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Diversity and distribution of benthic macroinvertebrates in Kodjoboué lagoon of Bonoua (South-East of Côte d'Ivoire)

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Abstract

This study highlighted the diversity and structure of the benthic macrofauna in the Kodjoboué lagoon. It was conducted monthly from April to September 2024 at four sampling stations. at four sampling stations. Benthic organisms were collected using a dragnet and a Van Veen grab. The inventory revealed 269 insect individuals divided into 17 taxa, 14 families, and 7 orders. The order Heteroptera (29.41%) is the most diverse and abundant (27%). The benthic population is more diverse and abundant at station S4. Predatory organisms predominate in the trophic structure of the insect population in this lagoon. The assessment of water quality using the Hilsenhoff index indicates that, with the exception of the waters at station S4, which are moderately polluted, the waters at the other stations are of poor quality.

Keywords: Benthic macroinvertebrates; Diversity; structure; Kodjoboué Lagoon; Bonoua

1. Introduction

Coastal lagoons are transitional ecosystems of high ecological and socio-economic importance. Located at the interface between marine, fluvial, and terrestrial environments, they rank among the most productive and biodiverse ecosystems on Earth [1, 2]. They play a crucial role in biogeochemical cycles and provide key ecosystem services such as fisheries, aquaculture, and hydrological regulation [3].

However, these fragile systems are increasingly threatened by anthropogenic pressures, including urbanization, agriculture, and domestic effluents, leading to water quality degradation and biodiversity loss [4]. Eutrophication, in particular, represents one of the major threats to lagoon functioning, often resulting in trophic imbalances and ecosystem decline [5]. Assessing the ecological status of such systems is therefore essential for their sustainable management.

Biological indicators, especially benthic macroinvertebrates, are effective tools for assessing ecological quality. Due to their limited mobility, taxonomic diversity, and variable tolerance to pollution, these organisms provide integrative information on environmental disturbances [6, 7].

The Kodjoboué Lagoon, a small lagoon fed by the Comoé River, supports various human activities such as fishing, navigation, and tourism. Although previous studies [8] described it as relatively undisturbed, the recent increase in anthropogenic pressures calls for an updated assessment of its ecological condition.

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This study aims to evaluate the current ecological status of the Kodjoboué Lagoon based on benthic macroinvertebrate communities. Specifically, it seeks to: (i) characterize the lagoon's physicochemical parameters; (ii) determine the taxonomic composition and structure of benthic macroinvertebrate communities; and (iii) assess the biotic integrity of the lagoon's waters using macroinvertebrate-based indices.

2. Materials and methods

2.1. Study area

The Kodjoboué lagoon is located in southeastern Côte d'Ivoire in the South Comoé region, approximately 4 km south of the town of Bonoua, between longitudes 3°35' 9" W and latitudes 5°14'11" N [8] (Figure 1). This area is adjacent to the Grand-Bassam wetland and covers an area of 3,404 km². Its average depth is very shallow, with a maximum of 2 m. This region has an average altitude of 90 m. The climate is characterized by four seasons: two dry seasons (mid-July to mid-September and December to March) and two rainy seasons (April to mid-July and mid-September to mid-November) [9]. The various sampling stations were selected based on their accessibility and proximity to sources of pollution. Four stations, numbered S1 to S4, were selected on this lagoon (Figure 1). These stations were sampled monthly from April to September 2024.

