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Spatio-Temporal Distribution of Zooplankton in Relation to Abiotic Factors in Urban Hydrosystems: In the Lakes Ehuikro, Kaby and Sokotè (Bongouanou, Ivory Coast)

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ABSTRACT

This study aims to determine the spatio-temporal distribution of zooplankton in relation to the environmental characteristics in lakes Ehuikro, Kaby and Socotè located in the East-Centre of Côte d'Ivoire in the region of Moronou. The zooplankton were sampled monthly from April 2017 to March 2018 using a plankton net of size 60 µm. A total of 42 taxa were observed (28 Rotifers, 6 Copepods, 3 Cladocerans and 5 other zooplanktonic organisms). The Rotifer group (45%) dominated the total abundance. In terms of density, the rotifers are largely dominated by the Brachionidae (51%). In all, the highest taxonomic richness and abundances were recorded during the rainy season (54.34%) against (45%) in the dry season. The variables strongly influencing taxonomic diversity and abundance are depth, conductivity, temperature, rate of dissolved solid particles, nitrate level, hydrogen potential, phosphorus level, dissolved oxygen proportion and the rate of saturated oxygen. The physicochemical characteristics of lakes Ehuikro, Kaby and Socotè determine its zooplankton biodiversity especially marked by the presence of 42 taxa, mainly composed of rotifers (45%), copepods (40%), cladocerans (8%) and other organisms (7%). Furthermore, the spatio-temporal distribution of zooplankton depends on the physicochemical parameters, in particular the depth, the conductivity, the temperature, the rate of dissolved solid particles, the nitrate level, the hydrogen potential, the phosphorus level, the rate of dissolved oxygen and the saturated oxygen, revealing high proportions of species tolerant to organic pollution during the study. This study made it possible to determine the level of pollution of the water of lakes Ehuikro, Kaby and Socotè through the zooplanktonic organisms that live there. And confirms the possibility of using Brachionidae as an indicator of pollution.

INTRODUCTION

The increasing urbanization and industrialization of cities, thereby contributing to increasing domestic and industrial liquid waste of organic matter and dissolved substances. In most developing countries, these domestic and industrial waste are generally discharged into aquatic ecosystems close to the cities without being treated or after limited treatment. In the long term, this results to a degrading of the quality of these aquatic environments, a decrease in diversity, and even the disappearance of water bodies **(Barroin, 1980).**

In Ivory Coast, the Kaby and Socotè lakes, artificial reservoirs located in the town of Bongouanou, formerly served as source of drinking water to the population, have not been spared from this situation. Indeed, in recent decades, the strong demographic growth, the extension of the city and the continuous discharges of domestic effluents have led to the degradation of the quality of these waters and their abandon by the populations as sources of drinking water for another water source (Lake Ehuikro) located in the outskirts of the city.

In the management of aquatic ecosystems, apart from the evaluation of the physicochemical parameters, zooplankton could be used as a biological indicator of pollution, eutrophication (**Neto *et al*. 2014**) and environmental changes (**Beaugrand *et al*. 2003; Beaugrand *et al*. 2004**). In a global context of increasing anthropogenic pressures on aquatic ecosystems, leading to their eutrophication, it would be wise to have indicators that can serve as benchmarks for aquatic ecosystems management. Ivory Coast has many lakes and other reservoirs which are subjected to the same pressures in a local climatic condition. Studying the zooplankton population in lakes Ehuikro, Kaby and Socotè, which are degraded or in an advance process of degrading, could serve as a reference database for the scientific community and for the managers of these ecosystems.

The aim of this present study therefore was to constitute a reference database for the management and development of aquatic ecosystems through the study of the spatio-temporal variation in the composition and structure of the zooplanktonic population in the lakes Ehuikro, Kaby and Socotè.

Study environment

Our study environment consisted of three water reservoirs (**figure 1**) in the region of Bongouanou, lakes Sokotè, Kaby and Ehuikro divided into seven study stations.

The Sokotè water reservoir is located in the heart of the city, in the city of Bongouanou between latitude 6 ° 23 ’46" North and longitude 4 ° 7 ’19" West.

The sacred lake Sokotè is home to some plant species. These species are found all around the lake. Among them, *Borassus aethiopum*, *Musa saprentum*, *Carica papaya*, *Cocos nucifera*, *Panicum maximum*, *Imperata cylindrica* and some other herbaceous plants occupy a prominent place in the waterbody.

This sacred lake does not depend on anyother source. Its source is very deep. It basically contains two species of fish *Clarias anguillaris* and *Oreochromis niloticus* with a strong dominance of *C. anguillaris*. Fishing is prohibited in this lake because of the sacred nature of the lake.

Lake Kaby, is a water reservoir created to supply drinking water to the population of the town of Bongouanou in the East-central of Ivory Coast in the Moronou region. This study area is located in the middle of the agglomeration of the city of Bongouanou. As a result, the lake receives rainwater, wastewater and household waste through runoffs. This environmental situation prompted the population to abandon it for another source of drinking water far away from the city. The kaby lake is shallow with an average depth of 1.15 m and an area of 3.5 ha.

Lake Ehuikro, a Drinking Water Supply (DWS) dam was built in 1973 as part of the national water supply program, taking its source from the sacred Yakpo river. It lie between latitude 6 ° 23 ’2" North and longitude 4 ° 57 ’25" West. It receives runoff from the village from which it takes its name (Ehuikro).

The Ehuikro DWS dam is bounded in the south by a poultry farm, pig farm and crops (rubber, maize, tomato and okra nurseries), to the east by the village of Ehuikro. The north and west are occupied by cassava and cocoa plantations and also by tomatoes, peppers and okra. The Ehuikro lake dam is home to plant species such as *Diplazium sammatii* (Kuhn) *C. Chr.*, *Nymphea sp*, *vetivers*, etc.

The climate of the study area is of the equatorial type with four seasons: a long rainy season (March to July); a short dry season (August); a short rainy season (September to October) and a long dry season from November to February.

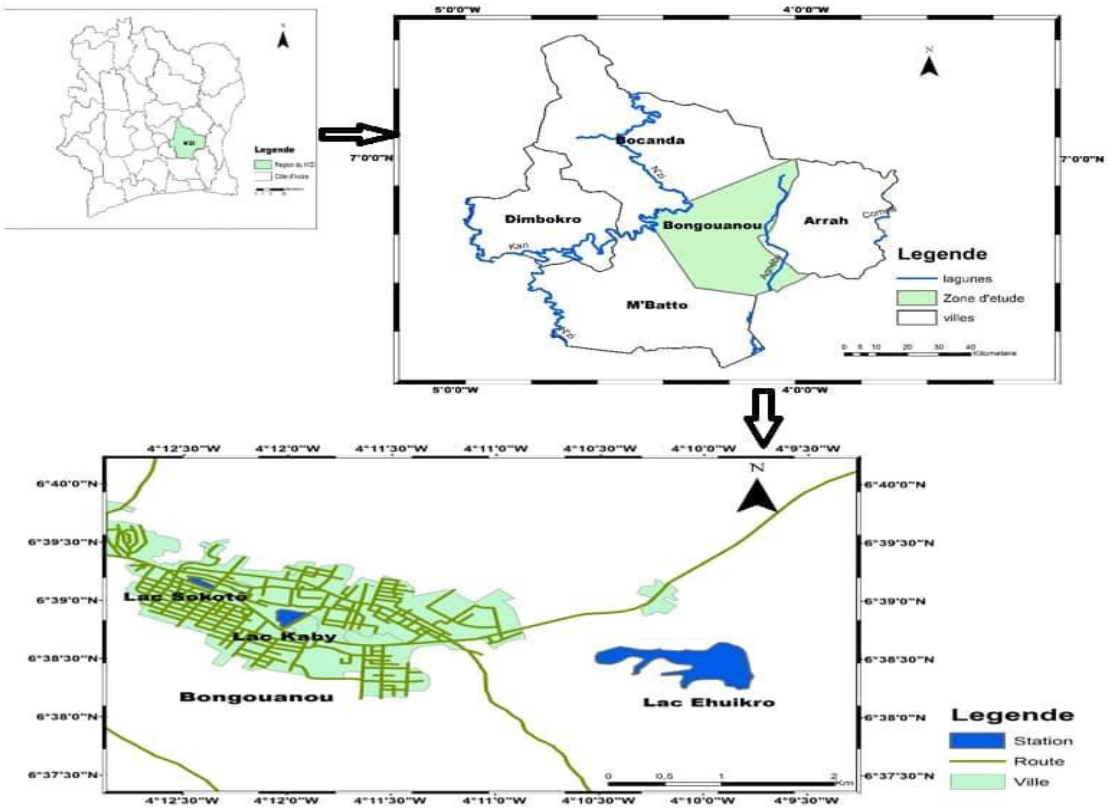

Figure No. 1: Geographical location of lakes Ehuikro, Kaby and Socotè

MATERIAL AND METHODS

Sampling and identification of zooplankton organisms

The zooplankton were collected once in a month, from April 2017 to March 2018 between 7 a.m. and 8 a.m.by filtration of 100 L of water (10 buckets of 10 L capacity) through a plankton net of 60 µm mesh size. The samples collected were reduced using a concentrator and then collected in a pillbox to which were added 1 to 2 mg of sucrose, 2 to 3 drops of neutral red, 1 to 2 drop (s) of liquid soap and formaldehyde (5%). Zooplanktonic organisms were identified according to the keys of **Pourriot**, **Francez** (**1986**) for rotifers, **Dussart (1967**) for copepods and **Amoros (1984)**

for cladocerans, then counted under a binocular magnifying glass of the type Engineering vision (EW 10X / 20).

