GSC Biological and Pharmaceutical Sciences

eISSN: 2581-3250 CODEN (USA): GBPSC2

Cross Ref DOI: 10.30574/gscbps

Journal homepage: https://gsconlinepress.com/journals/gscbps/

(RESEARCH ARTICLE)

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Diversity of zooplankton in the urban lakes of Yamoussoukro (central Côte d'Ivoire)

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GSC Biological and Pharmaceutical Sciences, 2025, 32(03), 180-185

Publication history: Received on 05 August 2025; revised on 14 September 2025; accepted on 17 September 2025

Article DOI: https://doi.org/10.30574/gscbps.2025.32.3.0354

Abstract

The urban lakes of Yamoussoukro, subject to strong anthropic pressure, present an ecological richness that is often overlooked, particularly in terms of zooplankton. This study aims to assess the zooplankton diversity of these aquatic environments in relation to their physico-chemical conditions and surrounding human activities.

The six (6) sampling campaigns revealed the presence of four (4) taxonomic groups : Rotifera, Cladocera, Copepoda, and Ostracoda, each playing a specific ecological role in lake food webs. Among these groups, Rotifera are rich in taxa and the most abundant. The composition and abundance of taxa vary between lakes, influenced by factors such as temperature, pH, dissolved oxygen, transparency, and depth.

Specific diversity, calculated using the Shannon index, shows low taxonomic richness in the urban lakes of Yamoussoukro, suggesting ecological imbalance.

In conclusion, zooplankton appears to be a powerful tool for ecological diagnosis and sustainable management of urban aquatic environments. A better understanding of this biodiversity can contribute to the development of conservation strategies adapted to the local context of Yamoussoukro.

Keywords: Diversity; Zooplankton; Artificial Lakes; Yamoussoukro

1. Introduction

Urban aquatic ecosystems play a vital role in maintaining biodiversity, particularly in tropical regions where biological productivity is naturally high **[1].** In Yamoussoukro, the political capital of Côte d'Ivoire, urban lakes are dynamic habitats subject to various anthropogenic pressures such as increasing urbanization, domestic waste disposal, and hydrological changes. Among aquatic communities, zooplankton occupies a strategic position in the trophic structure **[2]**. This important role is to transfer the energy fixed by producers to higher trophic levels [3]. Their short development cycle and small size make them easy to sample. Thus, studying zooplankton diversity in these lakes not only allows us to assess the ecological quality of the environments, but also to better understand the biological interactions that support their functioning.

This research aims to characterize the specific diversity of zooplankton in the main urban lakes of Yamoussoukro, while exploring the environmental factors that influence their distribution and abundance.

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2. Materials and methods

2.1. Study site

Yamoussoukro is located between 6°48' and 6°52' north latitude and between 5°12' and 5°18' west longitude **[4].** It has a humid tropical climate characterized by two (2) main seasons. The dry season lasts from November to February, and the rainy season from March to October, with the highest rainfall in September **[4],** (Figure 1). The dense and ramified hydrographic network of the Yamoussoukro district consists mainly of the Bandama River and its tributaries, as well as the N'Zi and Kan rivers. The city of Yamoussoukro has ten (10) artificial lakes **[5].** For this study, six (6) of these 10 lakes were selected for exploration (Figure 1). This choice was made based on their accessibility throughout the year, their geographical location, and the human activities carried out in their vicinity. A coding system was adopted to name these lakes. The lakes located in the city center have the codes L1, L2, and L3. Those located at the eastern, western, and southern ends have the codes L4, L5, and L6, respectively.