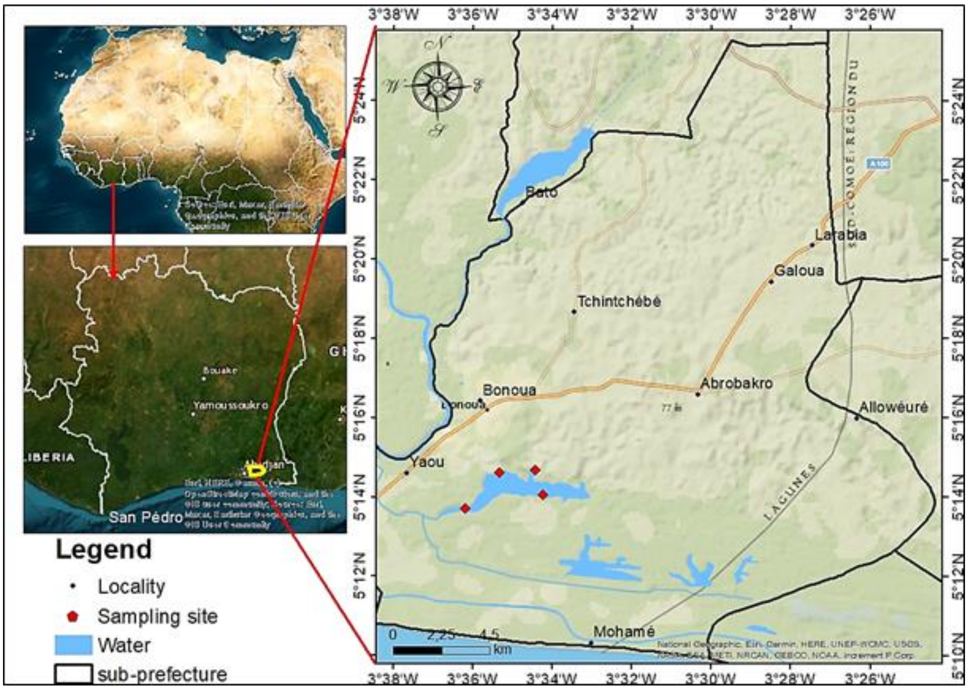

Figure 1 Location of sampling stations on the Kodjoboué lagoon

2.2. Data collection

2.2.1. Measurement of physicochemical parameters

The physicochemical parameters of the water, including pH, conductivity, temperature, salinity, and dissolved oxygen content, were measured monthly at each station before sampling benthic macroinvertebrates. The measurements were taken using a pre-calibrated multiparameter meter. Water transparency was estimated using a 30 cm diameter Secchi disk, while depth (cm) was determined using a graduated weighted rope.

2.2.2. Sampling of benthic macroinvertebrates

Benthic macroinvertebrates were sampled using a Van Veen grab and a dragnet. The Van Veen grab was used to collect sediments from the shore offshore. Five samples were taken over a total area of 0.25 m² per station and per campaign [10]. The seine net was used along the banks over a distance of 2 m to dislodge organisms associated with submerged macrophytes, for a total area of 0.6 m² sampled per station and per campaign [11, 12].

2.2.3. Identification of organisms

The samples were sieved to 1 mm, then the organisms were sorted on a white-bottomed tray and fixed with 5% formaldehyde. In the laboratory, they were rinsed on a 300 µm sieve [13, 14] , then identified under a binocular magnifying glass using the keys provided by [15, 16]. The organisms were identified to genus or species level, then counted and weighed.

2.2.4. Analysis of the composition and structure of the population

The ichthyological population captured by the video surveillance system was characterized by various types of indices, including taxonomic richness, Shannon and evenness indices, percentage of occurrence, and abundance.

- The taxonomic richness of macroinvertebrates in the Kodjoboué lagoon is the total number of taxa recorded at a given sampling station. This synthetic index is a good indicator of a station's carrying capacity [17].
- The Shannon index [18] was used to measure the degree of organization of the insect population at each sampling station in the Kodjoboué lagoon. It was calculated using the following equation: $H' = - \Sigma\ (Ns/Nt)\ \log\ (Ns/Nt)$, where H' = Shannon & Weaver index (1949); abundance of species i, i ranging from 1 to S (total number of species); NT = total number of individuals. [22]
- The Pielou [19] evenness index was used to assess the quality of the distribution of individuals within the species in the environment [20, 21, 22]. It is calculated using the formula: $E = H'/Log2Rs$

where E = evenness index; H' = Shannon-Weaver index; Rs = number of species. Equitability was assessed using the following grid [23]: Low equitability ($E< 0.6$), Medium equitability ($0.6 < E < 0.8$) and High equitability ($E > 0.8$).

If E is low, it means that a small number of taxa account for the majority of individuals in the environment. When E is high, it means that individuals are well distributed.

The percentage of occurrence (F) provides information on the environmental preferences (habitat) of taxa. It is calculated using the formula $F = (Fi \times 100) / Ft$. Depending on the value of F, the following classification is adopted [22]: constant taxa ($F \geq 50\%$), accessory taxa ($25 \leq F \leq 50\%$) and accidental taxa ($F < 25\%$).

- The HBI index was used to assess the degree of disturbance experienced by the stations [24]. It is determined using the following formula: $HBI= \Sigma\ (xi / ti)\ /N$. Where xi= number of individuals of taxon; Ti=tolerance of taxa; N=Number of individuals constituting the sample.