The results obtained are translated into taxonomic richness, in this case (%) F = Pi / Pt x 100; in Shannon diversity index Pi = ni / Σ ni & Equitability E = H '/ H'max and expressed in density (ind / L).

Measurement of environmental characteristics

The water temperature (° C), the pH, the conductivity (GS / Cm), the dissolved oxygen level (%) were measured using a Sper Scientifique multi-parameter.

The water transparency (cm) was assessed using a Secchi disc. The depth (cm) of the water was assessed using a measuring stick. The water coverage rate by aquatic plants and the type of substrate (sand, sand-gravel mixture, gravel, mud, deadwood-leaf-root mixture) were estimated by visual observation and expressed as a percentage.

Data analysis

Taxonomic richness, percentage of occurrence, Shannon and Equitability indices were used to determine the structure and dynamics of the zooplankton population. The percentage of occurrence (F) is obtained using the following formula: F = (Si / St) × 100, with Si: number of samples where taxon i was captured and St: total number of samples. The classification of taxa on the basis of their percentage of occurrence was made according to **Dajoz (2000)**: F ≥50: constant taxon; 25% ≤ F < 50% accessory taxon and F < 25: accidental taxon. Seasonal variations in the densities of zooplankton organisms were assessed by the Mann-Whitney U test. Redundancy analysis (RDA) was used to relate environmental variables to zooplankton taxa.

Sladecek index

According to **Sladecek, (1983)**, the quotient of the sum of the abundances of the genus *Brachionus* / *genus Trichocerca* makes it possible to determine the quality of a water reservoir. This quotient can be established for a body of water characterized by slow or fast flow. Or even for individual samples, if representatives of at least one of these *genus* is present. It is an

analogue of the 5 phytoplankton quotients proposed by **Thunmark (1945)** and **Nygaard (1949)** and often applied in limnology (**see Hohne and Klose 1966; Breitig and Tumpling 1982**)

In our study, we determined the quotient of the sum of the abundance of all species of the genus *Brachionus* over the sum of the abundance of all species of the genus *Trichocerca*. The results obtained were classified according to the grid of **Sládecek, (1983**).

QB / T = the sum of the abundances of the genus *Brachionus* / the sum of the abundances of the genus *Trichocerca*

QB / T values <1.0 → Oligotrophic

Values of 1.0 <QB / T <2.0 → Mesotroph

Values of QB / T > 2.0 → Eutrophic

RESULTS

Qualitative analysis of the population

In total, 42 zooplanktonic taxa were identified, including 33 taxa in Ehuikro and 28 taxa in Socotè and 31 taxa in Kaby. This population includes 26 *Rotifers*, 6 *Copepods*, 3 *Cladocerans* and 5 other organisms (**Table I**). These 42 taxa are distributed between 18 families and 27 genus. The most diverse families are those of the *Brachionidae* (9 species and 4 genus) followed by the *Cyclopidae* (6 species and 5 genus), *Licanidae* (3 taxa), *Filinidae* (3 taxa) the *Asplanchnidae* (2 taxa), the *Trichocercidae* (2 taxa) and *Synchaetidae* (2 taxa). The other families are mono-specific. Among these observed taxa, only *Brachionus angularis*. (F = 92.85%), Other insect larvae (F = 95%), *Copepod nauplii* (F = 83.66%), *Thermocyclops dicipiens* (F = 83.33%), *Polyarthra vulgaris* (F = 80 %), *Lecane leontina* (F = 53.33%), *Hexarthra mira* (F = 52%), *Mesocyclops sp* (F = 51.66%), *Brachionus falcatus* (F = 51.22%) *Diaphanosoma excisum* (F = 51 %), *Keratella tropica* (F = 50%), *Ostracode* (F = 50%), are constant. All other taxa are incidental or accidental.

In terms of spatial richness, the Ehui 2 (28 taxa) and Ehui 1 (27 taxa) stations are more abundant in zooplankton. The Soco1 station (22 taxa) is the least in terms of spatial richness.

In terms of seasonal taxonomic richness (**Table II**), the dry season (20 taxa) was less rich than the rainy season (22 taxa). The richest station in the dry season was Ehui 2 station (26 taxa) and the least rich was Kaby 1 station (20 taxa). Ehui 2 station (26 taxa) was the richest in the rainy season and the least rich in the rainy season was the Kaby 1 station (23 taxa).

Quantitative analysis of the population

The zooplankton population sampled in lakes Ehuikro, Sokotè and Kaby (**Figure 2**) was characterized by the numerical dominance of rotifers (45% of total abundance), followed by copepods (40%), cladocerans (8%) and the group of other zooplanktonic organisms (7%).

The structure of the Rotifer population was dominated by *Brachionus angularis* (24.05%) followed by *Brachionus falcatus* (11.45%), *Polyarthra vulgaris* (10.92%), *Keratella tropica* (7.60%), *Lecane leontina* (7.60%), *Cephalodella gibba* (6.91%), *Brachionus calyciflorus* (6.73%).

Copepods are marked by the dominance of *nauplii* (45.70%) compared to other stages (copepodites and adults) (54.3%) represented mainly by *Thermocyclops decipens* (27.61%), *Thermcyclops neglectus* (13.11%) and *Mesocyclops sp* (8.51%). Cladocerans are dominated by *Diaphanosoma excisum* (50.74%) followed by *Moina micrura* (32.66%).

Table No. 1: Distribution and occurrence (% OCC) of the different zooplankton taxa collected in lakes Ehuikro, Socotè and Kaby (Côte d'Ivoire) from April 2017 to March 2018.

GROUPS	FAMILLIES	TAXA	EHUI 1	EHUI 2	EHUI 3	SOCO 1	SOCO 2	KABY 1	KABY 2	% OCC
ROTIFERES	Brachionidae	*Brachionus angularis*	+	+	+	+	+	+	+	92,85
		Brachionus calyciflorus	+			+	+	+	+	27,38
		Brachionus plicatilis				+	+	+		5
		Brachionus falcatus	+	+	+	+	+	+	+	51,22
		Keratella lenzi	+	+						3,33

		Keratella tropica	+	+	+	+	+	+	+	50
		Anuraeopsis navicula	+	+		+	+	+	+	38,66
		Anuraeopsis fissa	+	+	+		+	+	+	23,33
		Plationus patulus						+	+	21,42
	Filinidae	*Filinia longiseta*	+	+	+	+		+	+	41,66
		Filinia opoliensis	+	+	+	+	+	+	+	31,66
		Filinia terminalis	+	+	+	+	+			18,33
	Licanidae	*Lecane leontina*	+	+	+	+	+	+	+	53,33
		Lecane monostyla	+			+	+			8,33
		Lecane Sp.	+	+	+			+	+	38,33
	Mytilinidae	*Mytilina mucronata*	+			+	+			5
	Gastropudae	*Gastropus minor*	+					+		1,66
	Asplanchnidae	*Asplanchna Sp.*	+	+				+	+	23,33
		Asplanchna girodi				+	+	+	+	20
	Trichocercidae	*Trichocerca Chattoni*	+	+	+	+	+	+	+	18,33
		Trichocerca Sp.	+	+	+	+	+	+	+	16,66
	Notommatidae	*Cephalodella gibba*	+	+	+		+	+	+	33,33
	Flosculariidae	*Lacinularia floculosa*	+							1,66
	Synchaetidae	*Polyarthra vulgaris*	+	+	+	+	+	+	+	80
		Polyarthra Remeta						+	+	17,85
	Hexarthridae	*Hexarthra mira*	+	+	+	+	+	+	+	52

Table No.1 continued: Distribution and occurrence (% OCC) of the different zooplankton taxa collected in lakes Ehuikro, Socotè and Kaby (Côte d'Ivoire) from April 2017 to March 2018.

