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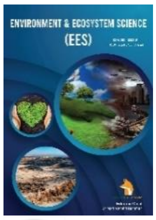

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RESEARCH ARTICLE

DIVERSITY OF ZOOPLANKTON COMMUNITIES AND ENVIRONMENTALS CONDITIONS OF THE MUNICIPAL LAKE OF MFOU (CAMEROON-CENTRAL AFRICA)

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ABSTRACT

Zooplankton biodiversity and water quality of the Mfou municipal lake was carried out from April to September 2014, following a monthly sampling frequency. Sampling for physicochemical analyses was carried out by direct sampling at the surface and along the water column using a 6L Van Dorn bottle. Zooplanktons were collected by filtering 100 L of water taken from the seagrass beds of the municipal lake, through a 64 µm mesh sieve. The 100 ml retentate collected was fixed with 10 ml of Formalin 5% and used for identification and counting. Physicochemical analyses revealed that the water of the Mfou municipal lake was relatively hot (25.5 ± 1.31°C), slightly acidic (6.95 ± 0.41 CU), moderately oxygenated (52.72 ± 12.27%), poorly mineralized and low loads of organic matter. A homogeneous quality of the water column ($p > 0.05$) and a low organic pollution with nitrogen as limiting factor of eutrophication (N/P Ratio = 12.88 ± 12.52) was observed. These characteristics enable to classify the Mfou municipal lake as mesotrophic. Biologically, 42 zooplankton species were recorded, including 29 species of Rotifers (69.05%), 10 species of Copepods (23.81%) and 3 species of Cladocerans (7.14%). A total zooplankton density was 2209 ind/L dominated by Rotifers with 933 ind/L (42%) mainly represented by *Brachionus falcatus* (188 ind/L), followed by Copepods with 827 ind/L (38%) dominated by *Ectocyclops hisurtus* (77 ind/L) and Cladocerans with 449 ind/L (20%) mainly represented by *Moina micrura* (344 ind/L) was recorded during the study period. These zooplanktons were quite diverse (H' = 4.22 ± 0.27 bits/ind) with a tendency towards an even distribution of species (E = 0.73 ± 0.05). The abiotic typology classifieds the lake into three groups according to the major origin of the pollutants while the biotic typology classifieds them into three groups according to the tolerance of the zooplankton species to organic matter. This lake is experiencing the early stage of anthropogenic disturbance. Regular hydrobiological studies are needed for monitoring the ecology of this hydrosystem.

KEYWORDS

Anthropogenic Factors, Mesotrophic, Mfou Municipal Lake, Physicochemical Analyses, Zooplankton Biodiversity

1. INTRODUCTION

Human's activities in pursuit of urbanization have transformed its ecosystem, leading to a disruption of some major ecological balances with disastrous consequences for the environment and strong repercussions on hydrosystems (Daccache et al., 2016). Over the years, these anthropogenic pressures have led to an increase in pollutants emissions of all kinds, with the bulk of this waste arriving in aquatic ecosystems, which are the major receptacle (Colas et al., 2014). Eutrophication has thus become a growing phenomenon in most developing countries due to the excess nutrients (nitrogen and phosphorus) discharged into nature, which are transported to aquatic environments without prior treatment. Among these hydrosystems, lakes, which constitute a major freshwater reserve on the planet, are host to numerous animal and plant organisms that maintain close relationships with their living environment (Zébazé Togouet, 2000). The animal organisms are made up of zooplanktons living suspended in the water column, whose own movements cannot resist the currents of the water mass. Zooplankton communities play several roles : an essential link to the freshwater food web, sensitive to variations in environmental conditions and a bioindicator of pollution, hence the interest that these organisms arouse among ecologists (Zébazé Togouet, 2008 ; Moss, 1998).

In Cameroon, most work on zooplanktons of lake has been carried out in urban areas. This mainly concerns the Yaounde municipal lake, the Mefou dam lake and the Ebolowa municipal lake among others (Nziéleu Tchapgnouo, 2006; Zébazé Togouet, 2008 ; 2000 ; Nonga Tang, 2008 ; Tajo, 2013). There is paucity of data on lakes in peri-urban areas, hence the need to carry out this work on the Mfou municipal lake. The general objective of this work was to assess the biodiversity and zooplankton community structure of the Mfou municipal lake in close relation to the physicochemical quality of water. More specifically, to : (a) measure the lake's physicochemical characteristics to determine the trophic level of water ; (b) identify and count the zooplankton species present in the lake ; (c) analyze the structure of the lake's zooplankton populations ; (d) establish an abiotic and biotic typological approach to the lake based on physicochemical and biological characteristics.

2. MATERIALS AND METHODS

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2.1 Description of the study site

This study was carried out in Cameroon, Center Region, Mefou and Afamba Division, city of Mfou. This locality is a moderately populated peri-urban area with an extensive hydrographic network, semi-intensive agricultural activity and industrial activity marked by a wood processing plant located at the entrance to the town. The study site is the municipal lake of Mfou, which has the following geographical coordinates taken with a GARMIN GPS : 03°43'24.60'' North latitude and 011°38'25.24'' East longitude. The lake have an altitude of 692 m, with an average depth of around 2 m, a perimeter of 362.14 m, a surface area of 2436.97 m² and a water volume of around 4873.94 m³ (Figure 1).

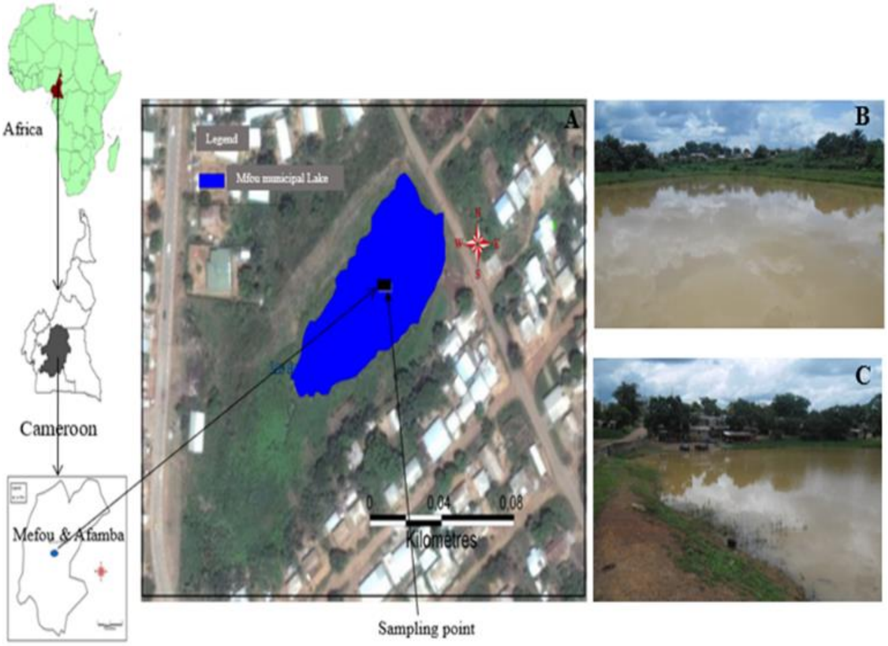

Figure 1: Geographical location of the study site : (A) Mfou municipal lake ; (B) General situation ; (C) Herbarium and pollution source.

