µm-mesh size and 26cm in diameter. According to the methodology of Kurki [11], samples were taken vertically over the entire water column at different depths and for better diving of the net to a desired depth, a weight of known mass is attached to the plankton net. The zooplankton organisms took about 3minutes to be accumulated in the net, then the net is raised up to the surface and the drain pipe is opened and let the contents of the container flow into the flask. Before proceeding to the next sampling, the net was rinsed with distilled water. The samples were preserved by adding 5ml of 4% formalin solution and the operation was repeated until the desired number of samples is reached.

Analysis of Zooplankton Samples

The zooplanktonic species of Rotifers, Cladocerans and Copepods were identified under a binocular magnifier brand WF 10X-18MM. The species identification was based on the specific morphological characters observable using different determination keys [22, 23, 24, 25, 26, 27].

Individuals of each identified species were also counted, the counting effort being set at 400 individuals. Thus, the counting rate varied according to the abundance of the species until the sample was exhausted. The zooplankton density (number of individuals / liter) was obtained by dividing the number of taxa obtained in the volume of water analyzed by the volume swept by the plankton net in the water column of the lake according to the following relationship [28]:

$$D = (n * 1000) / V$$

Where D: the density (expressed in individuals per liter),
n: the number of individuals found in the volume of water analyzed under the microscope,
V: the volume of water swept (in ml).The obtained results were used to calculate the various indices which are helpful in characterization of the composition and evolution of zooplankton.
The Shannon-Weaver diversity index accounts for the diversity of the species that make up the stands in an environment. It establishes the link between the number of species and the number of individuals in the same ecosystem or in the same community. It was calculated using the following formula:

$$H' = -\Sigma [(ni / N) * \log_2 (ni / N)]$$

Where H: 'represents the specific diversity,
Σ: the sum of the results obtained for each of the represented species,
ni: the number of individuals recorded for species i,
N: the total number of individuals considering all the species and
Log 2: the logarithm to base 2.
Specific richness is the total number of species in a sample.
Simpson's index (d) is used to estimate the biodiversity β of a community. It is calculated according to the formula:

$$d= 1- \Sigma [(ni \times (ni-1))/ (N \times (N-1))]$$

Where ni: represents the number of individuals recorded for species i, Σ: the sum of the results obtained for each of the species present and
N: the number of individuals in the sample.
The closer its value is to 100%, the closer the environments are from the point of view of faunistic composition. *The Piélou index J* is used to measure the equitability (or even distribution) of the species in the stand in relation to an equal theoretical distribution for all the species. It is obtained by the formula:

$$J = H' / \log_2 S$$

Where H': is the Shannon-Weaver index,
$\log_2$: is the logarithm to base 2 and
S: is the number of species present.
The J index varies from 0 (dominance of a single species) to 1 (even distribution of individuals in the stands).

Statistical Analysis
One-way analysis of variance (ANOVA-1) pairwise Tukey comparison was used to compare the means of the different depths at each sampling site. The test was performed using the Past software. In order to establish the influence of depth on the distribution of zooplankton species in the sampled sites and to better account for their distribution in the lake, a Principal Component Analysis (PCA) was applied to all of the biotic parameters. This analysis was performed with Canoco software. 5.

Results

Species Composition of Zooplankton at Site I at Different deptHs

Twelve (12) zooplankton species including 4 copepods, 7 rotifers and one Cladoceran species were identified at the first sampling site. The twelve species belong to 7 families of which the family of Brachionidae was most represented with 4 species. Nauplii and shrimp larvae are considered as copepods when considering their forms.
The copepod group is the most abundant (89.326 individuals /m^3) and decreases with the depth increasing. The maximum is observed at the surface of the water while the minimum is observed at a depth of 50m (it supposes an average of 437 individuals /m^3).
For all these species, the highest abundance is recorded at the surface except for the Cladocerans whose highest abundance was noted at a depth of 25m (Table 1).

