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Spatiotemporal Distribution of Cladocera and Rotifer of the Mangrove Waters of Mouanko (Coastal Cameroon): Influence of Some Abiotic Variables

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Abstract

The Mouanko mangrove is subjected to major anthropogenic activities such as agriculture, fishing and deforestation, hence information on Cladocerans and Rotifers amongst other aquatic organisms in order to monitor and manage this ecosystem is vital. The aim of this work is to study the physicochemical parameters of the environment that influence the diversity and spatiotemporal distribution of Cladocerans and Rotifers in the mangrove waters of Mouanko. This study was carried out from November 2019 to October 2020 at 8 sampling stations. Both biological and physico-chemical sampling and analyses were done following standard recommendations. The results of the phyico-chemical analyses revealed that the waters of the Mouanko mangroves were slightly basic (7.64 ± 0.71 UC), moderately oxygenated (69.56% ± 14.29%) with low levels of nutrients [NO_2^- (0. 06 ± 0.05 mg/L), NH_4^+ (0.39 ± 0.3 mg/L) and PO_4^{3-} (up to 0.12 mg/L)] and high values of electrical conductivity (up to 6531.04 µS/cm), salinity (up to 3.71‰). 15 species of Cladocerans and 30 species of Rotifers were identified accounting for a total abundance of 612 ind/L. The species richness was higher in freshwater influenced zones (40 taxa) compared to marinewater influenced zones (17 taxa). Among these species, the Cladocera, *Penilia avirostris* was the most abundant in marinewater influenced zones (84 ind/L) while the Rotifer, *Keratella tecta* was the most abundant in freshwater influenced zones (64 ind/L). Shannon-Weaver's diversity and Pielou's equitability indices indicated that freshwater influenced zones host a diverse community with a tendency towards equi-partition of species while marinewater influenced zones revealed the opposite. The low levels of organic pollution indicator variables recorded and the high diversity of the freshwater influenced zones population studied attested to the low level of anthropization in this environment. High salinity and electrical conductivity values influence the distribution of these organisms.

Keywords

Cladocera, Rotifers, Spatio-Temporal Distribution, Abiotic Variables, Coastal Cameroon

1. Introduction

Mangroves refer to an ecosystem that has developed physiological characteristics that allow them to thrive in tidal intertidal areas and to withstand extreme variations in environmental conditions [1]. They play ecological, socioeconomic, climate regulation, and coastal protection roles [2]. They contribute to the maintenance of a great diversity of flora and fauna, thus providing direct products and services to the populations in the form of construction wood, wood-energy and tannins. Mangroves have been identified in 124 countries of the world including Cameroon [3]. In Cameroon, these mangroves are strongly threatened by many anthropic activities with an impact on the fauna which they contain particularly zooplanktons. Zooplankton constitute essential part of the aquatic ecosystem [4]. Among these groups are the Cladocerans and Rotifers, which represent an important component in the structure and functioning of aquatic ecosystems [5]. Through their grazing activity, these groups of organisms form an essential trophic link between primary producers and higher trophic level organisms for which they are an important energy resource [6] [7] [8] [9]. In addition, they are good indicators of water quality in the global context of eutrophication of aquatic environments due to rapid urbanization, industrialization and the use of plant protection products [10] [11]. Knowledge of the distribution of these two groups is important not only for monitoring the quality of aquatic ecosystems but also for understanding energy transfer in these ecosystems.

In Cameroon, many works have been carried out on zooplankton in lotic and lentic environments. These include those of [5] [12] [13] [14] [15]. These works show that lotic and lentic environments host a diversified zooplankton microfauna. In the coastal zone, few studies have already been conducted on this group of organisms, such as that of [16] in the Kienke estuary at Kribi. However, data on the zooplanktonic species richness in the Mouanko mangroves located in this ecosystem are non-existent. Given that the Mouanko mangroves is subjected to major anthropogenic activities such as agriculture, fishing and deforestation, it is therefore urgent to have scientific databases on Rotifers and Cladocerans amongst other aquatic organisms in order to monitor and manage the ecosystem. It is within this framework that the present study on the diversity and spatio-temporal distribution of Cladocerans and Rotifers in the mangrove waters of Mouanko in relation to the physicochemical parameters of the environment was carried out.