2.2 Data collection

Movement on the lake was made possible using an inflatable MR II Zodiac. Sampling was carried out from April to September 2014 on a monthly frequency, with samples for physicochemical analyses were taken both at the surface and about 2 m deep in the central part of the lake, while for biological analyses, samples were taken in the seagrass beds all around the lake.

2.2.1 Physicochemical analyses

Water was collected for physicochemical analyses at the surface by direct sampling, while at depth of around 2 m, samples were taken using a 6L Van Dorn bottle, then transfer into 250 and 1000 ml double-capped polyethylene bottles, without bubbles, filled to the brim and stored in coolers for laboratory analysis. Some parameters were measured *in sity :* temperature was measured using a mercury column thermometer graduated to 1/100th of a degree, hydrogen potential (pH) was measured using a SHOTT GERÄTE CG 812 portable pH meter, transparency (Zs) was measured with a 30 cm diameter black and white Secchi disk, percentage of dissolved oxygen saturation (O_2) was measured using a HACH HQ14d oximeter and electrical conductivity and Total Dissolved Solids (TDS) were measured using a HANNA Hi 99300 portable TDS/Conductimeter. Other parameters such as turbidity, color, suspended solids (SS) and nutrient compounds (NO_3^-, NO_2^-, NH_4^+ and PO_4^{3-}) were measured in the laboratory using the colorimetric method on a HACH/DR 2010 spectrophotometer. Dissolved carbon dioxide (CO_2), alkalinity, calcium hardness and oxidizability were measured by volumetric method, while Biochemical Oxygen Demand for 5-day (BOD_5) was measured by respirometry using a LIEBHERR brand BOD meter and chlorophyll "a" content measured by the spectrophotometric method (Lorenzen, 1967). These physicochemical analyses were carried out according to the standard methods and recommendations by (American Public Health Association [APHA], 1998; Rodier et al., 2009).

The stoichiometric ratio N/P (nitrogen concentration/phosphorus concentration) was calculated for the lake and compared to a study conducted by some researcher, standard ratio value (N/P = 16) according to the following formulas (Redfield et al., 1963):

$$[\boldsymbol{N}] = [\boldsymbol{NO_3^-}] + [\boldsymbol{NO_2^-}] + [\boldsymbol{NH_4^+}] \quad (1)$$

$$[\boldsymbol{P}] = [\boldsymbol{PO_4^{3-}}] \quad (2)$$

Nitrogen, phosphorus or the two elements will be limiting if the ratio N/P is less than, greater than or equal to 16, respectively. The trophic status of the water of Mfou municipal lake was characterized using the classification system developed by (Organization for Economic Cooperation and Development [OECD], 1982) (Table I).

Table 1: Limit values of the trophic water classification system according to (OECD, 1982). avg: mean value; max: maximum value; min: minimum value.

Trophic status	PO_4^{3-} ave. (µg.L⁻¹)	Chl 'a' moy. (µg.L⁻¹)	Chl 'a' max. (µg.L⁻¹)	Secchi moy. (m)	Secchi min. (m)
Oligotrophic	< 10	< 2,5	2,5 - 8	> 6	> 3
Mesotrophic	10 - 35	2,5 - 8	8 - 25	6 - 3	3 – 1,5
Eutrophic	35 - 100	8 - 25	25 - 75	3 – 1,5	1,5 – 0,7
Hypereutrophic	> 100	> 25	> 75	< 1,5	< 0,7

2.2.2 Biological analysis

Zooplanktons were collected by direct sampling of 100 L of water between the surface and 0.5 m depth in the seagrass beds around the lake, then filtered through a plankton filter with 64 µm mesh sieve of 10 cm diameter. A retentate of 200 ml was collected and divided into two portion : the first portion of 100 ml (unfixed) was used to observe life forms and movement patterns and second portion of 100 ml fixed in the field with 10 ml of Formalin (5%). In the laboratory, counting of zooplankton species was done in duplicate by taking 10 ml volume of fixed and homogenized sample, pipetted into a 90 mm diameter Petri dish which was squared into 3 mm squares (Legendre and Watt, 1972). This technique, described by prevents any repetition of counting (Gannon, 1971). As required by a researcher, 100 organisms were counted, and if the sample did not contain that many individuals, counting was carried out until the sample was exhausted (Frontier, 1973). Identification and counting was done under a

WILD M5 binocular loupe at 250x and 500x magnification. Three groups of zooplankton organisms were selected:

- Rotifers were identified on the basis of morphological characteristics such as body shape and the ciliary structure on the anterior part of the body. Organisms that could not be identified with a binocular magnifying lens underwent a mastax study by dissolving their tissues in sodium hypochlorite and mounted on an Olympus CK2 microscope following the technique described by (Sanoamuang, 1993). Identification keys and books used were those of (Durand and Levêque, 1980 ; Koste, 1978 ; Pourriot and Francez, 1986 ; Zébazé Togouet, 2000).

- Cladocerans were identified on the basis of morphological characteristics such as body shape, shape of head capsule in ventral or dorsal view and detailed examination of the appendages of the postabdomen and shape of the rostrum. The identification keys and books used were those of (Amoros, 1984 ; Rey and Saint Jean, 1980 ; Zébazé Togouet, 2000 ; Fernando, 2002).

- Copepods were identified on the basis of body shape, length of antennae and antennules, structure of leg pairs and lateral ornamentation of abdomen segments. Further dissection was carried out under an Olympus CK2 microscope when identification was not certain. Identification keys and books used were those of (Dumont, 1980 ; Dussart and Defaye, 1995 ; Fernando, 2002 ; Zébazé Togouet, 2000).