Table 1: Abundances, means and standard deviations of zooplankton species recorded by depth of site I from April to July 2020

Groups	Families	Species	0m	25m	50m	Means and SD	Significant (p<0.05)
Copepods	Diaptomidae	*Tropodi. Simplex*	28229	13796	604	14209.6±13817.1	NS
	Cyclopidae	*Mesocy. Leuckarti*	10778	1190	539	4169.0±5732.8	NS
	Palaemonidae	*larv. Crevette*	0	1	1	0.67±0.57	S
	Cyclopidae	*Nauplii*	32376	1208	604	11396.0±18171.7	S
Cladocerans	Moinidae	*Moina macroco.*	0	596	285	293.6±298.1	NS
Rotifers	Branchionidae	*B.patulus*	10929	399	275	3867.6±6115.6	NS
	Branchionidae	*K. tropica*	1205	63	68	445.3±657.8	NS
	Branchionidae	*K. quadrata*	226	98	55	126.3±88.9	NS
	Branchionidae	*K. cochlearis*	0	5	6	3.6±3.2	NS
	Notomatidae	*Cepha. Gibba*	452	2	59	171.0±245	NS
	Lecanidae	*L. leontina*	0	0	24	8.0±13.8	NS
	Notommatidae	*Mono. macula.*	0	0	21	7.0±12.1	NS

NS: not significant, S: significant

Species Composition of Zooplankton at Site II at Different Depths

Eleven (11) zooplankton species were identified. The same specific composition was observed as for site I except for the species *Keratella cochlearis* which was not observed at this site. The group of rotifers is still the most diverse with 6 species (*B. patulus, Keratella tropica, Keratella quadrata, Cephalodella gibba, Lecane leontina and Monommata maculata*). As at site I, copepods remain the most abundant with a density of 30.261 individuals / m^3. The Cladoceran group is the least diverse with a single species *Moina macrocopa* with an abundance of 1828 individuals / m^3. For this site, it is present at all depths (Table 2).

Table 2: Abundances, means and standard deviations of zooplankton species recorded by depth of site II near the REGIDESO catchment area from May to July 2020

Groups	Families	Species	0m	25m	35m	Means and SD	Significant (p<0.05)
Copepods	Diaptomidae	*Tropodi. Simplex*	5804	726	617	2382.3±2963.7	NS
	Cyclopidae	*Mesocy. Leuckarti*	4862	823	547	2077.3±2415.5	NS
	Palaemonidae	*larv. Crevette*	0	115	100	71.6±62.5	NS
	Cyclopidae	*Nauplii*	15076	910	681	5555.6±8245.6	NS
Cladocerans	Moinidae	*Moina macroco.*	1131	389	308	609.3±453.5	NS
Rotifers	Branchionidae	*B patulus*	1696	165	39	633.3±922.4	NS
	Branchionidae	*K. tropica*	1093	162	56	437.0±570.5	NS
	Branchionidae	*K. quadrata*	75	28	35	46.0±25.3	NS
	Notommatidae	*Cepha. Gibba*	0	26	21	15.6±13.7	NS
	Lecanidae	*L. leontina*	0	2	5	2.3±2.5	NS
	Notommatidae	*Mono. macula.*	0	17	5	7.3±8.7	NS

NS: not significant

Species Richness of Zooplankton in the Two Sampled Sites

At both sites, copepods were the most abundant and varied significantly ($p < 0.05$). They were represented at 85.6% followed by rotifers with 12.4% while the Cladocerans only represent 1.9%. The maximum value observed for the first two groups was recorded at the surface and decreases with depth increasing. The group of Cladocerans is rarely represented (Figure 2).