2.3. Data processing

Kruskal-Wallis (multiple comparisons) and Mann-Whitney (comparison of two samples) nonparametric tests were performed for the various comparisons when the parameters did not follow a normal distribution. Indeed, the value of “asymptotic significance” indicates an absence of significant differences between variables when these values are greater than 0.05, and vice versa when they are less than 0.05. The data collected were processed using statistical software, Statistica version 7.1 in Excel (Microsoft Office 2010).

2.4. Canonical correspondence analysis

According to [25], canonical correspondence analysis (RDA) is a method used in ecology to show species-environment relationships (SER). It is used to study the relationships between a table Y (n, t) of faunal diversities and a table X (n, p) of environmental parameters [26]. In this approach, X must influence Y, and we will seek to predict Y based on X. The principle is to evaluate the linear combination of environmental variables that maximizes the variability observed in table Y. These tests were performed using STATISTICA software version.

3. Results

3.1. Physicochemical characteristics of the Kodjoboué lagoon

Six parameters were measured in this study. These are temperature, pH, dissolved oxygen, transparency, depth, and conductivity (Table 1). The results for the environmental variables measured are presented in Table I.

The waters of the lagoon are cooler at station S1, with an average value of 29.69 ± 0.01 °C, and warmer at station S4, with 31.81 ± 2.78 °C. The pH of the water ranges from 6.06 ± 0.27 at station S3 to 7.29 ± 0.19 at station S2. The dissolved oxygen in the water is lower at S3 and higher at station S4, with average dissolved oxygen values of 5.55 ± 4.44 mg/L and 7.28 ± 3.65 mg/L, respectively. The waters of the Kodjoboué lagoon are less mineralized at station S4, with an average conductivity value of 11.00 ± 11.31 µS/cm, and more mineralized at station S1, with an average value of 26.50 ± 2.12 µS/cm. The waters are slightly salty, with an average value of 0.01‰ at all stations. The waters of the Kodjoboué lagoon are less transparent at station S4, with an average value of 22.77±31.45, and more transparent at station S1, with 31.57 ± 43.75 cm. The lagoon is shallower at station S4 (64 cm) and deeper at station S1 (211.5 cm). The averages of physicochemical parameters such as temperature, pH, dissolved oxygen, conductivity, and salinity show no significant differences between stations (Kruskal-Wallis; $p > 0.05$). However, significant differences (Kruskal-Wallis tests, $p < 0.05$) were observed between the average values for transparency and depth at the stations.

Table 1 Physicochemical characteristics of the waters of the Kodjoboué lagoon

	STATIONS			
Physicochemical parameters	**S1**	**S2**	**S3**	**S4**
Temperature (°C)	29.69±0.00	30.90±1.88	30.59±1.97	31.81±2.78
pH	6.69±1.25	7.29±0.19	6.06±0.27	5.89±0.28
Dissolved oxygen level (mg/L)	6.33±0.71	6.68±1.07	5.55±4,44	7.28±3.65
Conductivity (µs/cm)	26.50±2.12	14.50±4.95	16.00±7,07	11.00±11.31
Depth (cm)	151.75±84.49	162.75±36.41	190.5±28,99	132±96.16
Salinity (%)	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00
Transparency (cm)	31.57±43.75	28.61±39.44	26.56±36.68	22.77±31.45

3.2. Diversity and structure of the benthic macrofauna of the lagoon

3.2.1. Taxonomic composition

The taxonomic compositions and occurrences of aquatic insects recorded at the various stations in the Kodjoboué lagoon are presented in Table 2.

A total of 17 taxa belonging to 14 families, 7 orders, and a single class (Insects) were identified.

Among these orders, Heteroptera dominate the inventoried fauna with 4 families and 5 taxa, representing 29.41% of the total species richness. They are followed by Odonata, with 3 families and 4 taxa (23.53%). Coleoptera and Diptera come next, with 3 families and 3 taxa (17.65%) and 1 family and 2 taxa (11.76%) respectively. Finally, Ephemeroptera, Trichoptera, and Plecoptera are poorly represented, each with only one family and one taxon, accounting for 5.88% of the total diversity.

The distribution of the taxonomic diversity of aquatic insects varies according to the sampling stations in the Kodjoboué lagoon. Station S4 has the highest diversity with eight taxa, followed by stations S1 and S2, which each have seven. Station S3 appears to be the least diverse with six taxa.