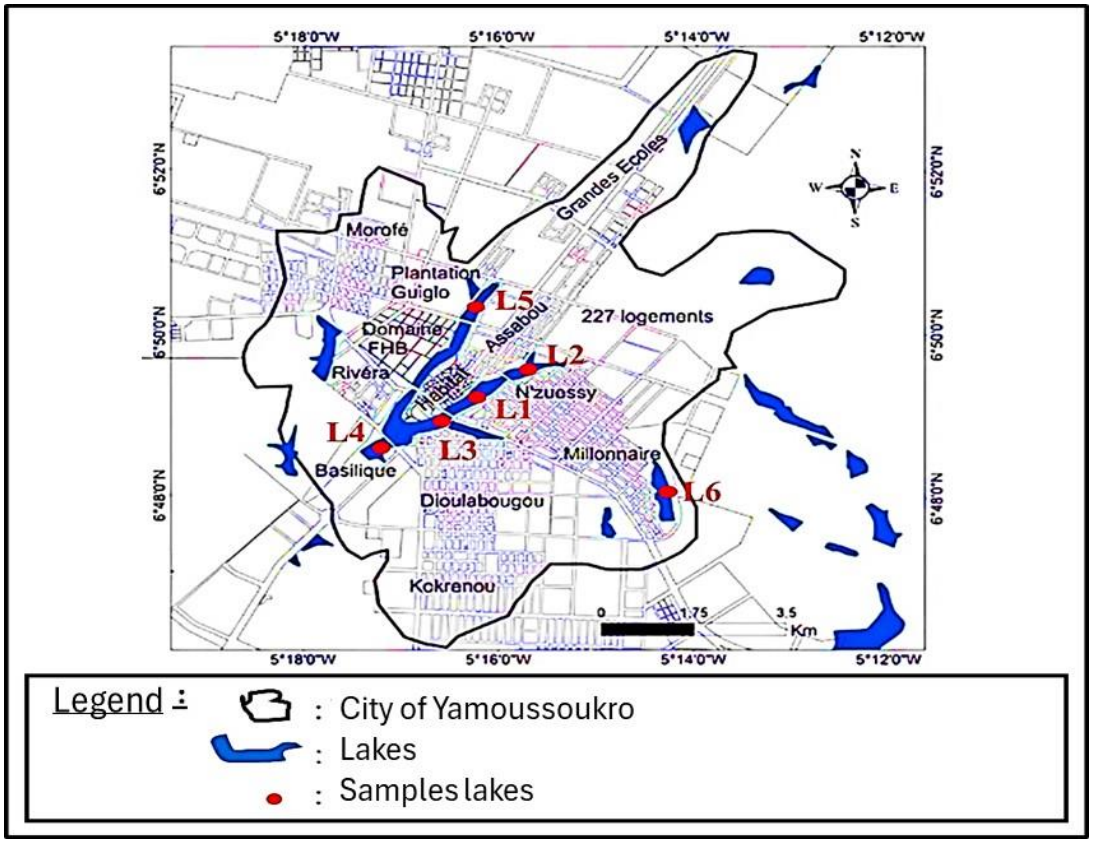

Figure 1 Location of the six urban lakes sampled in the city of Yamoussoukro

2.2. Methods

2.2.1. Measurement of abiotic parameters

Water temperature (°C), pH, conductivity (µS/Cm), and dissolved oxygen (mg/L) were measured using an HQ40d multiparameter meter. Water transparency (cm) was assessed using a 30 cm diameter Secchi disk attached to a long rope. Water depth (cm) was measured using an 8 m long board with regular graduations. The coverage of the lakes by macrophytes and the type of substrate were estimated visually and expressed as a percentage.

2.2.2. Sampling

In the field, sampling of the zooplankton community in the urban lakes of Yamoussoukro was carried out between 6 a.m. and 9 a.m. for daytime sampling, and between 8 p.m. and 10 p.m. for nighttime sampling. Zooplankton collection consisted of filtering 30 L of water (3 buckets with a capacity of 10 L). This volume of water was then filtered using a plankton net with a mesh size of 20 µm **[6]**. The selected sample was collected and stored in 100 mL pill bottles labeled with the addition of 5 drops of 70% ethanol. In the laboratory, zooplankton organisms were observed by taking a 10

mL subsample using a micropipette. This subsample was mounted between a slide and cover slip and then observed under an Optika B-192 photonic microscope with a 40× objective lens. The zooplankton organisms were identified and counted. Identification was carried out using the keys provided by **[7]** for rotifers, **[8]** for copepods, and **[9]** for cladocerans. These species were counted using an Optika *M226799* inverted microscope.

2.2.3. Data analysis

Taxonomic richness, percentage of occurrence, Shannon and Equitability indices were used to determine the structure and dynamics of the zooplankton community. The percentage of occurrence (F) is obtained using the following formula : $F = (Si / St) \times 100$, where Si is the number of samples in which taxon i was captured and St is the total number of samples.