2. Materials and Methods

2.1. Study Site

This study was conducted in the Mouanko district located in the Department of Sanaga-Maritime, Littoral Region, Cameroon (**Figure 1**). The climate of this area is of the coastal tropical type with two seasons: the rainy season from March to October and the dry season from November to February [17] [18]. The soils are ferralitic and hydromorphic with vegetation dominated by mangroves of the genus Rhizophora [19]. Its hydrography is made up of numerous rivers including the Sanaga, Kwa-kwa and Wouri [20]. In total, 08 sampling stations (named ED1 to ED4 in freshwaters influenced zones and ES1 to ES4 in marinewater influenced zone) were selected. These stations were selected based on criteria such as wide area coverage, accessibility, and the presence of potential pollution sources.

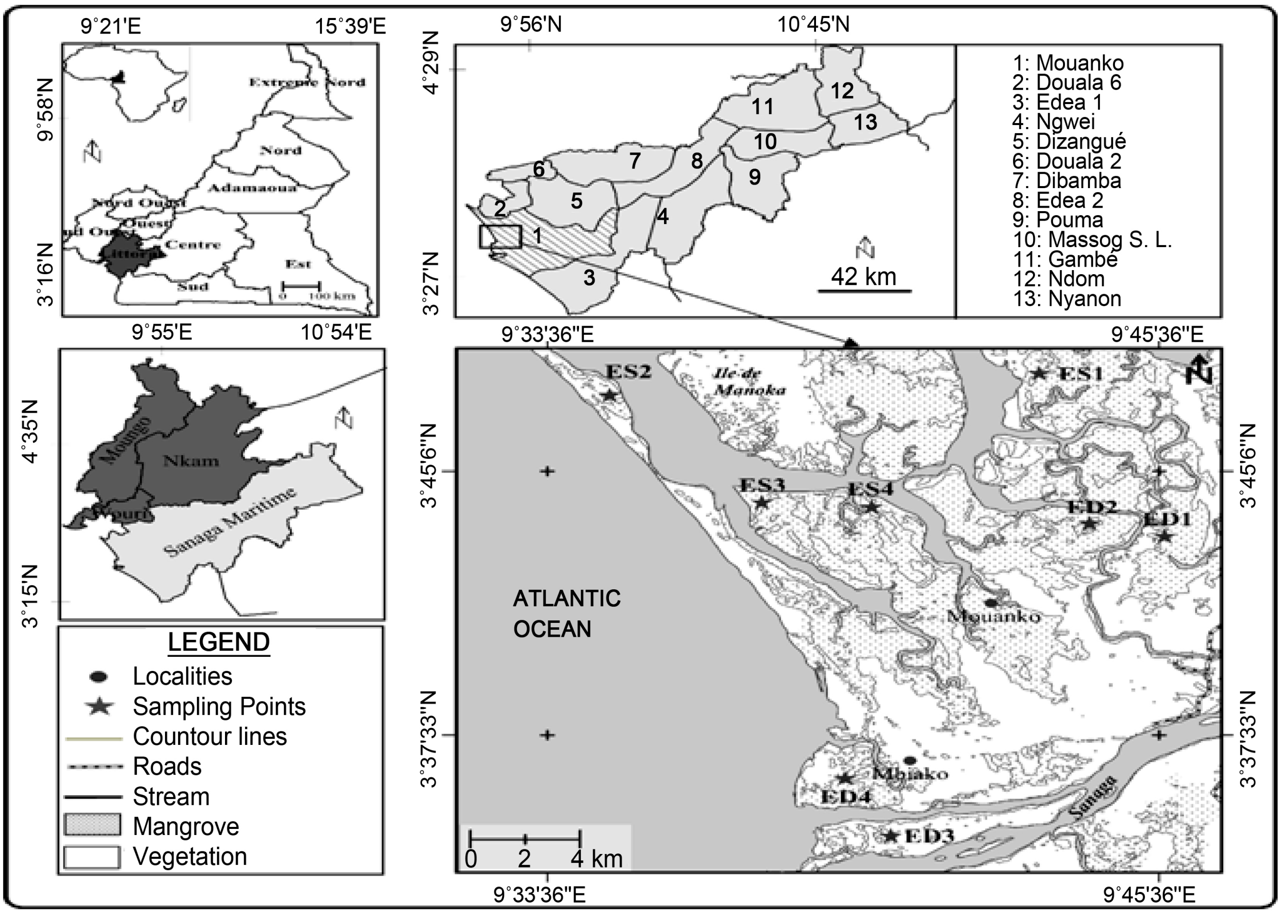


Figure 1. Map showing the sampling stations in a part of the Cameroon estuary.

2.2. Sampling

Samples for physico-chemical and biological analysis were taken monthly in the 08 study stations for 12 months. Concerning physico-chemical analysis, the sampling were done using double-capped polyethylene bottles (250 and 1000 mL), without bubbles, and then transported to the laboratory in a refrigerated chamber. Concerning biological analysis, Rotifers and Cladocerans were collected at each station by filtering 100 L of water through a 64 µm mesh plankton filter. The filtrate obtained was collected in a 350 mL flask and then fixed and stored in 96˚ alcohol.

2.3. Data Collection

Measurements of physico-chemical variables were made both in the field and in the laboratory following the recommendations of [21]. In the field, temperature (˚C), salinity (mg/L), pH (UC) and electrical conductivity (µS/cm) were measured using a water test multiparameter; dissolved oxygen (%) was measured using a Hach HQ 30d oximeter. In the laboratory, suspended solids (mg/L), PO_4^{3-} (mg/L), the forms of nitrogen (NO_2^-, NO_3^- and NH_4^+) were measured by colorimetry with the spectrophotometer of mark HACH DR/3900.