GROUPS	FAMILLIES	TAXA	EHUI 1	EHUI 2	EHUI 3	SOCO 1	SOCO 2	KABY 1	KABY 2	% OCC
COPEPODES	Cyclopidae	*Thermocyclops dicipiens*	+	+	+	+	+	+	+	83,33
		Thermocyclops neglectus		+	+		+	+		43,33
		Paracyclops affinis		+	+					23,33
		Mesocyclops sp.	+	+	+	+	+			33,66
		Halycyclops koensis	+	+	+					33,33
	Indeterminée	*Nauplii*	+	+	+	+	+	+	+	83,66
CLADOCERES	Moinidae	*Moina micrura*				+	+	+	+	43,33
	Sididae	*Diaphanosoma excisum*		+	+			+	+	51
	Bosminidae	*Bosminia longirostris*				+	+	+	+	38,33
AUTRES ORGANISMES	Chironomidae	Larves de chironomidae		+	+			+	+	41,33
	Cyprididae	Ostracode	+	+	+	+	+	+	+	50
	Indeterminée	larves de chaoborus		+	+	+				16,33
	Centropyxidae	Centropyxis		+	+					21

	Indeterminée	Autres larves d'insectes	+	+	+	+	+	+	+	95
TOTAL	17	40	27	28	25	22	25	27	26	

Diversity index:

The highest value of the Shannon index (**Table N°2**) was recorded during the dry season at Ehui 1 station (2.74bits / ind) and the lowest during the dry season (1.81bits / ind) at the Kaby 2 station. The same was true for the Equitability index (0.89) during the dry season against (0.60) during the dry season in Ehui 1 and Kaby 2 stations.

Table No. 2: **Seasonal variations in the diversity indices of the zooplankton population collected in lakes Ehuikro, Sokotè and Kaby (Côte d'Ivoire) from April 2017 to March 2018.**

DIVERSITY INDEX	SAISONS	EHUI 1	EHUI 2	EHUI 3	SOCO 1	SOCO 2	KABY 1	KABY 2
TAXONOMIC RICHNESS	Dry saison	22	26	20	17	22	20	18
	Rainy season	20	25	22	17	22	23	20
SHANNON INDEX	Dry season	2 ,74	2,59	2,50	2,1	2,4	1,93	1,81
	Rainy season	2,46	2,67	2,68	2,2	2,5	2,71	2,3
EQUITABILITY INDEX	Dry season	0,89	0,79	0,84	0,74	0,76	0,63	0,6
	Rainy season	0,82	0,83	0,87	0,79	0,80	0,83	0,78

Spatial variation in the total density of zooplankton sampled in the lakes Ehuikro, Sokotè and Kaby from April 2017 to March 2018.

The highest zooplankton density (**Figure 2**) was observed at Ehui 2 station (413.4 ind / L), i.e. 32.94% of the total zooplankton, against the lowest at Soco 2 station (192 ind / L), i.e. 15.27% of the total zooplankton. The average abundance obtained in the sampling points of Ehuikro (285 ind / L) was higher than those recorded in the Kaby (268 ind / L) and Socotè (202 ind / L) lakes.

The highest density of rotifers was sampled in Lake Ehuikro 364 ind / L against the lowest in Lake Sokotè 190 Ind / L, with the highest density of rotifers observed at Ehui 2 station (178 ind / L) or 30, 91% of the rotifers, against the lowest density observed at the Ehui 3 station (77.6 ind / L) or 14.04% of the rotifers.

The greatest abundance of copepods was observed in Lake Ehuikro (413 ind / L) against the lowest in Lake Socotè (134 ind / L). The highest density at the Ehui 2 station (190 ind / L), i.e. 34.81% of the copepods, against the lowest density observed at the Kaby 2 station (50 ind / L), i.e. 10.69% of the copepods.

Cladocerans experienced the highest abundance in Lake Kaby 2 (50 ind / L), against the lowest in Lake Socotè (39 ind / L). The highest density was observed at the kaby 2 station (35 ind / L) 24.64% of cladocerans. Against (0 ind / L) at Ehui 1 station.

The highest abundance of other zooplankton organisms was observed in Lake Kaby with 63ind / L against the lowest abundance in Sokotè 30 ind / L, with the highest densities in the Kaby 2 stations (36 ind / L) against lowest at Ehui 1 station (0 ind / L).

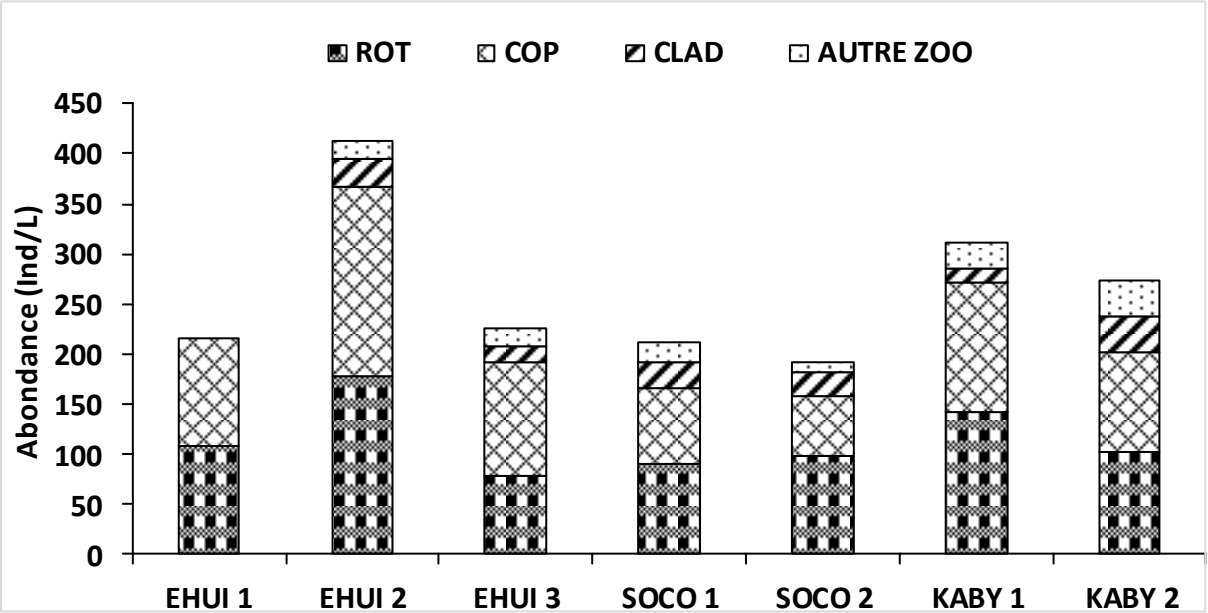

Figure No. 2: Spatial variation in the total density of zooplankton sampled in lakes Ehuikro, Kaby and Socotè from April 2017 to March 2018. ROT = Rotifère; COP = Copepod; CLAD = Cladoceran; OTHER ZOO = Other Zooplanktonic Organism.

Spatio-temporal variation in total abundance.

The abundance of the organisms sampled (**Figure 3**) during the rainy season in all stations (976 ind / L) was highest than that sampled in the dry seasons in all stations (816 ind / L). The highest spatial abundance was observed during the rainy season at Ehui 2 (208 ind / L) and the lowest spatial abundance was observed during the dry season at Soco1 (81ind / L).

The highest abundances of rotifers was observed in Ehui 2 during the dry (98 ind / L) and rainy (80 ind / L) seasons, against the lowest in Ehui 3 (35 ind / L) during the rainy season and Soco1 (35 ind / L) during the dry season.

As for the copepods, the highest abundances was observed at Ehui 2 during the dry (99 ind / L) and rainy (93 ind / L) seasons; against the lowest at Kaby 2 (20 ind / L) during the dry season and soco 1 (24 ind / L) during the dry season.

Cladocerans experienced the greatest abundance in Kaby 2 (27 ind / L) during the rainy season. Against (0 ind / L) at Ehui 1 during the dry and rainy seasons.

The other zooplanktonic organisms experienced the highest abundance during the rainy seasons at Kaby 1 (22 ind / L) and (20ind / L) at Kaby 2. Against 0 ind / L at Ehui 1in all seasons.