The classification of taxa based on their percentage of occurrence was carried out according to Dajoz (2000) : $F \geq 50$: constant taxon ; $25\% \leq F < 50\%$ accessory taxon and $F < 25$: accidental taxon. Seasonal variations in taxonomic richness and densities of zooplankton organisms were assessed using the Mann-Whitney U test with Statistica v 7.1 software. Zooplankton taxa and environmental variables were correlated with SOM. This is version 2 of the SOM Toolbox interface for Matlab®.

3. Results

3.1. Overall taxonomic composition of zooplankton

The taxonomic composition and occurrences of zooplankton taxa in the urban lakes of Yamoussoukro are recorded in Table 1. A total of 31 taxa belonging to 17 families and 4 groups were collected from all lakes. The groups encountered are Rotifera, Copepoda, Cladocera, and Ostracoda.

Among these groups, Rotifera has the largest number of taxa with 23 taxa. Next come Copepoda (4 taxa) and Cladocera (3 taxa). Finally, there are the ostracods (1 taxon). The rotifer group is dominated by the Brachionidae family. Within the rotifer group, taxa are most commonly found in the Brachionidae (seven taxa) and Trichocercidae (five taxa) families. The copepod group is dominated by the Cyclopidae family.

The distribution of specific zooplankton richness by lake indicates that Lake 1 has more taxa (21 taxa). In contrast, Lake 4 has fewer taxa (10 taxa).

Analysis of occurrences shows that three (3) taxa are common and constant in all lakes. These are Brachionus angularis angularis, Mesocyclops leuckarti leuckarti, and Tropodiaptomus sp. All other taxa are incidental or accidental.

Table 1 Taxonomic compositions and occurrences of zooplankton species in urban lakes in Yamoussoukro (Ivory Coast) from July 2021 to May 2022

Groups	**Familles**	**Taxa**	**Acronyms**	**Lake 1**	**Lake 2**	**Lake 3**	**Lake 4**	**Lake 5**	**Lake 6**
Cladocera	Bosminidae	*Bosmina longirostris*	Blo	***	**	***	*	-	***
	Chydoridae	*Leydigia acanthocercoides*	Lac	-	**	***	-	-	**
	Daphniidae	*Simocephalus* sp.	Ssp	***	-	-	-	-	*
Copepoda	Diaptomidae	*Tropodiaptomus* sp.	Tsp	***	***	*	**	**	*
	Pseudodiaptomidae	*Pseudodiaptomus gordioides*	Pgo	-	-	-	-	-	**
	Cyclopidae	*Mesocyclops leuckarti*	Mle	***	*	***	**	**	***
		Nauplii sp.	Nsp	***	**	**	***		**
Rotifera	Conochilidae	*Conochilus hippocrepsis*	Chi	-	**	**	*	**	***
	Filiniidae	*Filinia opoliensis*	Fop	-	*	*	-	-	*
	Testudinellidae	*Testudinella patina*	Tpa	*	-	*	-	*	*
	Asplanchnidae	*Asplanchna* sp.	Asp	***	**	-	-	**	-
	Brachionidae	*Anuraeopsis fissa*	Afi	***	*	*	-	-	-
		Brachionus angularis	Ban	**	**	**	***	*	*
		Brachionus caudatus	Bca	-	*	-	-	-	-
		Brachionus forticula	Brf	-	-	-	-	**	-
		Brachionus plicatilis	Bpl	*	-	-	**	**	-
		Brachionus urceolaris	Bur	-	-	-	*	*	-
		Platyias quadridentatus	Pqu	**	-	-	-	-	-
	Lecanidae	*Lecane bulla*	Lbu	***	-	*	**	***	*
		Lecane furcata	Lfu	**	-	-	-	-	-
		Lecane lunaris	Llu	*	-	**	-	-	*
	Lepadellidae	*Colurella uncinata*	Cun	-	-	*	-	-	-
Groups	**Familles**	**Taxa**	**Acronyms**	**Lake 1**	**Lake 2**	**Lake 3**	**Lake 4**	**Lake 5**	**Lake 6**
Rotifera	Notommatidae	*Cephalodella gibba*	Cgi	-	*	-	-	-	-