Regarding biological parameters, samples of Cladocerans and Rotifers previously fixed with 96˚ alcohol, were identified and counted using specific identification keys such as [7] [8] [22]-[29] under a stereoscopic microscope WILD M5 and an optical microscope of mark IVYMEN.

2.4. Data Analysis

The Organic Pollution Index (OPI) was calculated from the quality classes obtained using the concentrations of three physicochemical parameters, namely, ammonia nitrogen (NH_4^+), nitrite (NO_2^-), and phosphate (PO_4^{3-}) [30] to measure the level of pollution in the mangrove waters of Mouanko.

The frequency of occurrence (*F*) of a species, which represents the ratio of the number of samples where this species is noted to the total number of samples taken, was calculated according to the formula:

$$F = \left(Si/St\right) \times 100 \tag{1}$$

where *Si* is the number of stations where the taxon *i* was sampled and *St* is the total number of stations sampled.

The Shannon-Weaver diversity index (*H'*) was calculated according to the formula:

$$H' = -\left[\left(ni/N\right)\log_2\left(ni/N\right)\right] \tag{2}$$

where H' represents the specific diversity, (in bits/individual), *ni* the number of species *i*, *N* the total number of individuals. It reflects the diversity of species that make up the community in the environment.

Pielou's J-index was used to measure the equitability (or equi-partition) of species in the stand. It is obtained by the formula:

$$J = H'/\log_2 S \quad (3)$$

with H' the Shannon-Weaver index, $\log_2$ the logarithm to base 2 and S the species richness. The index J varies from 0 (dominance of a single species) to 1 (even distribution of individuals in the community).

Canonical Correspondence Analysis (CCA) was used to highlight the relationships between physico-chemical variables and zooplankton taxa. These analyses were carried out with the software Past for Windows version 3.