Among the species recorded, Naucoris sp is the only taxon common to all stations. The species *Somatochlora proparte* was observed simultaneously at stations S1, S2, and S3. Four taxa, *Laccophulus* sp., *Corixa* sp., *Notonecta* sp. and *Chalcolestes viridis* are specific to station S4, while *Chironomus imicola*, *Ranatra linearis*, *Xanthoperla* sp. and *Chironomus* sp. were only observed at station S2. Finally, *Ceriagrion tenellum* is a species exclusive to station S1.

Table 2 Occurrence of benthic macroinvertebrates sampled at different stations

Classes	**Order**	**Family**	**Taxons**	***Acronyms***	**S 1**	**S 2**	**S 3**	**S 4**
Insects	Beetles	Dytiscidae	*Laccophilus* sp.	*Las*				*
		Hydrophilidae	*Amphiops* sp.	*Amp*	**			
		Noteridae	*Noterus* sp.	*Nos*			*	**
	Diptera	Chironomidae	*Chironomus* sp.	*Chi*	*		*	
			Chironomus imicola	*Cim*		*		
	Ephemeroptera	Baetidae	*Baetis* sp.	*Bae*			*	**
	Heteroptera	Corixidae	*Corixa* sp.	*Cor*				*
			Micronecta sp.	*Mic*	*	*		*
		Naucoridae	*Naucoris* sp.	*Nau*	**	*	*	**
		Népidae	*Ranatra linearis*	*Ral*		*		
		Notonectidae	*Notonecta* sp.	*Not*				*
	Odonata	Coenagrionidae	*Ceriagrion tenellum*	*Cet*	*			
			Coenagrion sp.	*Csp*	**		**	
		Corduliidae	*Somatochlora Pro Parte*	*Sop*	*	**	*	
		Lestidae	*Chalcolestes Viridis*	*Chv*				*
	Stoneflies	Chloropelidae	*Xanthoperla* sp.	*Xan*		*		
	Caddisflies	Hydropsychidae	*Polymorphanisus* sp.	*Pos*		*		
Taxonomic Richness			17		7	7	6	8

** Constant (% OF> 50); *Accessory (% OF ≥50)

3.2.2. Percentage of occurrence of taxa

Table 2 lists the constant and accessory taxa recorded at the different stations. Accessory taxa are the most numerous at all stations, with percentages ranging from 57.14 % to 100 %. The percentage of constant taxa varied between 0 and 42.86 %. Out of a total of 7 taxa recorded at station S1, only 3 taxa (*Amphiops* sp., *Naucoris* sp., *Coenagrion* sp.) are constant, while the others (*Chironomus* sp., *Micronecta* sp. *Ceriagrion tenellum* and *Somatochlora pro parte*) are accessory. At station S2, 7 taxa were collected, of which only one is a constant taxon (*Somatochlora pro parte*) and 6 (*Chironomus Imicola, Naucoris* sp*., Micronecta* sp*., Ranatra linearis, Somatochlora pro parte*, *Xanthoperla* sp. and *Chironomus* sp.) are accessory taxa. Station S3 has 6 taxa (*Noterus* sp., *Chironomus* sp., *Baetis* sp., *Naucoris* sp., *Coenagrion* sp*., Somatochlora pro parte*), all of which are accessory. Station 4 contains 8 taxa, 3 of which are constant (*Noterus* sp., *Baetis* sp. and *Naucoris* sp.) and 5 (*Laccophulus* sp., *Corixa* sp., *Micronecta* sp., *Notonecta* sp. and *Chalcolestes viridis*) are accessory.

3.2.3. Macroinvertebrate community diversity index

The Shannon-Weaver index revealed that most study stations had high diversity values (Table 3). The lowest Shannon index value was recorded at S2 (1.57 bits/ind), while the highest value was observed at S1 (1.95 bits/ind). The Pielou regularity index ranged from 0.81 (S4) to 0.94 (S1). The Kruskal-Wallis test revealed no significant differences in diversity indices between the different stations ($p > 0.05$).

Table 3 Pielou's Equitability and Shannon diversity indices.