	Philodinidae	*Philodina vorax*	Pvo	*	-	*	-	*	-
		Rotaria neptunia	Rne	***	*	*	-	-	*
	Trichocercidae	*Trichocerca capucina*	Tca	*	-	*	-	-	*
		Trichocerca longiseta	Tlo	*	-	-	-	-	-
		Trichocerca pusila	Tpu	***	**	-	-	-	-
		Trichocerca similis	Tsi		**	***	-	-	***
		Trichocerca weberi	Twe	**	*	-	*	-	-
Ostracoda	Cyprididae	*Hemicypris anomala*	Han	*	-	-	-	*	-
Total = 4	**17**	**31**		**21**	**16**	**17**	**10**	**12**	**16**

3.1.1. Seasonal variation in zooplankton populations

Seasonal variation in taxonomic richness does not vary significantly from one season to another (Mann-Whitney U test, $p > 0.05$). The median value ranges from 13 taxa recorded in Lake 1 during the rainy season to 3 taxa obtained in Lakes 2 and 4 during the dry season (Table 2).

Table 2 Seasonal variation in the taxonomic richness of zooplankton in urban lakes in Yamoussoukro (Ivory Coast) from July 2021 to May 2022

Urban lakes of Yamoussoukro							
Seasons		Lake 1	Lake 2	Lake 3	Lake 4	Lake 5	Lake 6
Dry season	Min	3	1	3	2	1	2
	Med	9	**3**	5	**3**	4	4
	Max	13	11	6	7	13	16
Rainy season	Min	12	4	3	4	6	5
	Med	**13**	8	4	5	7	6
	Max	14	9	5	6	8	7

Extreme median values are in bold

3.2. Overall analysis of zooplankton populations

The proportions of zooplankton groups collected in urban lakes in Yamoussoukro based on their abundance are shown in Figure 2. The Rotifera group (57%) is the most abundant. The least abundant group is Ostracoda (1%).

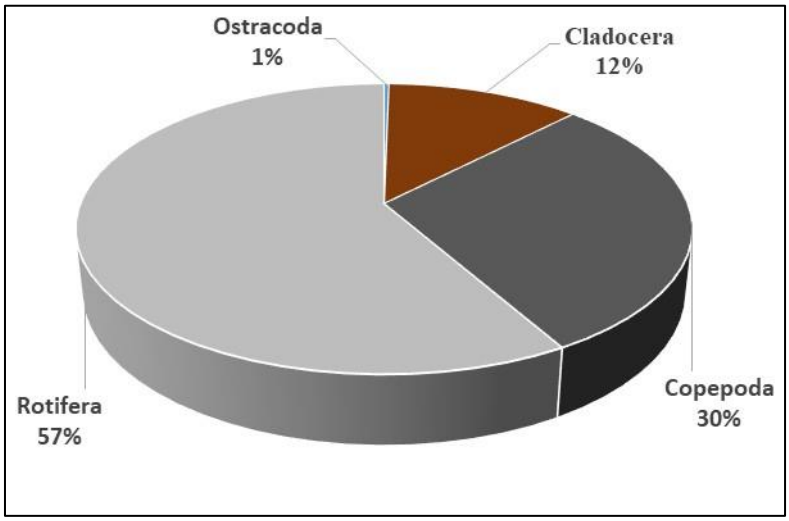

Figure 2 Quantitative contributions of zooplankton groups collected in the lakes of Yamoussoukro (Ivory Coast) from July 2021 to May 2022

3.3. Zooplankton abundance

The seasonal variation in zooplankton density does not vary significantly from one season to another (Mann-Whitney test, $p > 0.05$). The median values for density range from 600 ind./L obtained at Lake 4 during the rainy season to 7,000 ind./L recorded at Lake 1 during the dry season (Table 3).

Table 3 Seasonal variation in zooplankton density in urban lakes in Yamoussoukro (Ivory Coast) from July 2021 to May 2022

Urban lakes of Yamoussoukro							
Seasons		Lake 1	Lake 2	Lake 3	Lake 4	Lake 5	Lake 6
Dry season	Min	2000	100	1000	500	100	500
	Med	**7000**	1050	1150	800	3000	2000
	Max	9000	9000	2500	4000	8000	7000
Rainy season	Min	4000	1000	1000	500	2000	1800
	Med	5000	1000	1100	**600**	1000	1800
	Max	8000	2500	1200	1000	3500	4000

Extreme median values are in bold

3.4. Seasonal variations in Shannon diversity and Piélou evenness indices

Seasonal variations in Shannon diversity and Piélou evenness indices do not differ significantly from one season to another (Mann-Whitney U test, $p > 0.05$).