3. Results

3.1. Physicochemistry of the Environment

The Kruskal Wallis test varried significantly ($p < 0.05$) between months for all parameters studied except in the case of nitrite in freshwater influenced zones, suspended solids in marinewater influenced zones and orthophosphate in both environments.

Temperature values in freshwater influenced zones ranged from 25.7˚C (ED1 in September) to 32˚C (ED4 in April) (Figure 2(a)). In marinewater influenced zones, data fluctuated from 25.7˚C (ES1 in July) to 31.3˚C (ES2 in May) (Figure 2(b)). Overall, Mouanko mangrove waters had a mean temperature value of

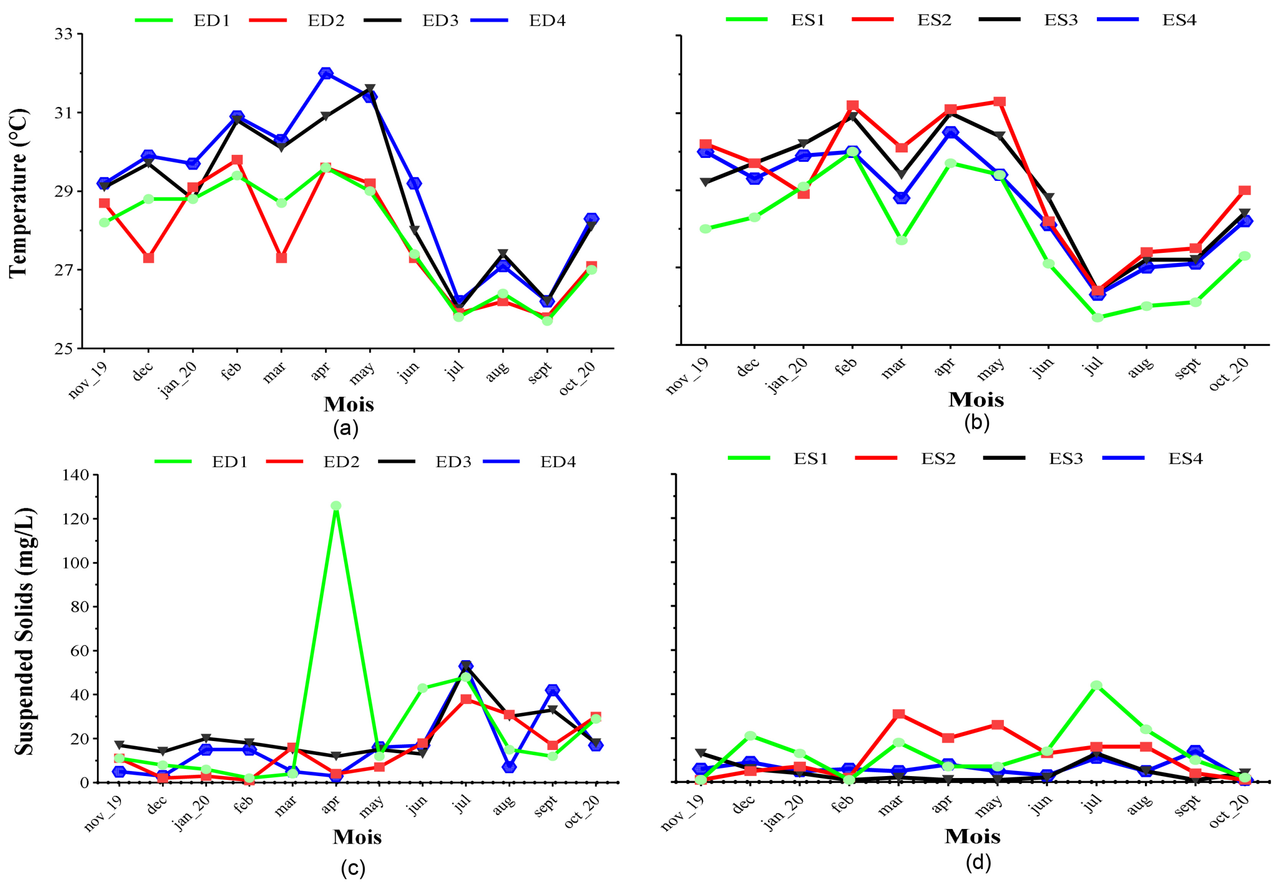


Figure 2. Spatial and temporal variations in temperature and suspended solids ((a), (c): freshwater influenced zones; (b), (d): marinewater influenced zones) during the study period.