Stations				
Indices	S1	S2	S3	S4
Equitability de Pielou	0.94	0.87	0.91	0.81
Shannon index	1.95	1.57	1.63	1.70

3.2.4. Relative abundance

Relative abundance of the main orders

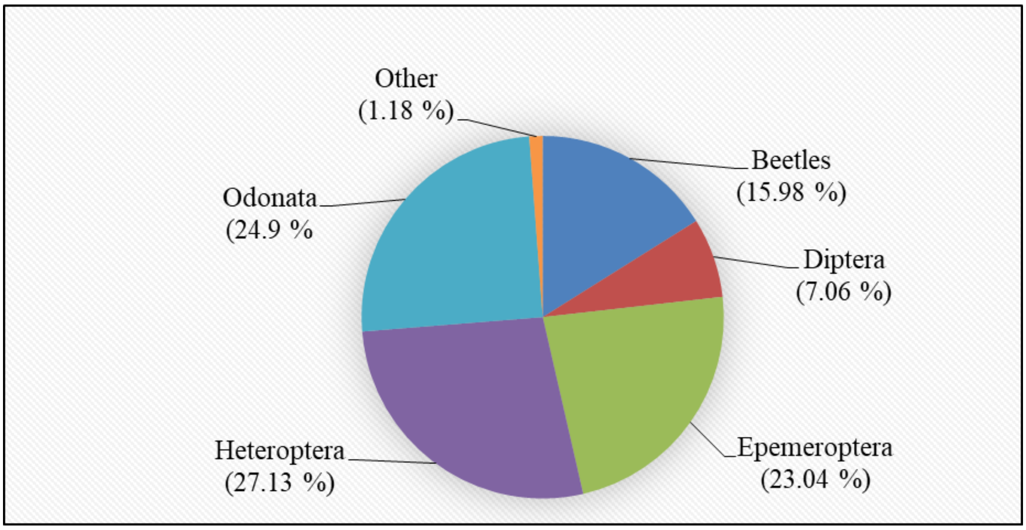

Figure 2 Relative abundance (%) of the most common orders in the Kodjoboué River

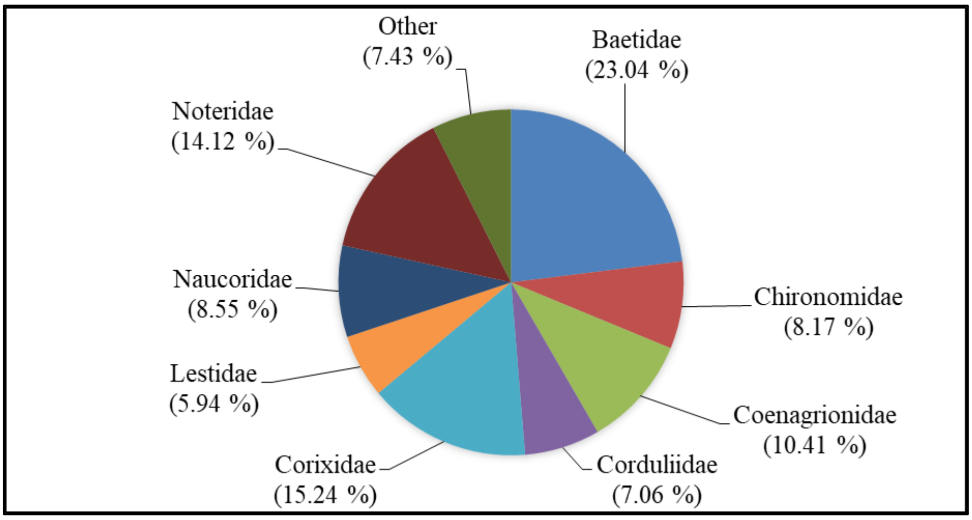

Figure 3 Relative abundance (%) of the most common families in the Kodjoboué River

A total of 269 individuals were collected between April and June 2024 in the Kodjoboué lagoon. The most abundant orders were Heteroptera (27.13 % of total abundance), followed by Odonata (24.9 %) and Ephemeroptera (23.04 %). The Other were the least represented (1.18 % each) (Figure 2). At the family level, Baetidae, Corixidae, and Noteridae were the most abundant, representing 23.04 %, 15.24 %, and 14.12 % (Figure 3) of the total abundance, respectively. Taxa such as Hydrophilidae, Dytiscidae, Chloroperlidae, and Hydropsychidae were the least abundant, with fewer than four specimens each. The taxa *Baetis* sp., *Noterus* sp., *Micronecta* sp., *Naucoris* sp. and *Somatochlora pro parte* alone account for more than 60 % of the total abundance of benthic fauna.