Zooplankton density was calculated using the formula:

$$\boldsymbol{D = (n \times v) / V} \tag{3}$$

With D : density (ind/L) ; n : number of individuals counted ; v : volume of water analyzed and V : volume of water filtered. The frequency of occurrence provides information on the environment preferences of a species and has been used to count the number of times it appears in samples using the formula (Dufrêne and legendre, 1997):

$$\boldsymbol{F = (Fi/Ft) \times 100} \tag{4}$$

With F_i = number of records containing the species i and F_t = total number of samples taken. Depending on the value of the frequency, five categories of taxa are defined according to the classification of (Dufrêne and Legendre, 1997) : 100% : Omnipresents taxa ; 75% ≤ F < 100% : Regulars taxa ; 50% ≤ F < 75% : Constants taxa ; 25% ≤ F < 50% : Accessories taxa and F < 25% : Rares taxa. Principal Component Analysis (PCA) will be used to establish the abiotic and biotic typology of the municipal lake of Mfou, on the basis of all the environmental parameters measured and the zooplankton densities collected.

Shannon & Weaver's diversity index (H') (1963) was used to highlight the overall diversity of zooplankton and their degree of organization, using the formula (Tonkin et al., 2013):

$$\boldsymbol{H' = S[(ni/N) \times log2(ni/N)]} \tag{5}$$

With H' = Shannon and Weaver's diversity index in bits/ind ; ni = Number of individuals of species i ; N = Total number of individuals considering all species. Simpson's diversity index (D) (1965) measures the probability that two randomly selected individuals belong to the same species, and is used to express the dominance of one species when it tends towards 0, or the codominance of several species when it tends towards 1. Its formula is :

$$\boldsymbol{D = 1 - \Sigma\{[ni\,(ni - 1] / [N\,(N - 1]\}} \tag{6}$$

With D = Simpson's diversity index ; ni = number of individuals of the given species ; N = total number of individuals. Pielou's evenness index (E) (1966) is use to evaluate the equal-representation of species in relation to a theoretical equal distribution for all species. It is obtained by the formula :

$$\boldsymbol{E = H' / log2S} \tag{7}$$

With H'= Shannon and Weaver diversity index ; S = Total number of species present. This index (E) is equal to 0 when a single taxon dominates and 1 when all taxa have the same abundance. Principal Component Analysis (PCA) will be used to establish the abiotic and biotic typology of Mfou municipal lake, on the basis of all the environmental parameters measured and the zooplankton densities collected.

3. RESULTS

3.1 Physicochemical parameters

Water temperature in the Mfou municipal lake varieds from 23°C in July to 27°C in April, May and September with an average of 25.5 ± 1.31°C (Figure 2A). Water transparency has a minimum value of 7 cm in July and a maximum value of 32 cm in April with an average of 22 ± 9.77 cm (Figure 2B). Potential Hydrogen (pH) values ranged from 6.14 CU (May) to 7.46 CU (September) with an average of 6.95 ± 0.41 CU (Figure 2C). Water color ranged from 328 Pt-Co (June) to 806 Pt-Co (May) with an average of 514.92 ± 124.48 Pt-Co (Figure 2D). Total Suspended Solids (TSS) levels fluctuated between 44 mg/L (May and June) and 469 mg/L (July) with an average of 161 ± 148.43 mg/L (Figure 2E). Turbidity ranged from 50 FTU (April) to 638 FTU (July) with an average of 206.75 ± 194.63 FTU (Figure 2F). Total Dissolved Solids (TDS) levels varieds from 15 mg/L in April to 92 mg/L in July with an average of 61.58 ± 22.39 mg/L (Figure 2G). Electrical conductivity fluctuated between 30 µS/cm (April) and 152.5 µS/cm (July) with an average of 112.18 ± 37.46 µS/cm (Figure 2H). Dissolved oxygen (O_2) levels fluctuated between 38.8% in April and 75.6% in August with an average of 52.72 ± 12.27% (Figure 2I). Dissolved carbon dioxide (CO_2) levels varied from 8.8 mg/L in April to 15.84 mg/L in June, July and August with an average of 13.05 ± 2.31 mg/L (Figure 2J).

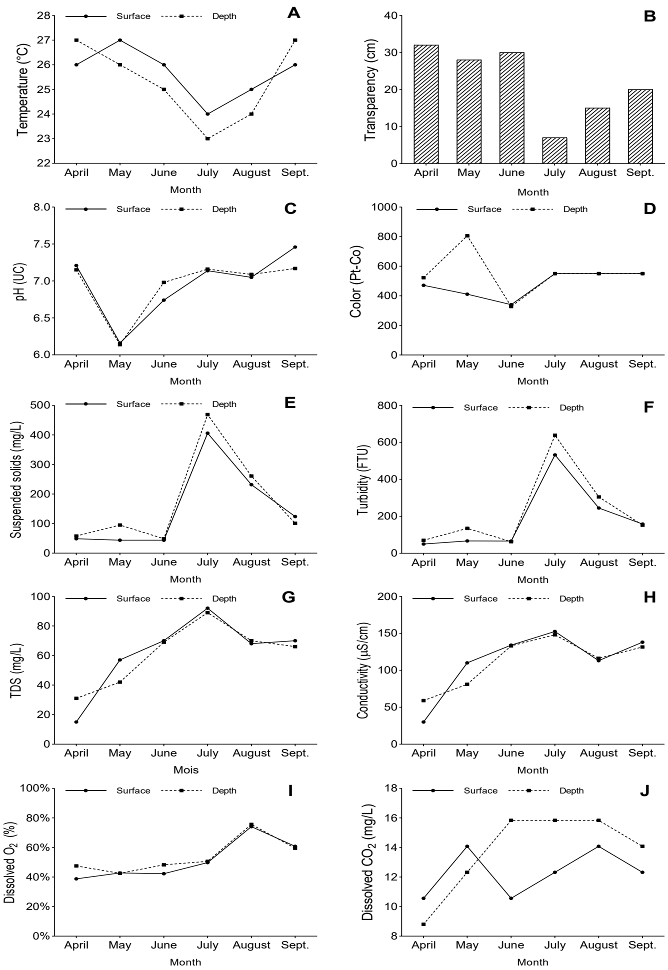

Figure 2: Spatiotemporal variations of temperature (A), transparency (B), pH (C), color (D), TSS (E), turbidity (F), TDS (G), electrical conductivity (H), dissolved O_2 (I) and dissolved CO_2 (J) over the study period.