28.5˚C ± 1.5˚C. The highest values were observed between the months of November to May and the lowest values were recorded between the months of June to October in both sites. Suspended solids (SS) values ranged from 1 mg/L (ED2 in February) to 126 mg/L (ED1 in April) in freshwater influenced zones (Figure 2(c)); while they ranged from 1 mg/L (ES1 in November and February; ES2 in November and October; ES3 in February, April, May and September, ES4 in October) to 44 mg/L (ES1 in July). Overall, Mouanko mangrove waters had a mean suspended solids value of 14.42 ± 16.8 mg/L (Figure 2(d)).

The rate of dissolved oxygen of water varied between 32% (ED1 in November) and 97.6% (ED3 in September) with an average of 72.33% ± 14.7% in freshwater influenced zones (Figure 3(a)). In sites influenced by marinewater, they varied from 36% (ES3 in March) to 88% (ES2 in May) with an average of 66.73 ± 13.42% (Figure 3(b)). In general, the mangrove waters of Mouanko were moderately oxygenated (69.56% ± 14.29%). The pH ranged from 5.85 (ED2 in November) to 9.55 (ED1 in October) in freshwater influenced zones (Figure 3(c)) and from 5.92 (ES1 in November) to 9.37 (ES1 in October) in marinewater influenced sites (Figure 3(d)). The mangrove waters of Mouanko were thus characterized as slightly basic (7.64 ± 0.71 UC).

Water salinity ranged from 0.01‰ (ED1 in July) to 0.703‰ (ED2 in January)