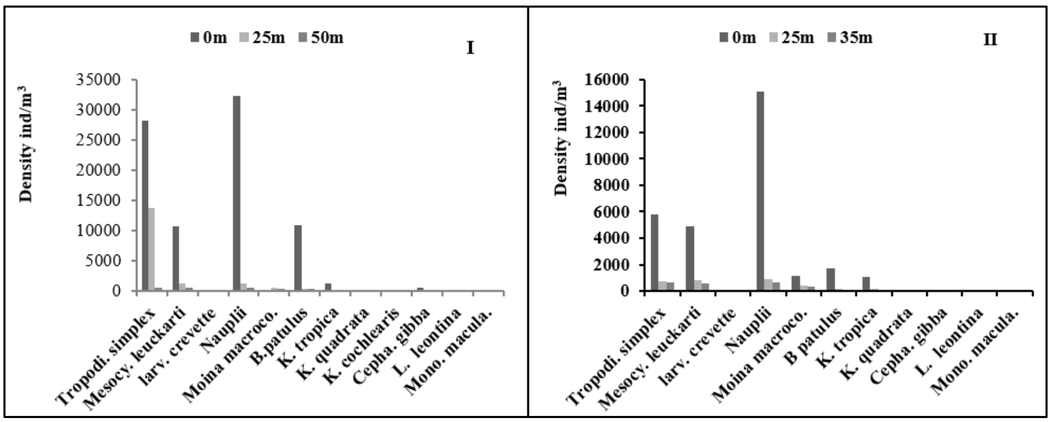

Fig 2: Variation of zooplankton species at the two sites

Distribution of Zooplankton Species According to Depth

A Principal component analysis (PCA) was applied to all biotic parameters to show how zooplankton species are grouped according to depth. The first two axes with 84.12% and 10.52% respectively explain the total dispersion of zooplankton species in relation to the different depths. They provide sufficient information on the total variance of zooplankton species. The two axes showed the species correlated positively with the depth of 0m containing surface water, and the species correlated with the depth of 50m (Figure 3).

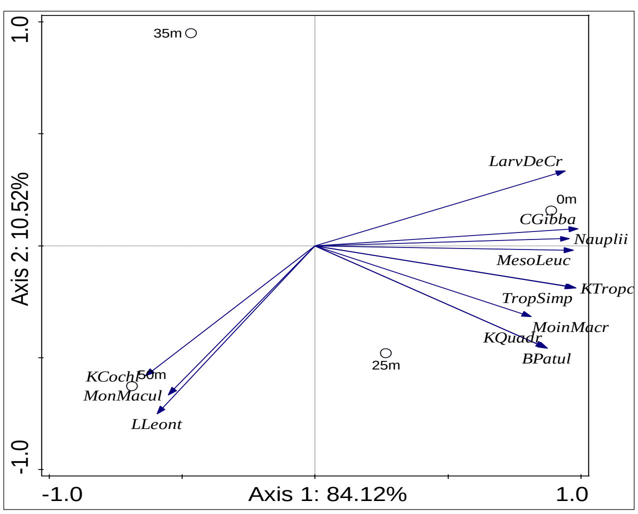

Fig 3: Principal Component Analysis (PCA) of zooplankton species

Shannon, Piélou and Simpson Diversity Indices

The three indices varied both with depth and time. For both sites, the highest Shannon and Sorensen index values (2.37; 4.85) respectively were found at a depth of 50m. The lowest values (1.41; 2.11) were found at the surface except the Shannon showing a value of 1.99 on site II. The dates of May 26 and June 16 were characterized by the high values (2.84; 0.82; 6.06) of the calculated indices. The date of April 23 shows that there was no fishing at site II in view of the values (0.00) of the three indices mentioned (Table 3).

Table 3: The variation as a function of depth and over time of the Shannon, Piélou and Simpson indices is presented.

Sites	Indices	23 of april	26 of may	16 of june	21of july	Sites	Indices	0m	25m	50 (35)m
Site I	H'	1.95	2.26	2.28	1.77	Site I	H'	1.41	2.21	2.37
	J	0.71	0.81	0.72	0.60		J	0.53	0.81	0.72
	d	3.70	4.29	4.75	3.09		d	2.11	4.36	4.85
Site II	H'	0.00	2.84	1.78	1.87	Site II	H'	1.99	1.96	2.29
	J	0.00	0.82	0.57	0.65		J	0.71	0.61	0.70
	d	0.00	6.06	3.09	3.32		d	3.05	3.90	4.43

Discussion

The zooplankton identified during this study was composed of Copepods, Cladocerans and rotifers. These results are dissimilar to those found by authors [6] [29] [30] who found that the zooplankton community of Lake Tanganyika is dominated mainly by copepods. This is due to the fact that the first two authors had used the 100µm wide mesh nets. This mesh allows rotifers to escape due to their small size. Thus, the study revealed that this zooplankton groups held second copepods group.