Water alkalinity fluctuated between 16 mg/L (September) and 72 mg/L (April) with an average of 40.17 ± 16.3 mg/L (Figure 3A). Calcium hardness rangeds from 4 mg/L $CaCO_3$ in May and August to 28 mg/L $CaCO_3$ in July with an average of 9 ± 7.11 mg/L $CaCO_3$ (Figure 3B). Nitrate levels differed significantly ($p < 0.05$) from surface to depth, ranging from 0.06 mg/L (September) to 1.8 mg/L (July) with an average of 0.79 ± 0.74 mg/L at the surface, and from 0 mg/L (May) to 0.7 mg/L (June) with an average of 0.29 ± 0.3 mg/L at the depth (Figure 3C). Nitrite levels ranged from 0 mg/L in June and August to 0.054 mg/L in July with an average of 0.014 ± 0.016 mg/L (Figure 3D). Ammonia levels fluctuated between 0.92 mg/L in April and 10.4 mg/L in July with an average of 3.14 ± 2.83 mg/L (Figure 3E). Orthophosphate levels varied from 0.11 mg/L in April to 1.72 mg/L in May with an average of 0.66 ± 0.51 mg/L (Figure 3F). Oxydability values fluctuated between 1.49 mg/L in June and 18.76 mg/L in July with an average of 8.66 ± 6.38 mg/L (Figure 3G). Biochemical Oxygen Demand (BOD_5) fluctuated between 5 mg/L O_2 in April and May to 48 mg/L O_2 in April with an average of 24.42 ± 16.24 mg/L O_2 (Figure 3H). Chlorophyll 'a' content fluctuated between 0.001 mg/L (June) to 0.009 mg/L (August) with an average of 0.0046 ± 0.0029 mg/L (Figure 3I). N/P Ratio levels varied from 0.64 in May to 87.53 in July with an average of 12.88 ± 12.52 (Figure 3J).

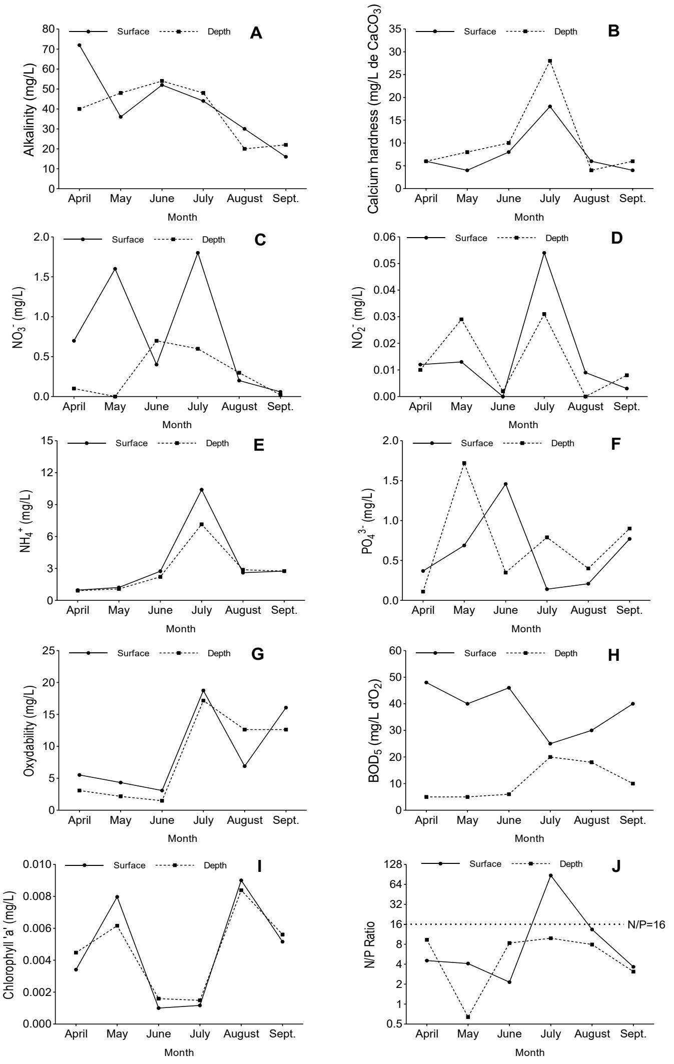

Figure 3 : Spatiotemporal variations of alkalinity (A), calcium hardness (B), nitrates (C), nitrites (D), ammoniacal nitrogen (E), orthophosphates (F), oxydability (G), BOD_5 (H), Chlorophyll a (I) and N/P ratio (J) over the study period.

3.2 Abiotic typology of Mfou municipal lake

The Principal Component Analysis (PCA) carried out with the environmental variables of the municipal lake of Mfou had a total variance provided by the first two factorial axes Dim1 (51.8%) and Dim2 (20.6%) which accounted for 72.4% of the total inertia. The factorial map showed the distribution of the sample months in relation to their physicochemical characteristics. Three main groups emerge in this factorial map (Figure 4) :

- Group I, where the Dim2 axis discriminates in positive coordinates against the month of July, with hard water loaded with nitrogen, highly mineralised, turbid, coloured and oxidisable organic matter.
- Group II, whose Dim1 axis discriminates in its negative coordinates between August and September, with water rich in chlorophyll 'a', well oxygenated and rich in dissolved carbon dioxide.
- Group III, where the Dim2 axis discriminates in negative coordinates against the months of April, May and June, where the water is high in temperature, transparent, alkaline, orthophosphates and organic matter.

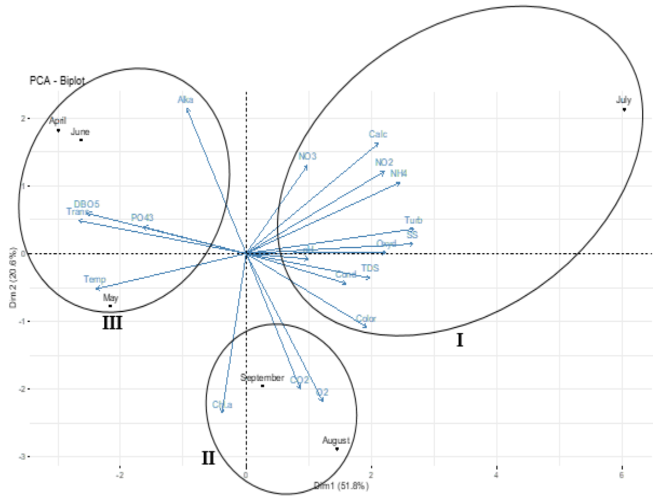

Figure 4: Principal Component Analysis (PCA) performed on the environmental variables of the municipal lake of Mfou during the study period.

3.3 Biological parameters

A total of 15 famillies and 42 zooplankton species were collected in the municipal lake of Mfou during the study period, belonging to the 3 major zooplankton groups : Rotifers, Cladocerans and Copepods.