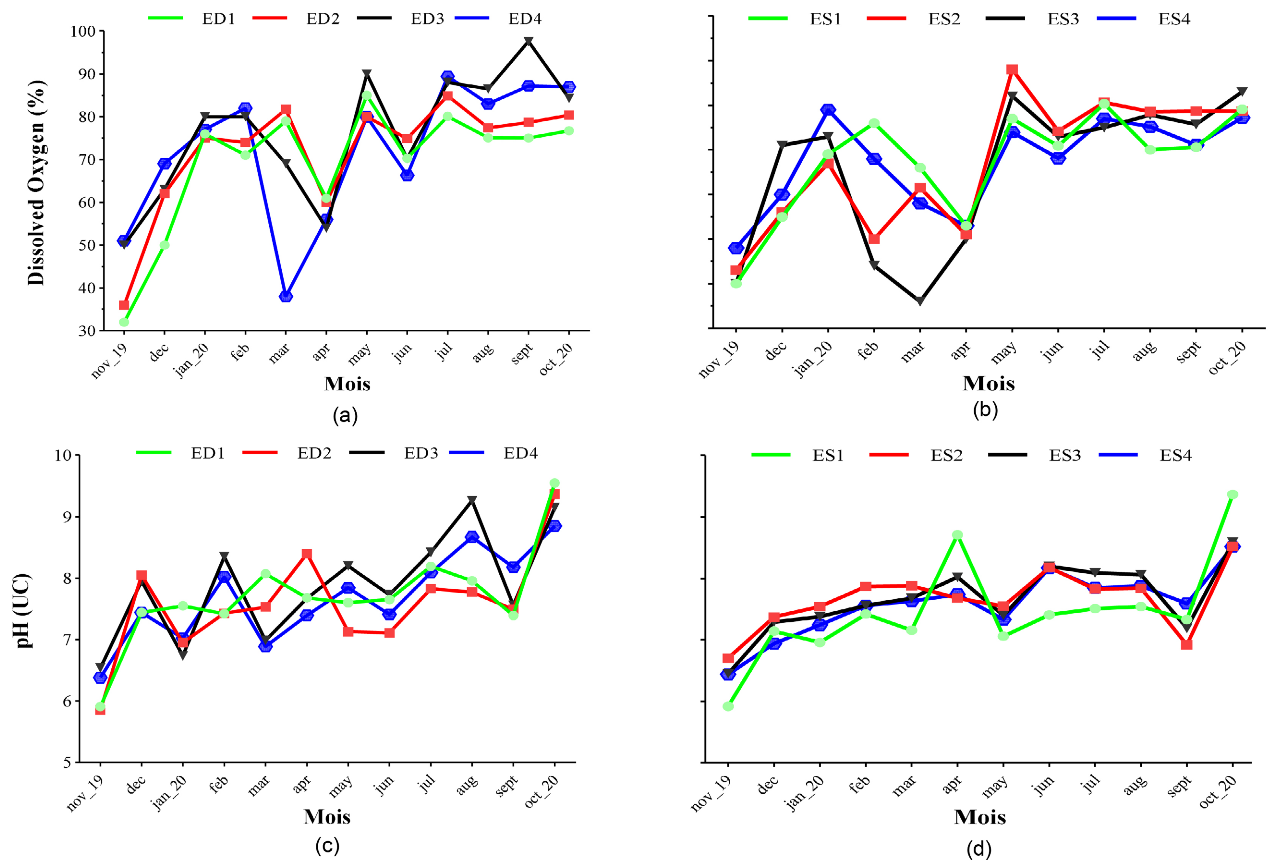


Figure 3. Spatial and temporal variations of dissolved oxygen and pH ((a), (c): freshwater influenced sites; (b), (d): marinewater influenced sites) during the study period.

with an average value of up to 0.15‰ in freshwaters influenced zones (**Figure 4(a)**). In marinewater influenced sites, it ranged from 23.3 mg/L (ES1 in October) to 13,220 mg/L (ES2 in April) with an average of up to 3.87‰ (**Figure 4(b)**). Spatially, the Mann-Whitney test showed a significant difference in the marinewater influenced sites between station ES1 with stations ES2 ($p = 0.000$), ES3 ($p = 0.01$) and ES4 ($p = 0.04$) while, station ES2 with station ES4 ($p = 0.03$). The variation curve of electrical conductivity showed a similar trend to that of salinity, varying from 21 µS/cm (ED1 in July) to 97.6 µS/cm (ED3 in September) with an average value of 142.58 ± 253.62 µS/cm in freshwater influenced sites (**Figure 4(c)**) and from 51 µS/cm (ES1 in October) to 23,300 µS/cm (ES2 in April) in marinewater influenced sites (**Figure 4(d)**). Spatially, the Mann-Whitney test showed a significant difference in the marinewater influenced sites between station ES1 with stations ES2 ($p = 0.000$), ES3 ($p = 0.02$) and ES4 ($p = 0.04$) and station ES2 with station ES4 ($p = 0.052$).

Recorded PO_4^{3-} concentrations ranged from 0 mg/L (ED2 in February and ED3 in December) to 0.84 mg/L (ED4 in October) in freshwater influenced sites (**Figure 5(a)**). In contrast, they ranged from 0 mg/L (ES1 in March, July and August; ES2 in November and February; ES3 in November and September) to