3.2.5. Spatial variation in the relative abundance of orders

Odonates dominate numerically at stations S1, where they represent 48 % of the orders inventoried. Heteroptera are abundant at station S2, with a relative abundance of 43.75 %. Coleoptera are abundant at 35.29 % at station S3, while at station S4, Ephemeroptera are present in large numbers (Figure 4).

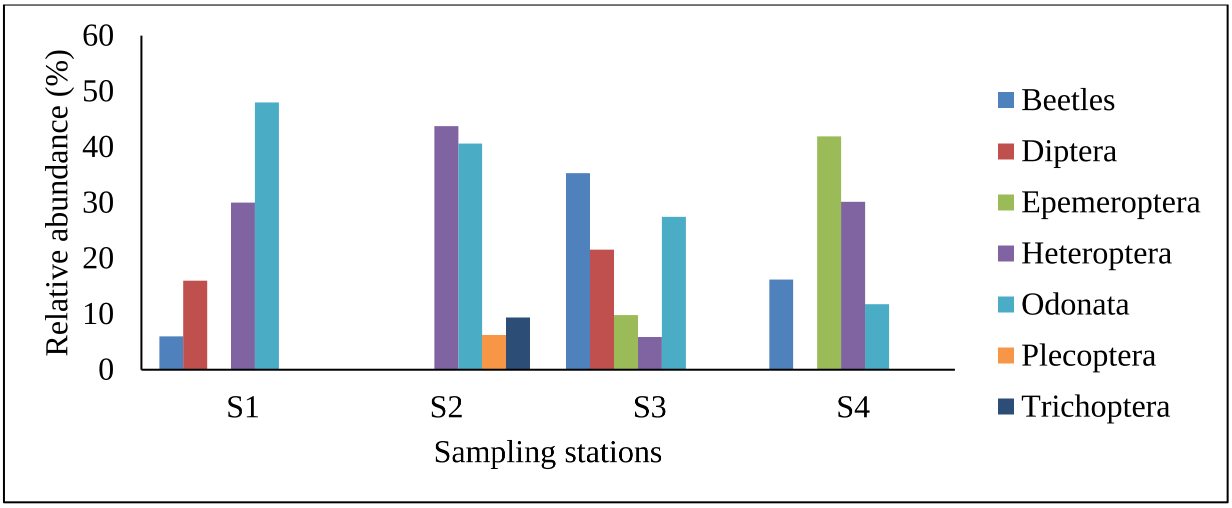

Figure 4 Spatial variation in the relative abundance of orders observed in the Kodjoboué River

3.3. Assessment of the ecological health of the stations

The Hilsenhoff index values calculated at the different stations are presented in Table 4. The Hilsenhoff index values ranged from 5.02 to 7.08. Stations S1 and S2, with values of 7.08 and 6.66 respectively, have "poor" water quality. Station S3, with a Hilsenhoff index value of 6.15, has "fairly poor" water quality. Only station S4 has "average" water quality, with an index of 5.02.

Table 4 Hilsenhoff index calculated from benthic macroinvertebrates at stations in the Kodjoboué lagoon*

Stations	Hilsenhoff Index	Water Quality	Assessment
S1	7.08	Poor	Very substantial organic pollution
S2	6.66	Poor	Very substantial organic pollution
S3	6.15	Fairly poor	Substantial organic pollution
S4	5.02	Average	Fairly substantial organic pollution

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3.4. Influence of abiotic parameters on the distribution of benthic macroinvertebrates

Canonical correspondence analysis (RDA) was performed to establish the relationship between benthic species and abiotic parameters in the Kodjoboué lagoon (Figure 2).

Axes F1 and F2 explain a total of 63.25% (F1=38.66 % and F2=24.59 %) of the total variability of the parameters.