The dominance of Copepods is due to several characteristics related to the organisms themselves. The first is their ability to accept very variable environmental conditions [31] [32]. The second is their resistance to more or less rapid fluctuations in the physical, chemical or biological characteristics of the environment [33]. Finally, the possibility of surviving the diapause state allows some species of this group to be transported from one environment to another and have a wider range [34]. The study found that the Diaptomidae family is the most common at both sites and in all depths. Our results are corroborated by those found in freshwater by other authors [35] [36]. Zooplankton species have been found in all depths, this is due to the fact that zooplankton in general and copepods in particular perform migratory movements to flee predators. Similar results were found [37]. On the other hand, the Cladoceran group was poorly represented. Its absence in abundance in the pelagic zone could be explained by several reasons, including strong predation by clupeids [38] or its absence at the time of sampling. The only species identified at the pelagic level would probably come from the coast. Similar results were found in the area near the shore of Lake Tanganyika [11]. The presence of Cladocerans is thought to be due to the rise in the lake's water level, which would have caused shoreline material to stir up to other parts of the lake, thus recruiting new species in the pelagic environment. The thick-shelled eggs of Cladocerans hatch late when conditions become favorable again, particularly the presence of nutrients [39] [40]. The production of phytoplankton and, consequently, that of zooplankton are thus favored. The latter would have been a favorable environment in the pelagic zone to hatch thus contributing to their presence. Similar results were found on the lakes of the Ossa complex in Cameroon which stated that the flooding contributes to the contribution of new species of riverine Cladocerans or recruited from other bodies of water [41]. The study found that the surface layer is the most populated and decreases with depth. This could be explained by predation of some fish species like *Limnothrissa miodon* as confirmed by others researchers [42].

There is a preponderance of copepods. This distribution never exceeds the dissolved oxygen limit. In this area, photosynthesis takes place which provides favorable conditions for the life of zooplankton. Hence dissolved oxygen is more concentrated there than in other layers [43].

Zooplankton Diversity

The distribution of various zooplankton organisms depends on environmental factors, food availability and predation on them [44]. The variation of Shannon and Piélou indices during the study period reveals a great instability in the structure of the zooplankton community. This is explained by the variation in environmental conditions prevailing during the study period. This instability can also be justified by the preponderance of accidental or rare species [39]. The calculated index values (Table 3 below) show that the deep waters are more diversified. This implies the presence of many species which perform vertical migrations to flee from predators. The Shannon Diversity Index can also be used to assess the pollution of lake water. Some researchers stress the importance of diversity indices for assessing water quality [45]. They use both the Shannon and the Simpson index according to the following classification rule:

H '> 3 (or d> 6) indicates clean water; 3> H '> 2 (or 6 ≥ d ≥ 3) indicates low contamination; 2> H '> 1 (or 3 ≥ d ≥ 2) indicates moderate contamination and 1> H'> 0 (or d <2) indicates heavily polluted water. By analyzing the results found during this study, the average value of Shannon index was between 2 and 3 whereas Simpson index was ranging between 3 and 6. According to this classification [45], our results show that the water of the pelagic zone of Lake Tanganyika is classified among low contaminated waters category with a tolerable contamination level. This water is propitious to the development and diversity of zooplankton. These statements are similar to those of Matta *et al.* [46] and dissimilar to those of Simboura and Zenetos [47]. The last two authors state that a Shannon index between 1.5 and 3 shows that the water is heavily polluted. The classification of Lake Tanganyika in the category of weakly polluted lakes confirms the assertion of Bailey [48]. He had suggested that the pollution was not degrading the quality of the water, its level was still low. The pollutants got diluted immediately while they are entering the lake.

Conclusion

The study on the current state of zooplankton diversity in the pelagic zone of Lake Tanganyika along Bujumbura City revealed that zooplankton population is mainly formed by copepods, rotifers and Cladoceran. Its distribution varies with depth variation in the photic zone depending on environmental conditions. The results of the present study have reflected that the water of the pelagic environment of Lake Tanganyika is classified among the waters of low pollution level with a tolerable level. Hence, the protection of this natural ecosystem is essential for a sustainable management of fishery resources.

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