Table 4 shows that the median values of the Shannon diversity index range from 1 bit/ind. (lakes 2 and 3) to 2 bit/ind. (lake 1). Table 5 shows that the zooplankton community is evenly distributed across all lakes. The median values of the Piélou equitability index range from 0.8 (lakes 1, 2, and 5) to 0.95 (lake 3).

Table 4 Seasonal variation in the zooplankton diversity index of urban lakes in Yamoussoukro (Ivory Coast) from July 2021 to May 2022

Urban lake of Yamoussoukro							
Seasons		Lake 1	Lake 2	Lake 3	Lake 4	Lake 5	Lake 6
Dry season	Min	1,9	1,4	1,1	0,7	0,8	0,7
	Med	**2**	1,8	1,3	1,2	1,6	1,7
	Max	2,2	2,1	1,4	1,5	2,4	2,5
Rainy season	Min	1	1	0,8	1,1	1,3	1,2
	Med	1,9	**1**	**1**	1,1	1,5	1,4
	Max	2	1,9	1,3	1,6	1,9	1,8

Extreme median values are in bold

Table 5 Seasonal variation in the zooplankton equity index for urban lakes in Yamoussoukro (Ivory Coast) from July 2021 to May 2022

Urban lakes of Yamoussoukro							
Seasons		Lake 1	Lake 2	Lake 3	Lake 4	Lake 5	Lake 6
Dry season	Min	0,82	0,9	0,9	0,8	0,85	0,9
	Med	0,85	0,93	**0,95**	0,9	0,9	0,92
	Max	0,87	0,97	0,98	0,98	0,95	0,95
Rainy season	Min	0,78	0,4	0,84	0,75	0,3	0,88
	Med	**0,8**	**0,8**	0,87	0,9	**0,8**	0,92
	Max	0,85	0,9	0,98	0,98	0,9	0,95

Extreme median values are in bold

3.5. Zooplankton distribution profile

The SOM (Self-Organizing Map) analysis enabled the 36 samples (6 lakes x 6 campaigns) to be classified based on the presence/absence matrix of zooplankton taxa in the urban lakes of Yamoussoukro. This classification was based on the distribution and probability of occurrence of the taxa. This allowed us to select the 30-cell map (5 rows x 6 columns) with the lowest topography and quantification errors.

Four groups (I to IV) were determined using the cells of the self-organizing map following a detailed examination of the Ascending Hierarchical Classification (AHC) using Ward's method and Euclidean distance. Different figures on the Kohonen map were used to illustrate the groups (Figures 3 and 4). Thus, the samples collected from lakes 3 and 4 constitute group I. It represents 9.67% of all samples (G test : $p < 0.05$). Group II is characterized by samples from lake 1. It represents 38.7% of the samples (G test : $p < 0.05$). Group III includes samples from lakes 5 and 6. It represents 19.35% of all samples. Group IV includes samples from lake 2. This group represents 32.25% of the samples (G test : $p < 0.05$).