This canonical analysis shows that taxa such as *Ranatra linearis*, *Xanthoperla* sp., *Coenagrion* sp., *Chironomus* sp., *Somatochlora pro parte*, *amphiops* sp., *Chironomus imicola*, *Ceriagrion tenellum* and *Polymorphanisus* sp. have a strong negative correlation with F1. This correlation reflects the presence of the following parameters: pH, transparency, depth, salinity, conductivity, and dissolved solids, which influence their distribution at the stations. Species such as *Notonecta* sp., *Laccophulus* sp., *Corixa* sp., *Baetis* sp., *Chalcolestes viridis*, *Naucoris* sp., *Micronecta* sp. and *Noterus* sp. are strongly positively correlated with the F1 axis. This strong correlation can be explained by the presence of temperature and dissolved oxygen at the stations. On axis F2, we observe a strong negative correlation between taxa such as *Chironomus* sp., *Amphiops* sp., *Coenagrion* sp., *Chironomus imicola*, *Ceriagrion tenellum*, *Notonecta* sp., *Laccophulus* sp., *Corixa* sp., *Baetis* sp., *Chalcolestes viridis* and *Noterus* sp. This correlation is influenced by the presence of transparency, temperature, and dissolved oxygen parameters. However, taxa such as *Chironomus* sp., *Ranatra linearis*, *Xanthoperla* sp., *Naucoris* sp., *Micronecta* sp., *Somatochlora pro parte* and *Polymorphanisus* sp. have a strong positive correlation on the F2 axis. The strong correlation shows the presence of parameters such as dissolved solids, pH, depth, and conductivity at the stations.

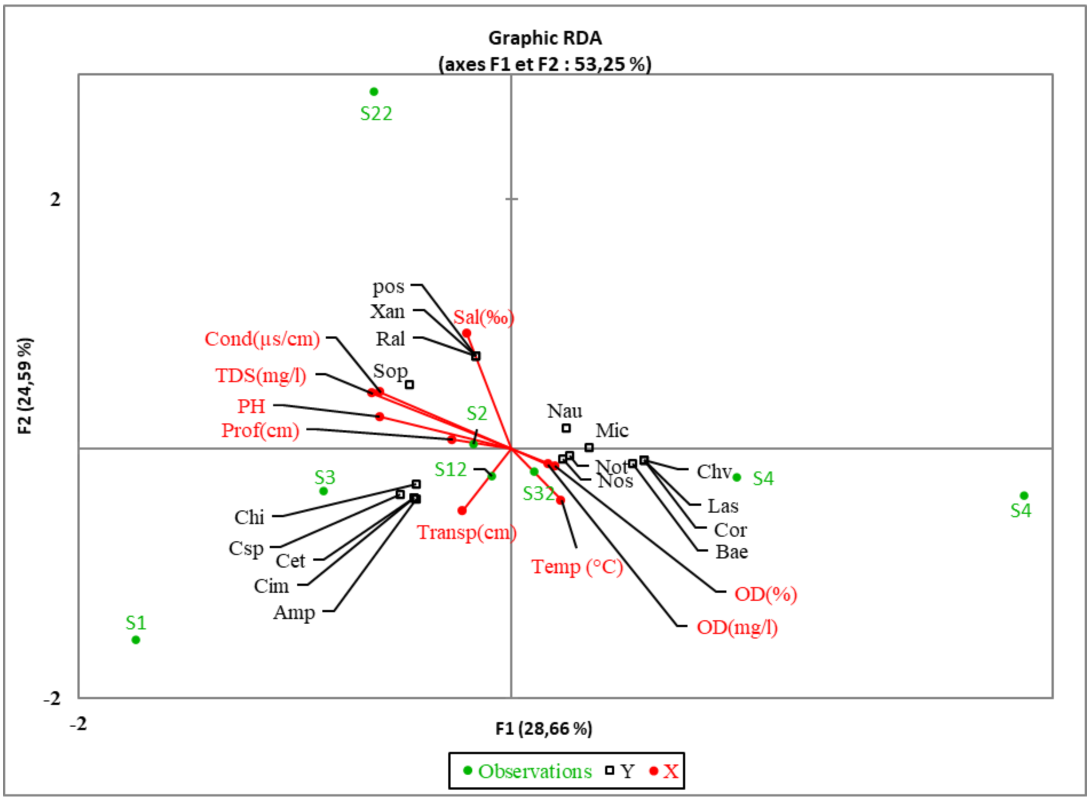

Figure 2 Analysis of the distribution of benthic macroinvertebrates according to the physicochemical parameters of the Kodjoboue lagoon.

4. Discussion

Analysis of the environmental variables measured at the various sampling stations in the Kodjoboué lagoon shows no significant variation between stations. For temperature, the average values ranged from 29.69 ± 0.01 °C to 31.81 ± 2.78 °C, indicating that the lagoon waters are relatively warm. This trend reflects the temperature in the tropics. According to [27], the water temperature in intertropical Africa is high, often exceeding 20°C. Furthermore, [28] showed that at temperatures ranging between 25°C and 30°C, the waters are favorable for aquatic life. This temperature range is close to that observed by [8] (28.19 to 29.2°C) in the same environment.