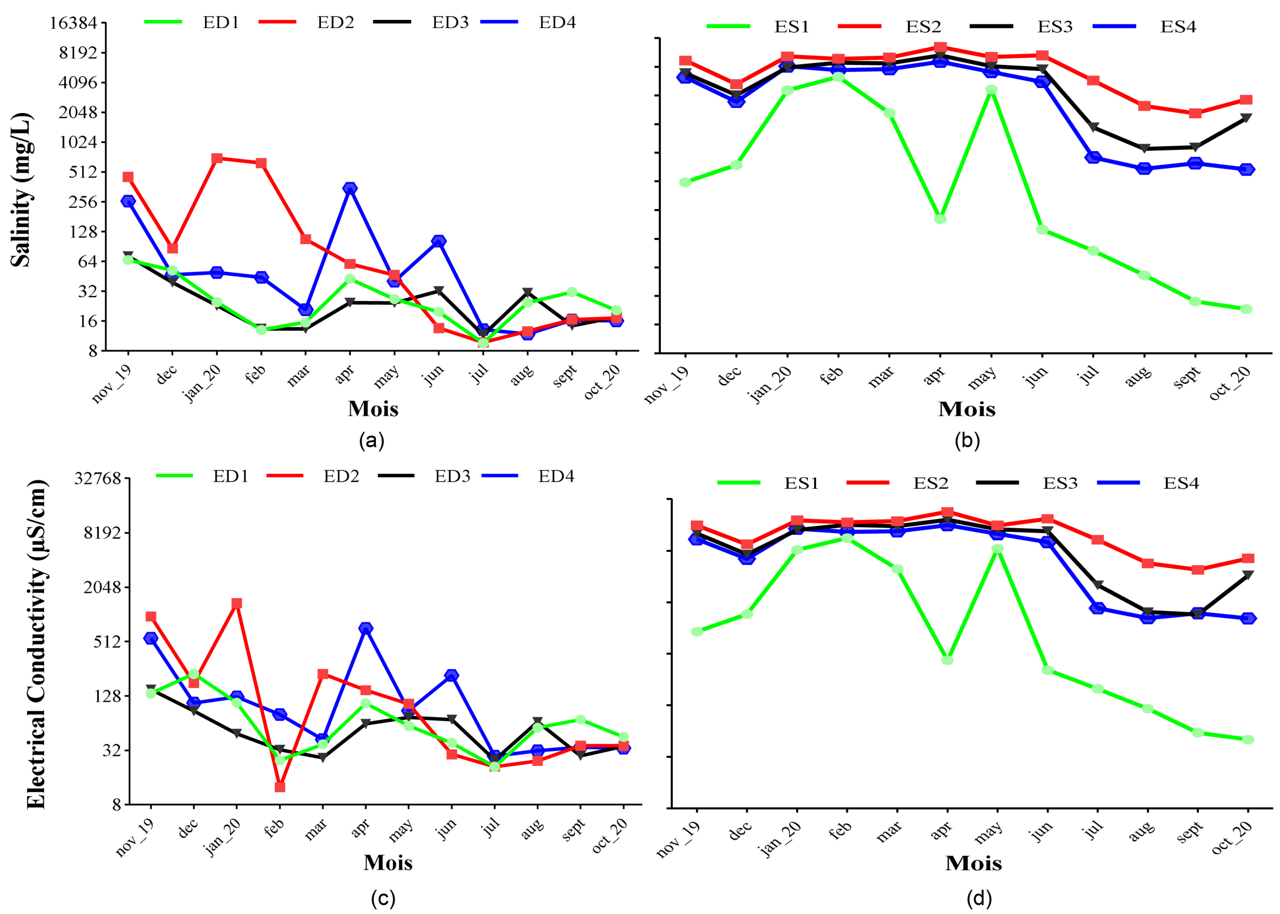


Figure 4. Spatial and temporal variations in Salinity and Electrical Conductivity ((a), (c): freshwater influenced zones; (b), (d): marinewater influenced zones) during the study period.