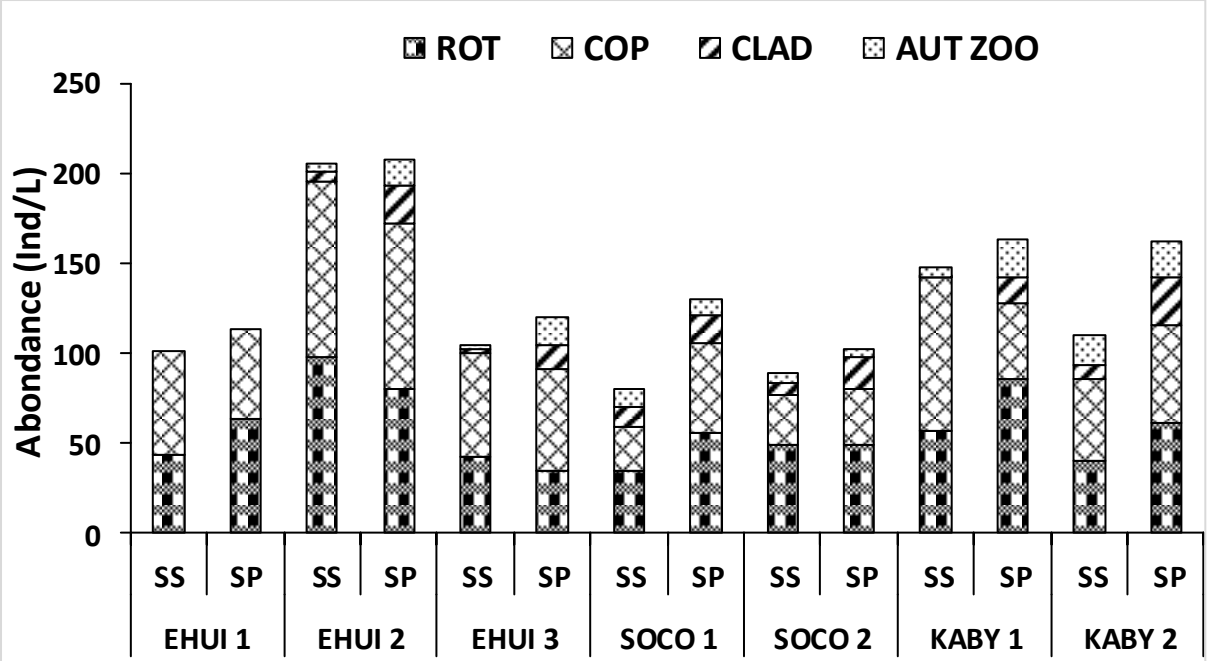

Figure No. 3: **Spatio-temporal variation in the total density of zooplankton sampled in Lakes Ehuikro, Kaby and Socotè from April 2017 to March 2018**.

SS = Dry season; SP = Rainy season, ROT = Rotifer; COP = Copepod; CLAD = Cladoceran; AUT ZOO = Other Zooplanktonic Organism.

Spatio-temporal variation in the structure of the rotifer phylum

Rotifers (**Figure 4**) constituted a total abundance of 785 ind / L, or 45% of the total zooplankton, dominated by *Brachionidae* (50.92% of rotifers). In terms of taxa, the most abundant was that of *Brachionus angularis* (189 i nd / L) or 25.34% of rotifers and the lowest taxon was that of *Anuareopsis navicula* (8.8 ind / L) or 1.64% rotifers.

In terms of station, the richest in rotifers is Ehui 2 with 178 ind / L / that is 33.22% of which 80 ind / L in the rainy season and 98 ind / L in the dry season.

The station least rich in rotifers is that of Soco 1 with (73.6 ind / L) of which 31.4 ind / L in the rainy season and 42.2 ind / L in the dry season.

In terms of season, the abundance observed in the rainy season (263.6 ind / L) was lower than that of the dry seasons (272.2 ind / L).

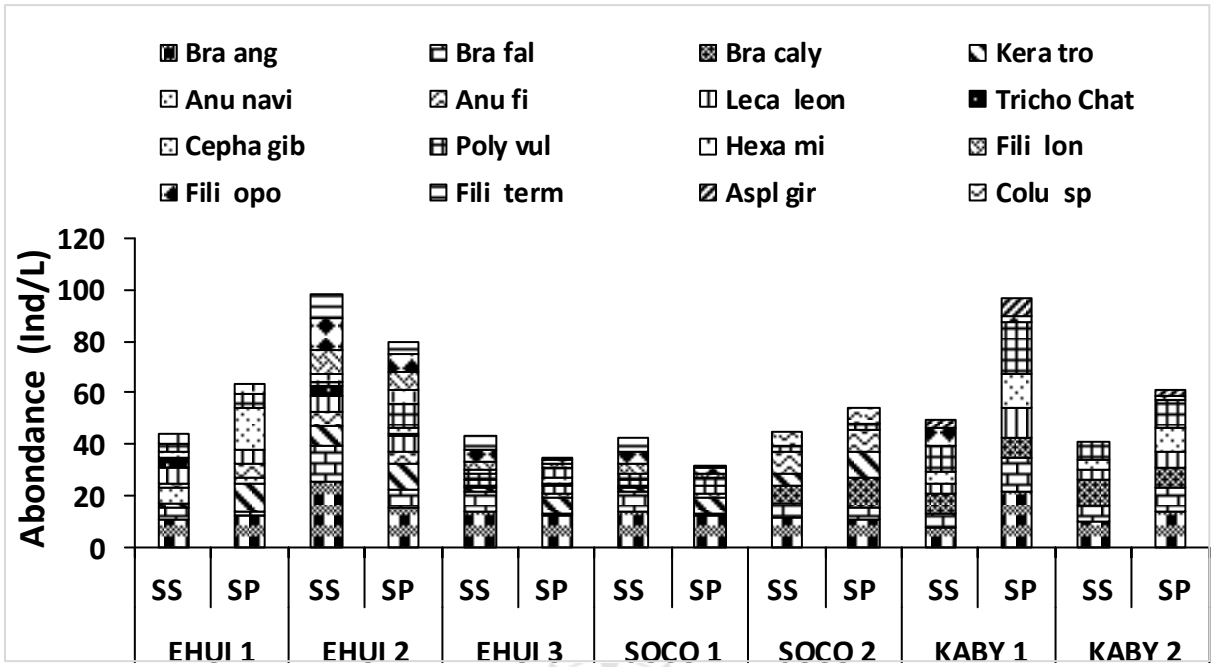

Figure No. 4: **Spatio-temporal variation in the structure of the phylum of rotifers sampled in the Ehuikro, Sokotè and Kaby from April 2017 to March 2018.** SS = Dry season; SP = Rainy season.

Spatio-temporal variation in the structure of the phylum of copepods

The copepods constituted a total density of 722 ind / L, corresponding to 40% of the total zooplankton, dominated by *Cyclopidae* (54.23%) (**Figure 5**). In terms of taxa the most abundant was that of *nauplii* (330 ind / L), that is 45.70% of copepods followed by *Thermocyclops dicipiens* (178 ind / L) that is 24.65% of copepods and the lowest taxon was *Halycyclops koensis* (20 ind / L), i.e. 2.77% of copepods.

In terms of station, the richest in copepods is Ehui 2 with 191 ind / L / thai is 26.45% of which 93 ind / L in the rainy season and 98 ind / L in the dry season.

The least rich station was that of Kaby 2 with (50 ind / L) that is 6.92%: including 30 ind / L in the rainy season and 20 ind / L in the dry season.

In terms of the season, the abundance in the rainy seasons (333 ind / L) was lower than that of dry seasons (389 ind / L).

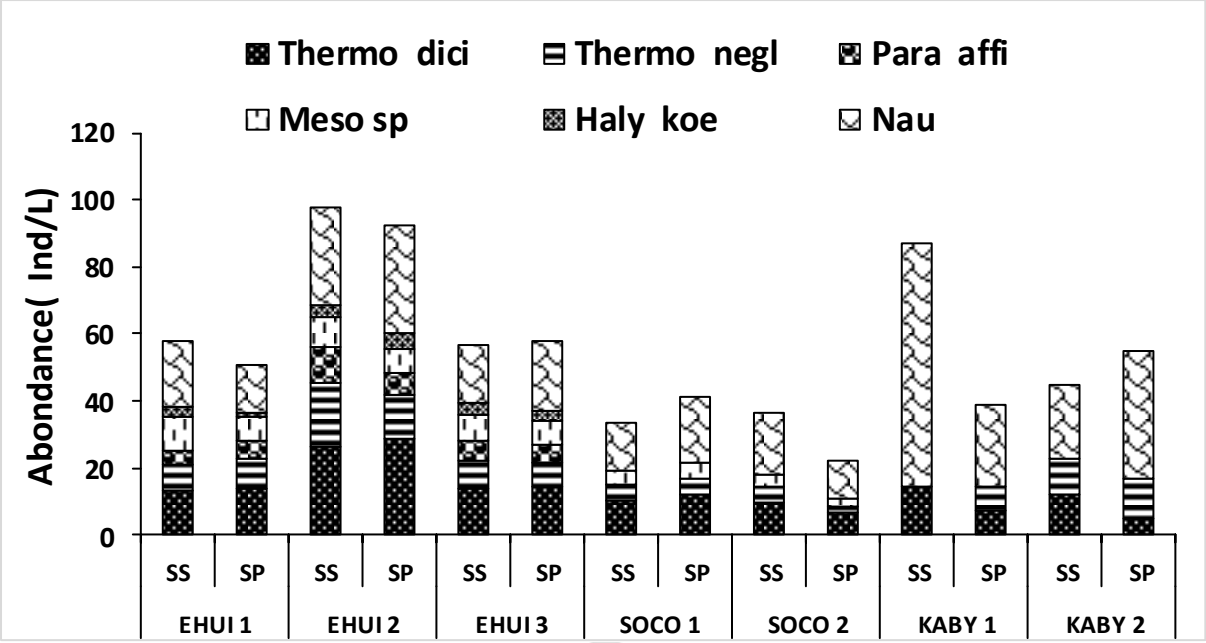

Figure No. 5: **Spatio-temporal variation in the structure of the phylum of copepods sampled in Ehuikro, Kaby and Sokotè from April 2017 to March 2018**. SS = Dry season; SP = Rainy season.