The average pH values recorded in the waters of the Kodjoboué lagoon range from 6.06 ± 0.27 to 7.29 ± 0.19. These pH values show that the waters of this lagoon are suitable for aquatic life. According to [29], pH variations that can ensure the development and protection of aquatic life are between 6 and 9. These values fall within the range obtained by [30] and [31], who observed values between (6.55-7.8) and (7.5-9.8) respectively.

The low conductivity levels (11.00 ± 11.31 µS/cm to 26.50 ± 2.12 µS/cm) recorded in this lagoon would indicate low levels of natural or anthropogenic sediments throughout the Kodjoboué lagoon. The average dissolved oxygen values observed in the waters of the Kodjoboué lagoon range from 5.55 ± 4.44 mg/L to 7.28 ± 3.65 mg/L. These values indicate good oxygenation of the waters of this lagoon. These values would be adequate for aquatic life. Indeed, [32] note that a dissolved oxygen content of between 4 and 6 mg/L characterizes optimal aquatic life conditions.

The inventory of macroinvertebrates in the Kodjoboué lagoon identified 17 taxa distributed among 14 families, 7 orders, and one class (insect class). This composition is lower than that reported by [8], who collected 74 taxa from the same lagoon. This difference in taxa could be related to the different sampling efforts in the two studies. Indeed, [8] carried out seasonal sampling over a period of one year, unlike this study, which was conducted in two campaigns during the rainy season.

In this study, only insects were recorded in this lagoon. These results are very similar to those obtained by [8] in the same environment. The latter note the presence of four classes, such as insects, gastropods, arachnids, and malacostracans, but with a dominance of insects (nearly 95%) in aquatic environments. This strong presence of insects in this hydrosystem is thought to be linked to the ubiquity of these organisms due to their high ecological plasticity. Indeed, insects represent the majority of benthic macroinvertebrates and their larvae are mostly exclusively aquatic [7, 16]. Among insects, the most abundant family is Baetidae. This quantitative predominance of Baetidae is thought to be linked to the nature of the different habitats characterized by a heterogeneous substrate rich in organic matter [33]. A habitat rich in organic matter provides favorable conditions for the development of certain families of mayflies, such as Baetidae.

The Shannon diversity and evenness indices for the benthic community in this environment indicate low community diversity, with Shannon values ranging from 1.57 bits/ind to 1.95 bits/ind, and a stable, balanced community with evenness values above 0.8. The balance and stability of the aquatic insect community in this lagoon would still be related to the availability of food resources and habitats conducive to their survival [34].

The assessment of water quality using the Hilsenhoff index shows that almost all stations have poor water quality. However, the high level of pollution observed in this lagoon is thought to be due to a high concentration of human activity on the shores of the lake near these three stations. In addition to the presence of market gardens, this shore is home to rubber plantations near these stations. This crop, which is heavily dependent on pesticides and chemical fertilizers, contributes to the discharge of chemicals through runoff into this part of the lagoon. According to [35], a high concentration of activities on the banks of an aquatic environment leads to high water pollution.

5. Conclusion

This study provided insight into the diversity and structure of benthic macroinvertebrates. The results for abiotic parameters reveal no spatially significant variation. The taxonomic composition of the benthic macroinvertebrates in this lagoon revealed 17 insect taxa divided into 14 families and 7 orders. The order Heteroptera (29.41 %) is the most diverse and abundant (27%). The distribution of taxonomic richness according to the habitats surveyed shows a high diversity and abundance of insects at station S4.

The similarity of the population between the stations in the lagoon reveals a low similarity of insect populations between the different sampling stations. Analysis of the structure of the populations shows that the benthic population of the Kodjoboué lagoon has moderate but stable and balanced diversity. Assessment of water quality using the Hilsenhoff index indicates that, with the exception of the waters at station S4, which are moderately polluted, the waters at the other stations are of poor quality. In view of the results obtained from the two quality indicators used, it would be necessary to conduct a more in-depth seasonal study in order to better understand the taxonomic composition of this lagoon and its ecological quality. This would enable biomonitoring of the waters of this aquatic environment to be considered.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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