3.3.1 Different zooplankton families

The Rotifera group was represented by 10 families, the most abundant being the Brachionidae with a total density of 656 ind/L, while the least represented family was the Notommatidae (2 ind/L) (Figure 5A). As for the Cladocerans, 3 families were identified, the most represented being the Moinidae with a total density of 344 ind/L, while the Sididae family (33 ind/L) was the least represented (Figure 5B). Among the copepods, 2 families were identified, the most represented being the Cyclopidae with a total density of 268 ind/L, while the Canuellidae family (25 ind/L) was the least represented during the study period (Figure 5C). There was a high abundance of nauplii larvae* (254 ind/L) and copepodites* (280 ind/L) which are respectively the larval and juvenile phases of Copepods (Figure 5C).

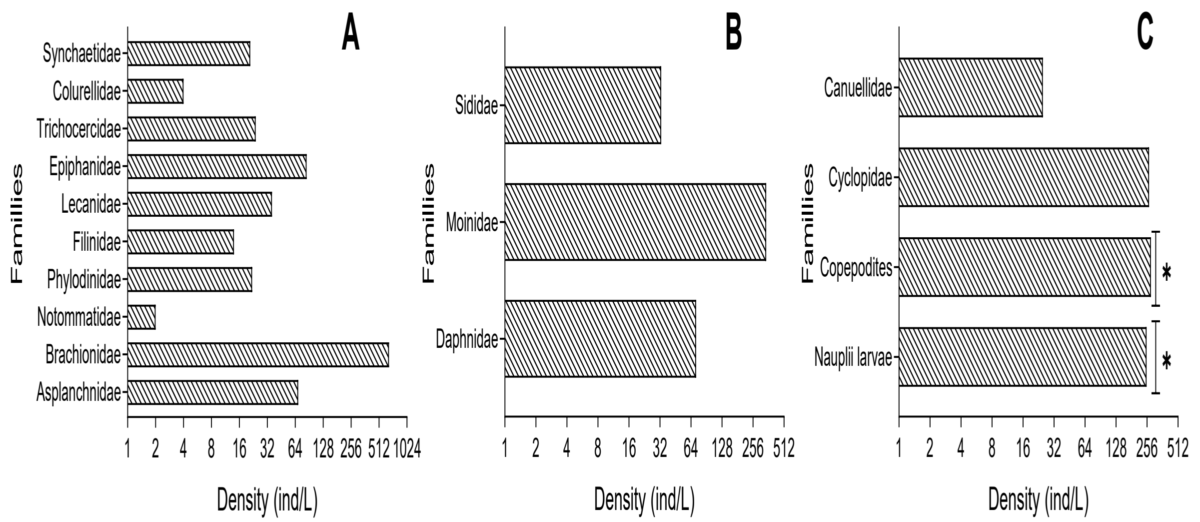

Figure 5: Total densities of the different families of Rotifers (A), Cladocerans (B) and Copepods (C) in the municipal lake of Mfou during the study period.

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3.3.1.1 Species richness, density and occurrence frequency of Rotifers

Twenty nine species of Rotifers were identified, belonging to 10 families (Table II). The most represented family was the Brachionidae (656 ind/L), dominated by the species *Brachionus falcatus* (188 ind/L). The species *Brachionus calyciflorus, Brachionus falcatus, Notholca squamula* (Brachionidae) and *Lecane bulla* (Lecanidae) were the omnipresent taxa (*****) of Rotifers found in 100% of samples during the study period. The total density of Rotifers was 933 ind/L (Table 2).

Table 2: Specific richness, densities and occurrence frequency of Rotifers.

Famillies	Species	Densities (ind/L)	Occurrence frequency
Asplanchnidae (Harring & Myers, 1926)	*Asplanchna brightwelli* (Gosse, 1850)	30	***
	Asplanchna girodi (Guerne, 1888)	8	*
	Asplanchna herricki (Guerne, 1888)	31	***
Brachionidae (Wesenberg – lund, 1899)	*Brachionus angularis* (Gosse, 1851)	139	****
	Brachionus bidentatus (Anderson, 1889)	37	**
	Brachionus calyciflorus (Pallas, 1851)	126	*****
	Brachionus falcatus (Zacharias, 1898)	188	*****
	Brachionus leydigii (Cohn, 1862)	37	****
	Brachionus quadridentatus (Müller, 1786)	15	*
	Brachionus plicatilis (Müller, 1786)	8	***
	Brachionus rubens (Ehrenberg, 1838)	1	*
	Keratella tropica (Apstein, 1907)	20	*
	Notholca squamula (Müller, 1786)	1	*****
	Plationus patulus (O.F Müller, 1786 ; Bryce,1931)	3	***
	Platyias leloupi (Gillard, 1957)	17	*
	Platyias quadricornis (Ehrenberg, 1832 ; Bryce, 1931)	64	**
Notommatidae (Hudson & Gosse, 1886)	*Proales* sp.	2	***
Phylodinidae (Ehrenberg, 1838)	*Rotaria citrina* (Ehrenberg, 1838)	2	**
	Rotaria neptunia (Ehrenberg, 1830)	5	**
	Rotaria rotatoria (Pallas, 1766)	15	*
Filinidae (Harring & Myers, 1926)	*Filinia hofmanni* (Koste, 1980)	12	*
	Filinia longiseta (Ehrenberg, 1834)	2	**
Lecanidae (Bartos, 1959)	*Lecane bulla* (Gosse, 1851)	17	*****
	Lecane papuana (Murray, 1913)	14	***
	Lecane obtusa (Murray, 1913)	5	*
Epiphanidae (Harring, 1913)	*Epiphanes clavulata* (Ehrenberg, 1831)	85	*
Trichocercidae (Remane, 1933)	*Trichocerca* sp.	24	**
Colurellidae (Bartos, 1959)	*Colurella obtusa* (Gosse, 1886)	4	**

Table 2 (cont): Specific richness, densities and occurrence frequency of Rotifers.			
Synchaetidae (Remane, 1933)	*Polyarthra vulgaris* (Carlin, 1943)	21	***
Total	**29**	**933**	**/**

3.3.1.2 Species richness, density and occurrence frequency of Cladocerans

Three Cladocerans species recorded in the Mfou municipal lake during the study belonged to 3 families. The most represented family was Moinidae with *Moina micrura* (344 ind/L) being the most abundant. The species *Ceriodaphnia cornuta* (Daphnidae) and *Diaphanosoma brachyurum* (Sididae) were the omnipresent taxa (*****) of Cladocerans found in 100% of samples during the study period. The total density of Cladocerans was 449 ind/L (Table 3).