Spatio-temporal variation of the phylum structure of cladocerans

The total abundance of cladocerans (**Figure 6**) was 149 ind / L, that is 8.31% of the total zooplankton, dominated by *Diaphanosoma excisum* (76 ind / L) or 51% of cladocerans. The least dominated taxon was *Bosmina longirostris* (25 ind / L) or 16.77% of Cladocerans.

Lake Ehuikro had the lowest abundance of cladocerans organisms with 42 ind / L that is 28.18% of cladocerans (16ind / L in the dry season and 26 ind / L in the rainy season) against 56 in / L for lake Kaby that is 37.58% of cladocerans (9 ind / L in the dry season and 47 ind / L in the rainy season.

In terms of station, the richest in cladocerans was that of Kaby 2 with 35 ind / L / that is 23.49% of cladocerans, including 27 ind / L in the rainy season and 8 ind / L in the dry season.

The station with least cladocerans was Ehui 1 with (0 ind / L).

In terms of season, the abundance in the rainy season (112 ind / L) was higher than that in the dry seasons (37 ind / L).

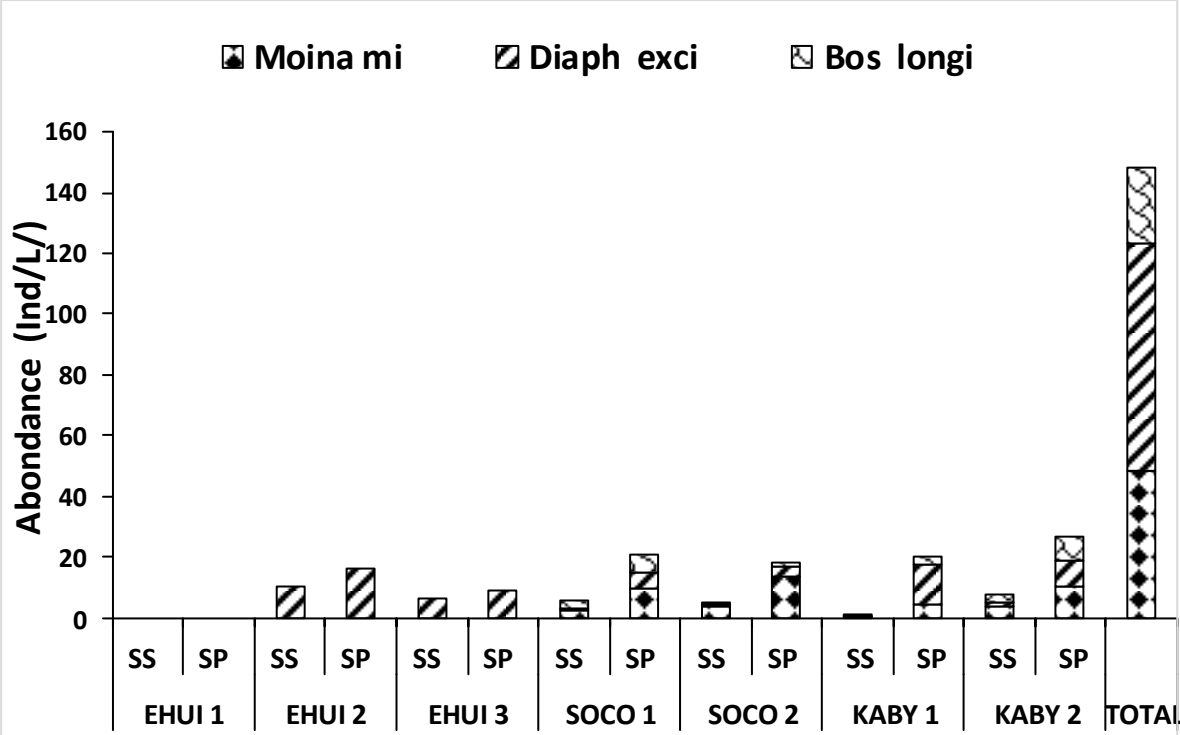

Figure No. 6: **Spatio-temporal variation in the structure of the phylum of cladocerans sampled in Ehuikro and Socotè from April 2017 to March 2018**, SS = Dry season; SP = Rainy season.

Spatio-temporal variation of the phylum structure of other zooplanktonic organisms.

The total abundance of other zooplankton organisms was 124 ind / L that is 6.91% of the total zooplankton, dominated by *Chironomidae larvae* (48 ind / L) which is 38.71% of other zooplankton organisms (**Figure 7**). The least taxa was that of Centropyxis (10 ind / L) that is 8.06% of other zooplanktonic organisms.

Lake Sokotè had the lowest abundance of other zooplankton organisms with 30 ind / L which is 24.19% of other zooplankton organisms (17 ind / L in the dry season and 13 ind / L in the rainy

season) against the highest abundance in Lake Kaby 57 in / L that is 47.97% of other zooplankton organisms (17 ind / L in the dry season and 40 ind / L in the rainy season).

In terms of station, the richest in other zooplankton organisms was that of Kaby 2 with 30 ind / L /, that is 24.19% of other zooplankton organisms including 19 ind / L in the rainy season and 11 ind / L in the dry season.

The least station in terms of richness was Ehui 1 (0 ind / L).

In terms of the season, the abundance obtained during the rainy seasons (83 ind / L) was higher than that of the dry seasons (41 ind / L).

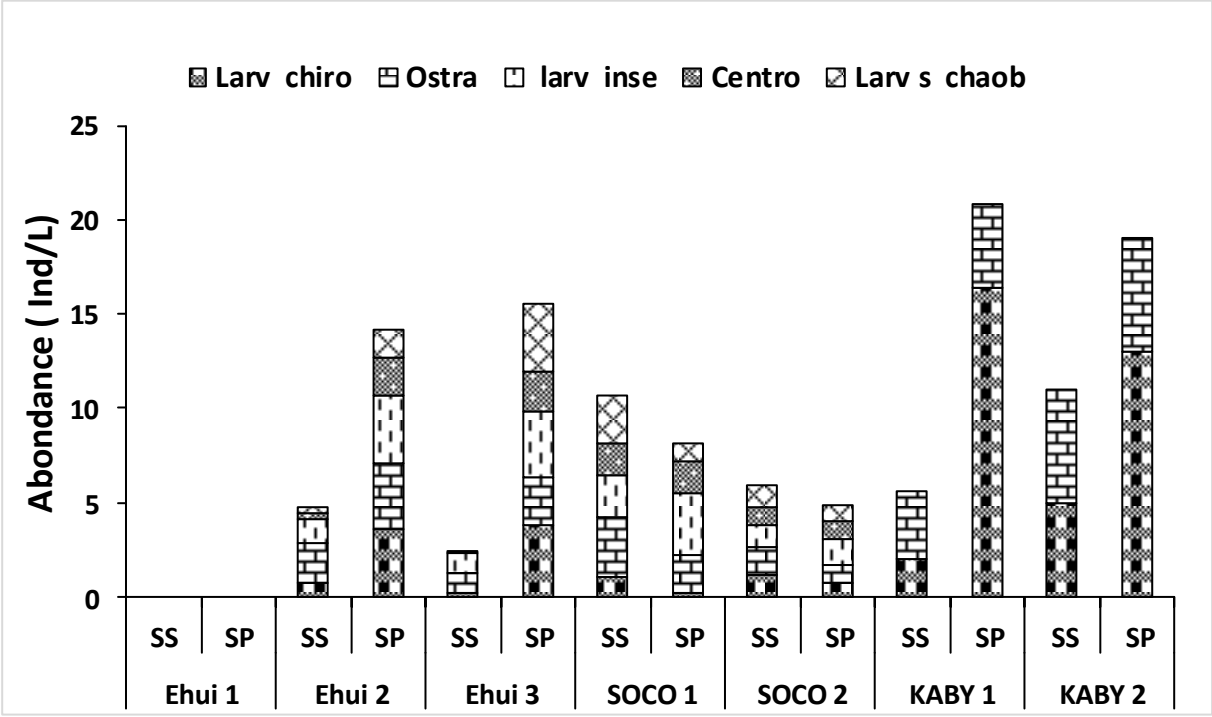

Figure No. 7: **Spatio-temporal variation in the structure of the phylum of other zooplanktonic organisms sampled in lakes Ehuikro, Kaby and Sokotè from April 2017 to March 2018**. SS = Dry season; SP = Rainy season.