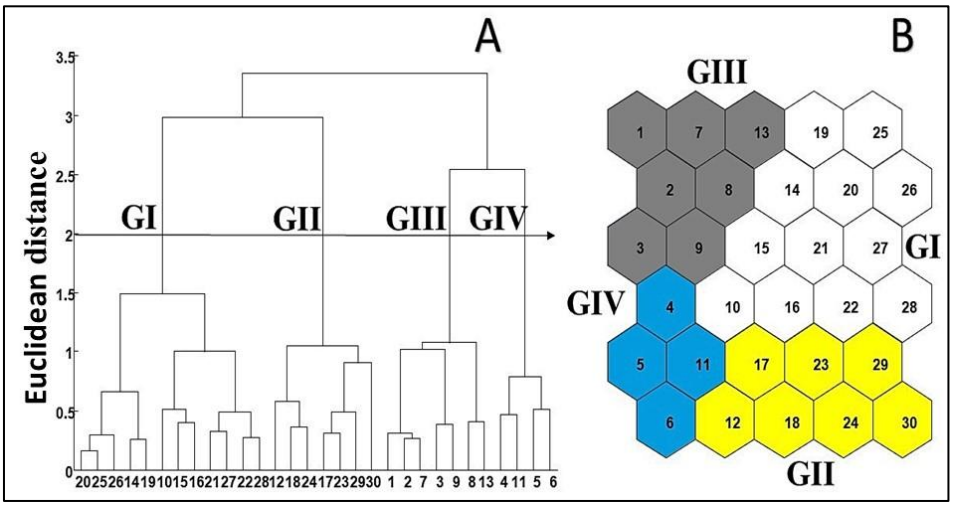

Figure 3 Ascending hierarchical classification of cells based on zooplankton species in urban lakes in Yamoussoukro (Ivory Coast) from July 2021 to May 2022 : A = Ascending hierarchical classification of cells in the Kohonen map using the Ward method and Euclidean distance as the assembly distance (the numbers [1 to 30] correspond to the cell numbers in the Kohonen map; the Roman numerals [I to V] represent the groups selected). B = Kohonen map with cells numbered from 1 to 30

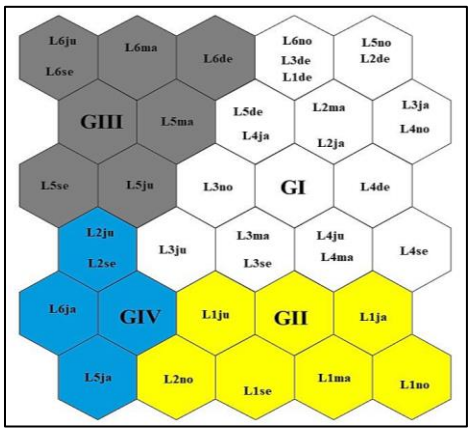

Figure 4 Distribution of samples according to the presence/absence data of zooplankton taxa collected in urban lakes in Yamoussoukro (Ivory Coast) from July 2021 to May 2022 : Roman numerals (I to IV) represent the defined groups ; Arabic numerals (1 to 9) designate the lakes, no = November, de = December, ja = January, ma = May, ju = July, se = September.

Group I, the least diverse, comprises three taxa (Brachionus plicatilis, Brachionus forticula, and Brachionus urceolaris). Group II, the most diverse, contains 12 taxa (Anuraeopsis fissa, Asplanchna sp., Lecane bulla, Lecane furcata,

Mesocyclops leuckarti, Platyias quadridentatus, Philodina vorax, Rotaria neptunia, Simocephalus sp., Trichocerca longiseta, Trichocerca pusila, and Trichocerca weberi.

Group III consists of six taxa (Bosmina longirostris, Conochilus hippocrepsis, Colurella uncinata, Leydigia acanthocercoides, Nauplii sp., and Trichocerca similis). Group IV has 10 taxa (Brachionus angularis, Brachionus caudatus, Cephalodella gibba, Filinia opoliensis, Hemicypris anomala, Lecane lunaris, Pseudodiaptomus gordioides, Trichocerca capucina, Testudinella patina, Tropodiaptomus sp.). The number of taxa recorded in the different groups differs significantly from one group to another (Mann-Whitney test, $p < 0.05$).

3.6. Abiotic parameters determining zooplankton distribution

Variations in pH, conductivity, temperature, dissolved oxygen, transparency, and depth for groups I to IV defined by Kohonen's self-organizing map are illustrated in Figure 5. The distribution of taxa in group I is determined by temperature.

The distribution of taxa in group II is characterized by dissolved oxygen, transparency, and depth. As for taxa in group III, their distribution is influenced by pH. The distribution of taxa in group IV is determined by conductivity.