Table 3: Specific richness, densities and occurrence frequency of Cladocerans.

Famillies	Species	Densities (ind/L)	Occurrence frequency
Daphnidae (Strauss, 1820)	*Ceriodaphnia cornuta* (Sars, 1886)	72	*****
Moinidae (Goulden, 1968)	*Moina micrura* (Kurz, 1874)	344	***
Sididae (Bairds, 1850)	*Diaphanosoma brachyurum* (Liévin,1848)	33	*****
Total	**3**	**449**	**/**

3.3.1.3 Species richness, density and occurrence frequency of Copepods

Ten copepods species were identified belonging to 2 families. The most represented family was Cyclopidae with the species *Ectocyclops hisurtus* (77 ind/L) being the most abundant. The species *Mesocyclops leuckarti, Metacyclops tropicus, Microcyclops davidi, Thermocyclops negletus* (Cyclopidae) and nauplii larvae were the omnipresent taxa (*****) of Copepods, found in 100% of samples during the study period. The total density of copepods was 827 ind/L, with a high abundance of nauplii larvae (254 ind/L) and copepodites (280 ind/L), which are respectively the larvae (*) and juvenile (**) phases of copepods (Table 4).

Table 4: Specific richness, densities and occurrence frequency of Copepods.

Famillies	Species	Densities (ind/L)	Occurrence frequency
Cyclopidae (Dana, 1853)	*Acanthocyclops* sp.	14	***
	Afrocyclops gibsoni (Brady, 1904)	16	**
	Allocyclops chappuisi (Kiefer, 1932)	12	***
	Ectocyclops hisurtus (Kiefer, 1930)	77	****
	Mesocyclops leuckarti (Claus, 1857)	50	*****
	Metacyclops tropicus (Kiefer, 1932)	31	*****
	Microcyclops davidi (Chappuis, 1922)	3	*****
	Thermocyclops negletus (Sars G. O., 1909)	37	*****
	Tropocyclops confinis (Kiefer, 1930)	28	****
Canuellidae (Lang, 1944)	*Canuella* sp.	25	**
/	Nauplii larvae*	254	*****
	Copepodites**	280	***
Total	**10**	**827**	**/**

3.4 Zooplankton structure

Temporal variation of zooplankton species richness revealed that April was the most diverse month with 32 species, while June was the least diverse with 20 species (Figure 6A). The density variation profile showed that zooplanktons were most abundant in August (486 ind/L) and least abundant in June (77 ind/L) (Figure 6B). The Kruskal-Wallis H-test showed significant variations ($p < 0.05$*) in zooplankton densities from one month to the next. Mann Whitney U test confirmed that zooplankton densities obtained in June were significantly lower ($p < 0.05$*) than those obtained in the other months (Figure 6B).

Total species richness was 42 species, dominated by Rotifers with 29 species representing 69.05% of total species richness, followed by Copepods with 10 species (23.81%) and Cladocerans with 3 species (7.14%) (Figure 6C). Total density was 2209 ind/L, dominated by Rotifers with 933 ind/L representing 42.24% of total density, followed by Copepods with 827 ind/L (37.44%) and Cladocerans with 449 ind/L (20.33%) (Figure 6D).

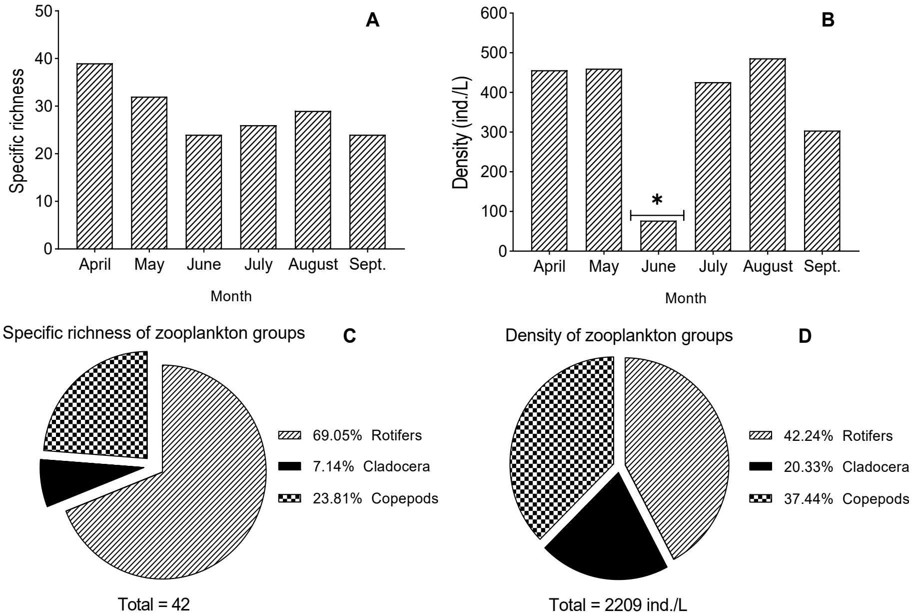

Figure 6: Variations of monthly (A) and total (C) species richness and monthly (B) and total (D) density of zooplankton organisms collected during the study period.

The Shannon and Weaver diversity index (H') was high every month, with values ranging from 3.93 bits/ind in August to 4.65 bits/ind in April with an average of 4.22 ± 0.27 bits/ind (Figure 7A). Simpson's diversity index had a minimum value of 0.89 bits/ind and a maximum value of 0.95 bits/ind, with an average of 0.93 ± 0.02 bits/ind (Figure 5B). The Pielou's equitability index (E) ranged from 0.68 (August) to 0.80 (April) with an average of 0.73 ± 0.05 over the study period (Figure 7B). The variations of the zooplankton structure showed that Rotifers had the highest densities except in August, while Cladocerans had the lowest densities throughout the study period. The maximum density for Rotifers was achieved in July with 240 ind/L (56%), for Copepods in August with 273 ind/L (56%) and for Cladocerans in April with 123 ind/L (27%) (Figure 7C).