Spatial analysis of physicochemical parameters

In Ehuikro the values of the level of dissolved solid (TDS = 167.9 mg / L); Conductivity (Cond = 285.87Ms / cm); Temperature (Temp = 28.34 ° C) and Transparency (Transp = 0.65cm) (**Table**

III) obtained during the dry seasons were higher than those obtained in the rainy seasons (TDS = 165.75mg / L) ; (Cond = 251.07); (Temp = 27.48 ° C) and the (Transp = 0.49cm), contrary to Hydrogen potential (PH = 7.92); the level of oxygen saturation (Sat TO_2 = 63.52 (%));dissolved oxygen level (TO_2 = 4.81 (mg / l)); phosphorus level ($P04^{3}$- = 0.05 mg / l) depth (Depth = 3.82cm) obtained during the rainy seasons which had higher values than those obtained in the dry seasons (pH = 7.44); (SatTO_2 = 55.29%); (TO_2= 4.16 mg / l); ($P0_4^{3-}$ = 0.04mg / l) depth (Depth = 2.95cm) Only the values of the Nitrate ($N0^{3-}$ = 0.01mg / l) were identical in all the seasons. The highest value of the physico-chemical parameters obtained at Ehuikro during the dry seasons was the Conductivity (Cond = 285.87Ms / cm) against the lowest, the level of Nitrate ($N0^{3-}$ = 0.01mg / l) constant in all seasons.

In Socotè the values obtained during the dry seasons level of dissolved solid (TDS = 233.25 mg / L); the Conductivity (Cond = 471.25Ms / cm) and Phosphorus level.

($P0_4^{3-}$ = 67.29mg / l) were higher than those obtained during the rainy seasons (TDS = 215.5mg / L); (Cond = 325.16Ms / cm); (P043- = 31.46 mg / l). Unlike the values of Hydrogen Potential (PH = 7.14); Temperature (Temp = 27.68 ° C); the level of oxygen saturation (Sat TO_2 = 33.97 (%); dissolved oxygen (TO_2= 2.62 (mg / l)); Nitrate level ($N0^{3}$- = 33.75 mg / l); the Transparency (Transp = 0.19cm) and the Depth (Depth = 0.59 m) obtained during the rainy seasons were higher than the values obtained during the dry seasons (PH = 6.96); (Temp = 26, 92 ° C); (SatTO2 = 31.91 (%); (TO_2 = 2.46 (mg / l)); ($N0^{3-}$ = 16.08 mg / l); (Transp = 0.16 cm) and the (Depth = 0.49cm).

The highest value of the physicochemical parameters obtained during the dry seasons was the Conductivity (Cond = 471.25Ms / cm) against the lowest value Transparency (Transp = 0.16 cm) also obtained during the dry seasons (**Table III**).

In lake Kaby the values of dissolved solid (TDS = 254.15 mg / L); Conductivity (Cond = 426.17 Ms / cm); Hydrogen Potential (pH = 7.26), oxygen saturation level (Sat TO_2 = 43.22 (%)); dissolved oxygen level (TO_2 = 4.81 (mg / l)); level of phosphorus ($P04^{3}$- = 16.88 mg / l); and Transparency (Transp = 0.25cm) (**Table III**) obtained during the dry seasons were higher than those of the rainy seasons (TDS = 160.85mg / L); (Cond = 246.7); (Temp = 27.48 ° C); (P^{H} = 6.83); (Sat TO_2 = 41.98 (%)); (TO_2 = 3.02 (mg / l)); ($P0_4^{3-}$ = 15.64 mg / l) and la (Transp = 0.2

cm), unlike the Temperature (Temp = 27.59 ° C); Nitrate level (N03- = 43.89 mg / l) and the depth (Depth = 1.27m) obtained during the rainy seasons which had values higher than those of the dry seasons (Temp = 26.7 ° C) (NO^{3-} = 17.09 mg / l); (Depth = 1.27m). The highest value of the physico-chemical parameters obtained at Ehuikro during the dry seasons was the Conductivity (Cond = 426.17Ms / cm) against the lowest, transparency (Transp = 0.2 mg / l), obtained during the dry seasons.

Table No. 3: **Mean values and standard deviation of the physicochemical parameters of the waters of lakes Ehuikro and Socotè measured from April 2017 to March 2018.**

LAKE	SEASONS	TDS (mg/L)	COND (Ms/cm)	pH	Temp (°C)	Sat TO2 (%)	TO2 (mg/l)	$P04^{3-}$ (mg/l)	$N0^{3-}$ (mg/l)	Transp (cm)	Depth (cm)
EHUIKRO	Mean SS	167,9	285,87	7,44	28,34	55,29	4,16	0,04	0,01	0,65	2,95
	SD	13,77	11,87	0,09	0,1	12,63	1,09	0,01	0	0,04	0,4
	Mean SP	165,75	251,07	7,92	27,48	63,52	4,81	0,05	0,01	0,49	3,82
	SD	5,92	7,74	0,33	0,59	3,19	0,54	0,01	0,01	0,04	0,43
SOCOTE	Mean SS	233,25	471,25	6,96	26,92	31,91	2,46	67,29	16,08	0,16	0,49
	SD	56,25	41,25	0,24	1,27	15,59	1,36	33,82	8,94	0,04	0,06
	Mean SP	215,5	325,16	7,14	27,68	33,97	2,62	31,46	33,75	0,19	0,59
	SD	4,5	6,08	0,54	0,32	18,77	1,49	1,46	16,15	0,05	0,06
KABY	Mean SS	254,15	426,17	7,26	26,7	43,22	3,43	16,88	17,09	0,25	1,04
	SD	1,23	2,71	0,06	0,04	0,19	0,15	2,59	3,96	0,01	0,06
	Mean SP	160,85	246,7	6,83	27,59	41,98	3,02	15,64	43,89	0,2	1,27
	SD	0,75	1,26	0,05	0,09	2,54	0,19	0,56	5,83	0,01	0,05

Spatio-temporal diagram indicating the trophic state of lakes Ehuikro, Kaby and Socotè

With respective QB / T of 0.88 (oligotrophic) in rainy seasons and 1.46 (mesotrophic) in dry seasons (**Figure 8**), Lake Ehuikro presents in rainy seasons the characteristics of an environment particularly poor in nutrients and rich in oxygen. In dry seasons, Lake Ehuikro presents the characteristics of an environment rich in nutrients.

Lake Kaby with respective QB / T of 2.63 (Eutrophe) and 4.00 (Eutrophe) during the dry and rainy seasons, is characterized by the strong presence of nutrient and the absence of oxygen.

Lake Socotè also with QB / T of 3.93 (Eutrophe) and 3.27 (Eutrophe) during the dry and rainy seasons respectively would be characterized by a strong presence of nutrients and an absence of oxygen.