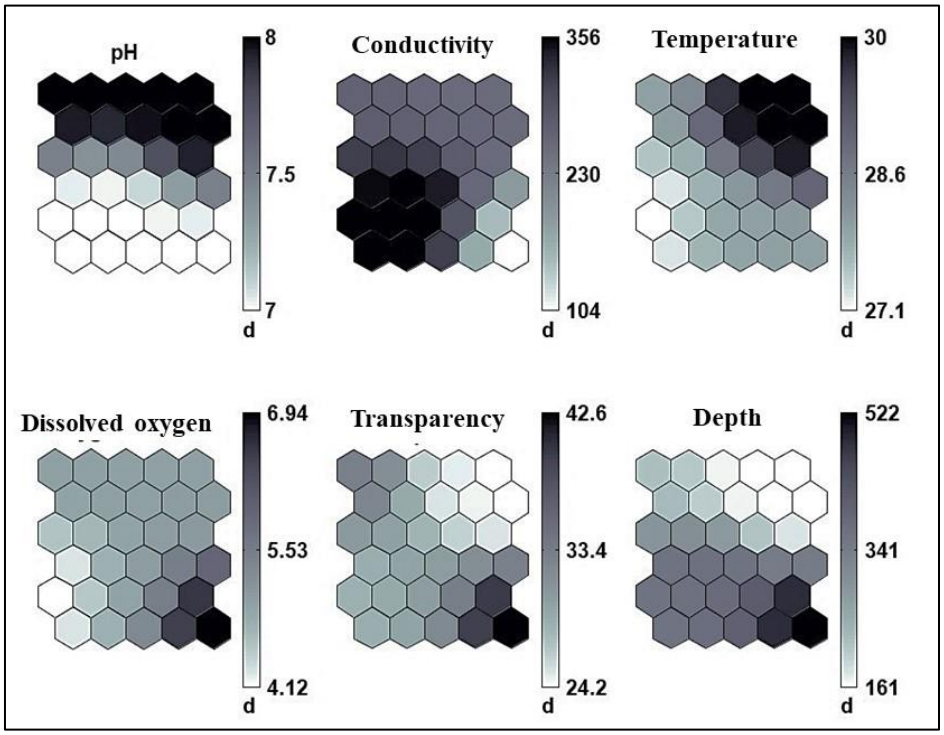

Figure 5 Kohonen self-organizing map (SOM) showing variations in abiotic parameters in groups I to IV: dark color = sites with very high abiotic parameter gradients ; d = scale

4. Discussion

Zooplankton sampling in the urban lakes of Yamoussoukro yielded 31 taxa. This taxonomic richness is identical to that observed by [10] in Lake Kaby in eastern Côte d'Ivoire (31 taxa) and by [11] in Lake Nokoué in southern Benin (31 taxa).

This could be explained by the fact that these lakes, located in the middle of urban areas and subject to domestic waste that can pollute the environment, may have the same ecological characteristics. However, this diversity is lower than that reported by [12], who identified 49 species of zooplankton in Lake Léré in Chad.

The distribution of taxonomic richness among groups shows that rotifers (57% of the taxa inventoried) largely dominate the zooplankton population. According to [6], this zooplankton group is the most abundant in freshwater. They can consume fine particles, such as bacteria and organic detritus, which are abundant in eutrophic aquatic ecosystems. He concludes that the predominance of rotifers in freshwater environments is a sign of eutrophication. This

predominance of rotifers could be explained by the fact that they reproduce preferentially by parthenogenesis in degraded environments [13].

This group is followed by copepods (30%) and cladocerans (12%). These results corroborate those obtained by [10] on Lake Kaby. Of the 10 rotifer families identified during this study, the Brachionidae family is the richest in taxa with 7 taxa. This diversity of Brachionidae is lower than that observed by [14] in Lake Ossa, and [15] in Lake Municipal de Yaoundé, which are eutrophic environments.

The taxonomic richness and density (abundance) of zooplankton in urban lakes do not vary significantly from one season to another. This can be explained by the availability of nutrients throughout the year. In fact, vegetable crops are grown around these lakes throughout the year using fertilizers, and rainwater carries domestic effluents into these lakes, enriching the environment with nutrients that promote algae growth, the first link in the zooplankton food chain. According to [16], fertilizers stimulate the development of algae, bacteria, and protozoa, which rotifers and cladocerans feed on to proliferate.

The Shannon diversity index and Piélou's evenness index are significant in all urban lakes in Yamoussoukro. These lakes would provide a favorable environment for the development of a large number of zooplankton.

5. Conclusion

The study of zooplankton diversity in urban lakes in Yamoussoukro identified 31 taxa belonging to four groups. These groups are dominated by rotifers. The presence of a variety of taxa indicates a certain biological balance, which is nevertheless fragile due to increasing urbanization and domestic pollution. These results underscore the crucial importance of zooplankton as a bioindicator of aquatic environment quality and call for integrated management policies that take local ecological dynamics into account. To ensure the resilience of these urban ecosystems, it is imperative to promote an eco-responsible approach combining scientific monitoring, community awareness, and sustainable development.

Compliance with ethical standards

Acknowledgments

The authors of this article would first like to thank the instructors whose criticism and suggestions helped improve this article. They would also like to thank the Laboratory of Biodiversity and Tropical Ecology at Jean Lorougnon Guédé University.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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