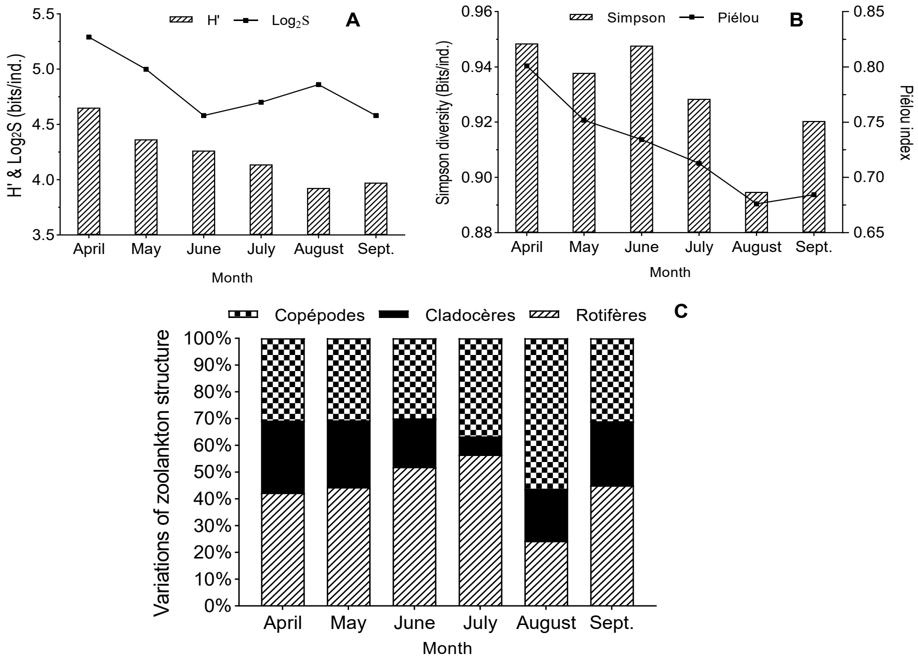

Figure 7: Temporal variations of Shannon-Weaver diversity index (A), Simpson diversity index and Pielou regularity (B), and variation of zooplankton structure (C) over the study period.

3.5 Biotic typology of the Mfou municipal lake

The Principal Component Analysis (PCA) carried out on the zooplanktons of the municipal lake of Mfou had a total variance which was provided by the first two factorial axes Dim1 (32.7%) and Dim2 (23.9%), which together accounted for 56.6% of the total inertia (Figure 8). The factorial map showed the distribution of the sample months in relation to their biological characteristics. Three main groups emerged in this factorial map (Figure 8):

- Group I, whose Dim1 axis discriminates in its negative part between the months of June and September and whose most represented species are the Rotifers : *Brachionus quadridentatus* (Brqua), *Epiphanes clavulata (Epcla), Filinia hofmani* (Fihof) and *Polyarthra vulgaris* (Povul).
- Group II, whose Dim1 axis positively discriminates the month of August, with the most abundant organisms being the Copepods : *Allocyclops chappuisi* (Alcha), *Ectocyclops hisurtus* (Echis), *Tropocyclops confinis* (Trcon), *Metacyclops tropicus* (Metro), copepodites (Copep) and nauplii larvae (Lanau) ; Rotifer *Lecane bulla* (Lebul) and Cladoceran *Moina micrura* (Momic).
- Group III whose Dim2 axis discriminates in its positive part between the months of April, May and July and whose most represented species are the Rotifers : *Asplanchna brightwelli* (Asbri), *Asplanchna herricki* (Asher), *Brachionus angularis* (Brang), *Brachionus falcatus* (Brfac), *Brachionus calyciflorus* (Brcal), *Brachionus leydigi* (Brley), *Platiyas quadricornis* (Plqua) and *Tricocerca* sp. (Trsp.) ; Cladocerans : *Ceriodaphnia cornuta* (Cecor) and *Diaphanosoma brachyurum* (Dibra) and Copepods : *Mesocyclops leukarti* (Meleu), *Thermocyclops negletus* (Thneg), *Acanthocyclops* sp. (Acsp.) and *Canuella* sp. (Casp.).

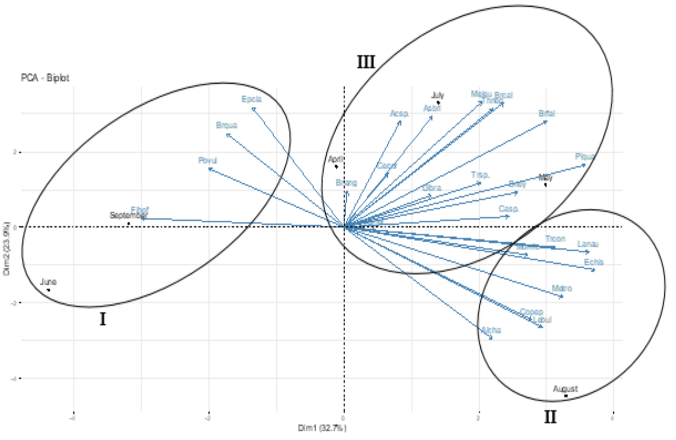

Figure 8: Principal Component Analysis (PCA) performed on the biological variables of the municipal lake of

4. Discussion

4.1 Physicochemical variables

Water temperature of the Mfou Municipal lake varied slightly, from surface (25.67 ± 1.03°C) to depth (25.33 ± 1.63°C) just like in most tropical lentic environments, where surface water temperature depends closely on sunshine and exchanges with the atmosphere (Atanlé *et al.*, 2012). Mean pH value (6.95 ± 0.41 UC) showed that the water of the Mfou municipal lake were slightly acidic due to the nature of the soils in this region and started that pH of the water was closely dependent on the nature of the substrate crossed (Nola et al., 1998). Total Suspended Solids (TSS) content (161 ±148.32 mg/L) which was very high during the study period, was thought to be due to erosion caused by untimely and irregular rainfall in the study area, which washed particles into the lake. Moreover, turbidity was also high thanks to high TSS derived from organic and inorganic particles suspended in the lake water. A group researchers pointed out that rainfall promotes erosion of mineral and organic particles from anthropized watersheds, and these particles are transported by runoff water into the hydrosystem causing water mixing, thereby raising TSS content of the environment which in turn leads to an increase in water turbidity and consequently colored water (Al-Aubadi et al., 2019). This suggestion opines the positive and significant correlations observed ($p < 0.01$) between these three parameters during the study period. Suspended particles led to a drop in water transparency, which correlated negatively and significantly with TSS ($p < 0.01$) and turbidity ($p < 0.01$), which was due to the fact that the low water transparency was consecutive to both an increase in TSS and turbidity (Cunha et al., 2019).