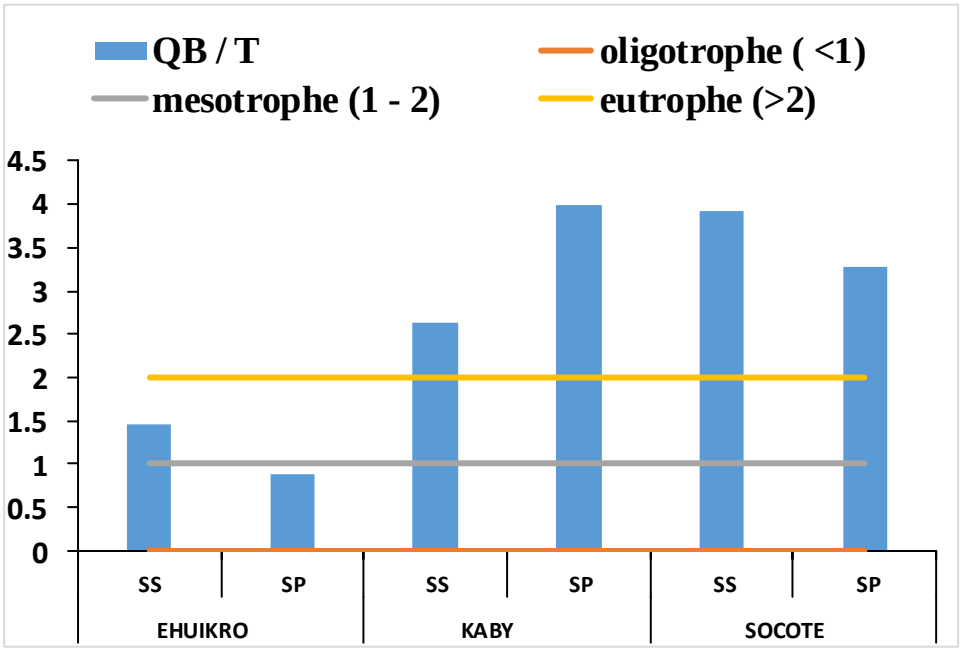

Figure No. 8: Spatio-temporal diagram indicating the trophic state of the lakes Ehuikro, Kaby and Sokotè.

Impact of abiotic variables on the distribution of the zooplankton population.

The results of the redundancy analysis (**Figure 9**) showed that the correlation between environmental factors and zooplankton taxa are mainly explained by the first two axes (61% of the total variance). The depth, conductivity, temperature, level of dissolved solid, nitrate level, hydrogen potential, phosphorus level, rate of dissolved oxygen and level of saturated oxygen are the variables that strongly influence the distribution of zooplankton organisms in the lakes Ehuikro, Sokotè and Kaby. The Ordination in the Redundancy Analysis (RDA) along axis 1 clearly separates the stations of Lake Socotè from those of lakes Ehuikro and Kaby. The group of organisms: *Anuraepsis fisa*, *Keratella tropica*, *Centropixis*, *insect larva*, *chaoborus larva*, are

correlated with Soco 1 station (dry and rainy season) and characterized by temperature, pH, dissolved oxygen level and the level of saturated oxygen.

The group of organisms: *Collumera sp*, *Moina micrura*, *Brachionus calyciflorus* and *Bosminia longirostris* are correlated with the Soco 2 station (dry and rainy season) and characterized by the level of phosphorus, the level of dissolved solid, the conductivity and the nitrate level. The ordination in the RDA along axis 2 clearly separates the station of Lake Ehuikro from those of Lake Kaby.

The group of organisms, *Cephalodela giba*, *Hexarthra mira*, *Mesocyclops sp*, *Paracyclops affinis*, *Halicyclops koensis*, *Thermocyclops negletus*, *Thermocyclops dicipiens*, *Filinia terminalis*, *Filinia longeseta*, *Hexarthra mira* and *Anuraepsis navicula* are correlated with stations Ehui1, Ehui 2 and Ehui 3 (dry and rainy season).

Organisms: *Brachionus angularis*, *copepod nauplii*, *Filinia opoliensis*, *Brachionus falcatus*, *Diaphanosoma excisum*, *Chironomidae larvae*, *Ostracods*, *Cephalodela gibba*, *Asplanchna girodi* and *Polyarthra vulgaris* are correlated with the Kaby 1 and Kaby 2 (rainy seasons) stations.

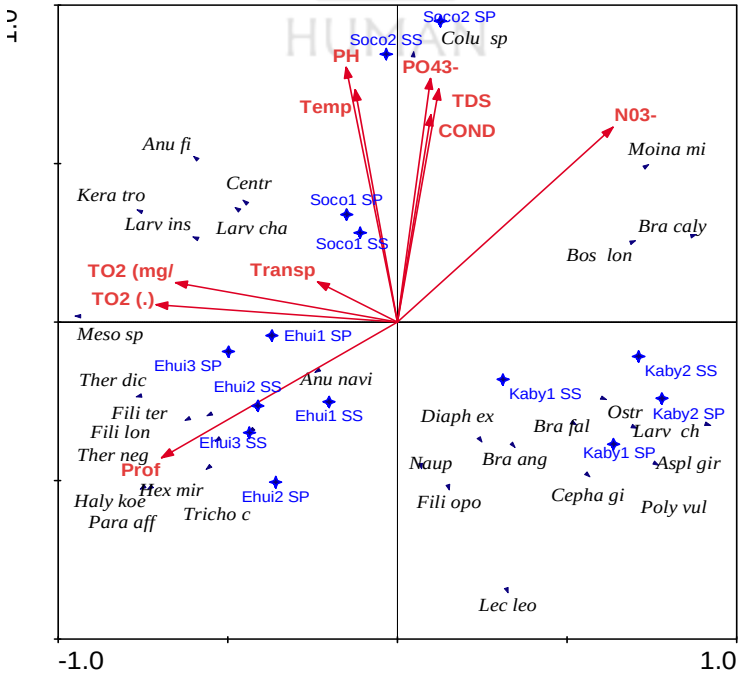

Figure No. 9: **The Ordination in the Redundancy Analysis of the main taxa of zooplankton in the lakes Ehuikro, Kaby and Socotè as a function of environmental variables**. *L leo* =

Lecane leontina; T dic = Thermocyclops decipiens, B caly = Brachionus calyciflorus, Al gir = Asplanchna girodi, A fisa = Anuraepsis fisa, B long = Bosmina longirostris, Ostr = Ostracode, L sp = Lecane sp, P vul = Polyarthra vulgaris, H mir = Hexarthra Mira, L chir = Larvae of chirominidae; M mic = Moina micrura, Diaph exci = Diaphanosoma excisum; Bra ang = Brachionus angularis.

DISCUSSION

The present study made it possible to collect 42 zooplankton taxa, including 33 taxa in Ehuikro, 28 taxa in Socotè and 31 taxa in Kaby. This richness (42 taxa) could be explained by the small area of the lakes with average depths of 0.54 m for Lake Socotè, 1.15 m for Lake Kaby and 3.38 m for Lake Ehuikro. The location of Socotè and Kaby lakes in the middle of an urban agglomeration, thus subjected to domestic waste discharges and the shrinking of their surface areas by the effect of galloping demography which can lead to pollution of their waters. As for Lake Ehuikro, it is located at the entrance to the city, around some agricultural plantations, fields and farms. This settlement is richer in species, in comparison to those of Lake Kaby by, Fofana *et al,* (2019) (31 taxa) and Adandedjan *et al.,* (2017), (31taxons) in Lake Nokoué. Several reasons (physicochemical characteristics and surface area of the environment and sampling devices) can explain these observations. The present study made it possible to identify 42 species with a net of 60 µm, against 30 species obtained by Aka *et al,* (1998) with a plankton net of 20 µm. The mesh of the nets used for capture could play a role in the collection of zooplankton.

Rotifers (45%) largely dominated the zooplanktonic population. They constitute the most abundant zooplankton group in reservoirs (Margalef, 1983). Rotifers are capable of ingesting small particles such as bacteria and organic detritus often abundant in eutrophic environments. It follows from Margalef, (1983) that a strong representation of rotifers in freshwater aquatic environments can be considered as a biological indicator of a high trophic level, moreover, the rotifers, the main zooplankton group in the present study has already been abundantly found in eutrophic and hypereutrophic environments such as the Mfoundi hydrographic network (Cameroon) (Foto Menbohan, 2012). The high taxonomic richness and the high abundances observed at the Ehui 2 station (25 to 26 taxa), compared to the Ehui 1 stations; Ehui 3; Soco 1 and Soco 2 (17 to 20 taxa) showed that this station, Lake Ehuikro offers better conditions for the development of the zooplankton population. In fact, in this station located in an almost swampy

area, the great diversity of habitats, the high levels of nutrients, the abundance of living animal, plants and food resources and the decrease in the speed of the water current are favorable to development and the proliferation of zooplankton. These observations are in agreement with those of Vannote et al. (1980), Lecerf (2005) who have shown the efficiency of the fluvial system to produce living matter in downstream areas of watercourses following the formation of retention areas for organic matter (dead arm, lentic facies).