Electrical conductivity was directly linked to TDS, enabling the characterisation of total ions dissolved in the water (Hamaidi-Chergui et al., 2013). This was explained by the positive and significant correlation ($p < 0.01$) observed between these two parameters, which, with low values, showed a weakly mineralized lake due to the low anthropization of the watershed, thereby limiting the mineralizing activity of bacteria. The average dissolved O_2 saturation content (52.71 ± 12.27%) showed that the lake's waters was moderately oxygenated, due to dissolution from atmospheric oxygen and photosynthesis by the aquatic vegetation (Zébazé Togouet, 2008). The significant negative correlation between dissolved O_2 and dissolved CO_2 ($P < 0.05$) can be explained, according to a study, by the fact that in water, respiration of organisms decreases O_2 while increasing CO_2, while photosynthesis by algae and aquatic plants consumes CO_2 while releasing O_2 (Boyd, 2020).

The lake's low alkalinity during the study period was thought to be due to obligatory photosynthesis, which caused some algae to cover their carbon needs by taking up hydrogen carbonate and carbonate (biogenic decalcification), which would have been conducive into increasing water alkalinity (Groga, 2012). Average nitrate levels were higher at the surface (0.79 ± 0.74 mg/L) than at depth (0.29 ± 0.3 mg/L) and a group researchers explained that in upper oxygenated layers of water body, ammonia oxidates directly into nitrates (Guilford et al., 2000). Nitrite levels were very low in the lake during the study period, reflecting the relatively high self-purification capacity of the waters in this ecosystem. The moderately high orthophosphate content (0.65 ± 0.51 mg/L) was due to the relatively high decomposition rate of organic matter (Rodier et al., 2009). The lake's low BOD_5 (24.41 ± 16.24 mg/L) and oxidizability (8.65 ± 6.38 mg/L) averages testify to the low degree of anthropization of the watershed, reflecting the lake's low level of oxidizable organic matter pollution. The relatively homogeneous physicochemical quality of the water column can be explained by the shallow depth of the lake's water, combined with their constant mixing. Nitrogen being the limiting factor of eutrophication (N/P Ratio = 12.88 ± 12.52), measures to be implemented for the management of pollution of such hydrosystems should focus on controlling the flow of nitrogen compounds into the lake. The abiotic typology classified the lake into three groups according to the major origin of the pollutants. According to the criteria established by the Organization for Economic Cooperation and Development [OECD] (1982), the physicochemical characteristics recorded during the study period enabled to classify Mfou municipal lake as mesotrophic.

4.2 Structure of zooplankton Community

Throughout the study period, 42 zooplankton species were recorded in Mfou municipal lake. This taxonomic richness was higher than that obtained in Ebolowa's municipal lake (29 species) and could be due to the fact that this eutrophic lake was located in an urban area and was subject to heavy effluent pollution from the hospital and market (Tajo, 2013). However, this taxonomic richness was lower than that recorded by in the lake of Mefou (46 species) and this could be due to the lake's very low level of anthropization (Nonga Tang, 2008). In the absence of disturbance, the structure of the populations that colonize a body of water responds to a certain equilibrium. An alteration in the physicochemical quality of the water and a change in abiotic factors cause a disruption in the biological edifice, generally resulting in a reduction in diversity and ecological successions, with fragile species being the most affected (Moisan, 2010). A study of zooplankton populations shows that Rotifers are mainly represented by the species *Brachionus falcatus* (188 ind/L). These Brachionidae are very numerous, as in most tropical lakes and linked this abundance to abiotic environmental factors such as temperature and organic matter content whitch are favorable to their growth (Nana Towa et al., 2019). Copepods were mainly represented by the species *Ectocyclops hisurtus* (77 ind/L) and Cladocerans by the species *Moina micrura* with 344 ind/L were least abundant as observed in most tropical lakes and this could be due to the fact that these organisms represent a preferential food for fish fry (Moss, 1998 ; Dakwen et al., 2015).

The variation in zooplankton densities throughout the study could be justified by the fluctuating organic and mineral matter contents of the lake offering nutrient resources and favouring the growth of greater numbers of individuals. The average density was 369 ind/L, reflected the oligotrophic or mesotrophic nature of Mfou municipal lake. According to a stady, stated that in oligotrophic and mesotrophic environments, average zooplankton densities are below 400 ind/L (Orcutt and Pace, 1984). The high dominance of Rotifers (933 ind/L) correlates with their great capacity to adapt to changing environmental conditions. It is for this reason that Berthon suggested the use of Rotifers as indicators of variations in environmental conditions (Berthon, 2014). The average density of Copepodes (827 ind/L) can be explained by the fact that they were better able to escape predation, but their ability to grow and reproduce was superior to that of Cladocerans in environments with limited food resources such as the Mfou municipal lake (Nogrady et al., 1993). The low density of Cladocerans (449 ind/L) could be explained by the phenomenon of predation, as they represent a preferential food source for fish fry (Dakwen et al., 2019). The significantly lower zooplankton densities ($p < 0.01$) in June compared to other months, would be due to the low organic matter inputs recorded in the lake during that month.

The biotic typology classified the lake into three groups according to the tolerance of the zooplankton species to organic matter. The strong presence of omnipresent taxa (24%) demonstrated the stability of zooplankton community, which are highly sensitive indicators of environmental pressures. The Shannon and Weaver diversity index (4.22 ± 0.27 bits/ind) and the Simpson diversity index (0.93 ± 0.02 bits/ind) were high, showing zooplankton populations that are quite diverse. This high diversity of organisms can be explained by the constant mixing of waters, which offers new living conditions favorable to certain species, thus increasing diversity (Butterwick et al., 2005). Pielou's equitability index was high (0.73 ± 0.05) showed a balanced hydrosystem with a trend towards evenness of zooplankton species throughout the study period.

5. Conclusion

The results of this study show that the water of the Mfou municipal lake had a high temperature, was slightly acidic, presented low mineralization, low organic matter content and were moderately oxygenated. The physicochemical quality of water column was homogeneous and a low organic pollution with nitrogen as limiting factor of eutrophication was observed thereby categorizing the lake as mesotrophic. Biological analyses showed that the specific richness and density of zooplankton organisms had the same structure, mainly dominated by Rotifers, which were by far the most diversified with the highest density, followed by copepods, which are moderately diversified, and Cladocerans which are

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weakly diversified. The abiotic typology classified the lake into three groups according to the major origin of the pollutants while the biotic typology classified its into three groups according to the tolerance of the zooplankton species to organic matter. The strong presence of omnipresent taxa demonstrated the stability of the zooplankton population, which are highly sensitive indicators of environmental pressures. These zooplanktons were quite diverse, with a tendency towards evenness of species. This study showed that the water of Mfou municipal lake located in a peri-urban area was undergoing the early stage of anthropogenic disturbance. Regular hydrobiological studies are needed to monitor the ecology of this ecosystem.

Ethical Clearance Statement

Not applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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