The average density and diversity of zooplankton are higher during rainy seasons (326 ind / L, total diversity) than during dry seasons (272 ind / L, total diversity). This could be explained by the arrival of rainwater with domestic effluents in the lakes, leading to an enrichment of the environment in nutrient salts promoting algal growth, the first food link for zooplankton. These observations are identical to those of Saint-Jean (1983), Okogvu and Ugwumba (2006). However, these findings do not corroborate the results of Fofana et al (2019), Onyema et al. (2003), Onyema and Nwankwo (2006) and Okogvu (2009) who showed that the highest abundances were obtained in the dry seasons. According to the latter, several stable conditions including the movement of water, the penetration of light, the reduction in rains observed in the dry season could promote the development of a rich zooplankton spectrum in dry seasons than in the rainy seasons. The low taxonomic richness and abundance recorded at Soco 1 station (dry season: 17 taxa) (rainy season: 17 taxa) would be due to the advanced degree of pollution of Lake Socotè, causing the less resistant organisms to disappear. Low values of taxonomic richness and abundance during dry seasons have already been observed by Foto Menbohan et al. (2012). The dynamic distribution of zooplankton organisms depends on a set of environmental factors including water temperature, light penetration, water chemistry (particularly pH, dissolved oxygen, toxic contaminants), availability of food (algae, bacteria) and predation by fish and invertebrates (Onyema and Ojo, 2008). Fluctuations in the Shannon index during the different seasons (dry season = 1.81 → 2.74) and (rainy season = 2.2 → 2.71) and the equity index (dry season = 0,6 → 0.89) and (rainy season = 0.79 → 0.87) reveal a great instability in the structure of the zooplankton community. This explains the variability of the environmental conditions that prevailed there during the study of the water reservoirs. This instability of the environment is also justified by the preponderance of accidental and/or accessory species (30/42 taxa). The abundance of cladocerans: *Moina micrura*, *Bosmina longirostis* and *Diaphanosoma excisum* during the rainy seasons is explained by lower temperatures and by high water levels.

According to Tchapgnouo et al. (2012), the rainy seasons contribute positively to the growth of cladoceran populations by providing new nutrients and by mixing the native nutrients present in the different strata of the lakes, thus promoting a high production of planktonic organisms and the drainage of new species of *cladocerans riparian* or recruited from other aquatic environments. In addition, rotifers (45%) are the main players in seasonal variations in diversity, with a strong participation of Brachionidae (51%). This dominance of rotifers is characteristic of tropical lakes (Mwebaza-Ndawula et al. 2005). (Ayoagui and Bonecker. 2004). The higher taxonomic richness (26 taxa) obtained in the dry season was consistent with the results of Okogwu (2009). But contrary to those of Ayoagui and Bonecker (2004), According to Ayoagui and Bonecker (2004) and Okogwu (2009), the lower rate of cladocerans would lead to a lack of competition with the more numerous rotifers. Indeed, according to Ayoagui and Bonecker (2004), the decrease in competitive dominant species would result in an increase in zooplankton diversity.

Rotifers more adapted to environmental changes and organic pollution would be less affected by certain phenomena such as high temperatures and degradation of water quality, unlike other organisms (Onana et al. 2014). Their proliferation in the environment is due to the accumulation of nutrients in the lakes. Hence the low richness of the environment in zooplankton organisms. The presence of *copepod nauplii* closely related to the high nitrate level (avg = 24.91 mg / L in Socotè lake), (avg = 0.003mg / L in Ehuikro lake) and (avg = 30.49 in lake Kaby) confirms that the Kaby and Socotè lakes are constantly subjected to organic pollution. These results are similar to the work of Adandedjan et al. (2017). The difference in density variation between nauplii and copepods could be explained by the development cycle of these organisms. Indeed, the development of nauplii and/or copepodites to the adult stage would lead to an increase in the density of the copepods to the detriment of the inferior stages. The preponderance of rotifers in the lake would be related to the high loads of organic matter in the water (high ammonia nitrogen content and conductivity). These organic matter induce a rapid multiplication of bacteria (Djuikom, 1998), which constitute the main food source of rotifers (Thouvenot et al. 2000). The strong presence of copepods and cladocerans in the lakes is linked to the seasonal constancy of the temperature :(Ehuikro (avg: 27.91 ° C), (Socotè (avg 27.30)); (Kaby (avg 27.13)) of the pH :(Ehuikro (avg: 7.63)), (Socotè (avg 7.05)); (Kaby (avg 7.04)) of the water of the environment. In addition, the high nitrate contents observed in Kaby (avg = 30.49) and Socotè (avg 24.91 mg /

L) confirm a significant organic pollution of these environments. Even if the high values of conductivity in Kaby (avg 336.33 Ms/cm) and socotè (avg 398.21 Ms/cm) compared to Ehuikro (avg 268.64 Ms/cm) seem to oppose the presence of zooplankton organisms in these lakes, according to some authors (Saint-Jean, 1983; Okogvu and Ugwumba, 2006), the adaptive capacity and tolerance of certain species of copepods (Thermocyclops, Mesocyclops and cladocerans to large variations in abiotic factors (conductivity, salinity and transparency) could explain their presence in this environment. Similar results were obtained by Onyema and Ojo (2008) in the Agboyi streams of the Lagos Lagoon in Nigeria, who found an increase in the abundance of rotifers and copepods (and copepodites) despite the increased rapid conductivity of water. On the other hand, according to Sacchi and Testard (1971), when the conductivity of water increases, the high osmotic pressure created can induce migration or death of organisms. Also, the anthropogenic pressures exerted on the lakes would result in the disturbance of their biotic and abiotic integrities.

The Sladecek index (1983) confirmed the trophic state of our various lakes:

Lake Ehuikro with a quotient of the sum of the abundance of the genus *Brachionus / Trichocerca* (QB / T = 0.88) in rainy seasons showed signs of an oligotrophic environment in this season. This QB / T = 0.88 could be explained by the wide area of this lake which would not allow the nutrients drained in it during the rainy seasons to accumulate in a fixed place which could lead to eutrophication. Also even if this water flows with a weak current, it must be recognized that this would facilitate the drainage of nutrients out of the lake, hence the strong presence of the *Trichocerca genus*, which are more sensitive to strong disturbances to the detriment of the *Brachionus genus*, which colonizes disturbed environments. Unlike the rainy season, Lake Ehuikro with a QB / T = 1.46 in dry seasons would show signs of a mesotrophic environment. Indeed, the absence of rains during this period and the reduction of the water body would cause the nutrients to group together in zones thus leading to algal growth. Thus leading to a disturbance of the environment, with the direct consequence of the strong presence of the genus *Brachionus* to the detriment of the genus *Trichocerca.*

Lake Kaby, with QB / T = 2, 63 and QB / T = 4.00 obtained in dry seasons and rainy seasons, respectively, would show signs of eutrophication in all seasons. This would be due to the arrival of rainwater and wastewater with it during all seasons, even if these actions are more intense

during rainy seasons (QB / T = 4.00), thus confirming the high levels of phosphorus and of nitrate taken from this environment. Hence the dominance of organisms of the *genus Brachionus* to the detriment of those of the *genus Trichocerca* in this lake.

Lake Sokotè, with QB / T = 3.93 and QB / T = 3.27 obtained respectively in dry and rainy seasons would reflect an advanced state of eutrophication of this environment. The causes of this eutrophication are numerous: first of all organic and chemical pollution of this environment by throwing of food (breads, roasted corn, milk, bananas, etc…) by the tourists coming to observe the fish. Then there is pollution by wastewater and rainwater and finally the effect of the sun on this environment. Hence the massive presence of organisms of the *genus Brachionus* to the detriment of those of the *genus Trichocerca* more sensitive to severe disturbances. These results confirm once again the degree of advanced disturbance of our study environments in ascending order: Lake Ehuikro, Lake Kaby and Lake Sokotè.

CONCLUSION

At Ehuikro 33 zooplanktonic taxa were collected. These taxa are distributed among four major zooplankton groups [Rotifers (21 taxa; 64.86%), Copepods (6 taxa; 16.21%), Cladocera (1 taxa; 2.70%) and the group of other zooplankton organisms (5 taxa, 10.81%)]. These 33 taxa are divided into 17 families and 25 genera plus the taxa whose families and genera have remained undetermined. In Kaby 31 zooplankton taxa have been identified. This stand includes 22 Rotifers (80%), 3 Cladocerans, 3 Copepods, and 3 other organisms. These 31 taxa are divided between 17 families and 21 genera. The most diverse families are those of Brachionidae (8 species and 4 genera) followed by Licanidae (3 taxa), and Synchaetidae, Asplanchnidae (2 taxa). The other families are mono-specific plus the taxa whose families and genera have not been determined. In Socotè, 28 zooplanktonic taxa were collected. These taxa are distributed among four major zooplankton groups [Rotifers (17 taxa; 60.71%), Copepods (4 taxa; 14.29%), Cladocerans (3 taxa; 10.71%) and the group of other zooplankton organisms (4 taxa, 14.29%)]. These 28 taxa are divided into 16 families and 20 genera plus the taxa whose families and genera have remained undetermined.

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