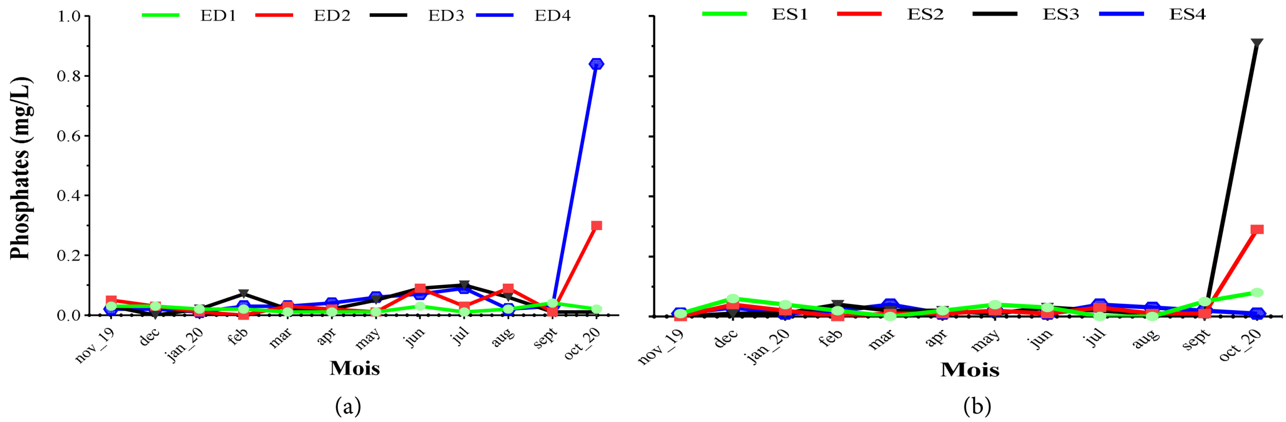


Figure 5. Spatial and temporal variations of PO_4^{3-} ((a): freshwater influences sites, (b): marinewater influenced sites) during the study period.

0.91 mg/L (ES3 in October) in marinewater influenced zones (**Figure 5(b)**). Overall, the mangrove waters of Mouanko had on average PO_4^{3-} values of 0.04 ± 0.12 mg/L.

For NH_4^+, freshwater concentrations ranged from 0 mg/L (ED2 in February) to 0.76 mg/L (ED2 in September) (**Figure 6(a)**). In marinewater influenced sites, they ranged from 0 mg/L (ES1 in February, ES3 in November and April) to 2.14 mg/L (ES2 in November) (**Figure 6(b)**). Globally, the mangrove waters of Mouanko had an average NH_4^+ value of 0.39 ± 0.3 mg/L. Water NO_3^- levels ranged from 0.94 mg/L (ED1 in November) to 14.4 mg/L (ED4 in December) in freshwaters influenced sites (**Figure 6(c)**) and from 0.84 mg/L (ES1 in November) to 15.2 mg/L (ES4 in February) in marinewater influenced sites (**Figure 6(d)**). In general, the mangrove waters of Mouanko presented on average, nitrate values of 5.98 ± 3.14 mg/L. NO_2^- concentrations ranged from 0.01 mg/L (ED1 in September; ED2 in May and September; ED3 in April, May and September; ED4 in April and September) to 0.41 (ED2 in July) in freshwater influenced sites (**Figure 6(e)**). In marinewater influenced sites, they ranged from 0.01 mg/L (ES1 in September and October; ES2 in September; ES3 in August; ES4 in February and October) to 0.35 mg/L (ES3-May) (**Figure 6(f)**). In all, the mangrove waters of Mouanko presented average nitrate values of 0.06 ± 0.05 mg/L.

Organic Pollution Index (OPI) values ranged from 3 (ED2 in August and October, ED4 in October) to 4.33 (ED1 in March and July; ED2 in January, February, May and September; ED3 in December, September and October) in freshwater influenced sites (**Figure 7(a)**) whereas, in sites under marinewater influence, they ranged from 2.33 (ED3 in October) to 4.66 (ED3 in May) (**Figure 7(b)**). Overall, the mangrove waters of Mouanko presented an average OPI value of 3.78 ± 0.4. This index showed no spatially significant difference ($p > 0.05$).

3.2. Biological Variables

3.2.1. Qualitative Analysis of the Stands

During the study period, a total of 45 taxa were identified. Rotifers were the

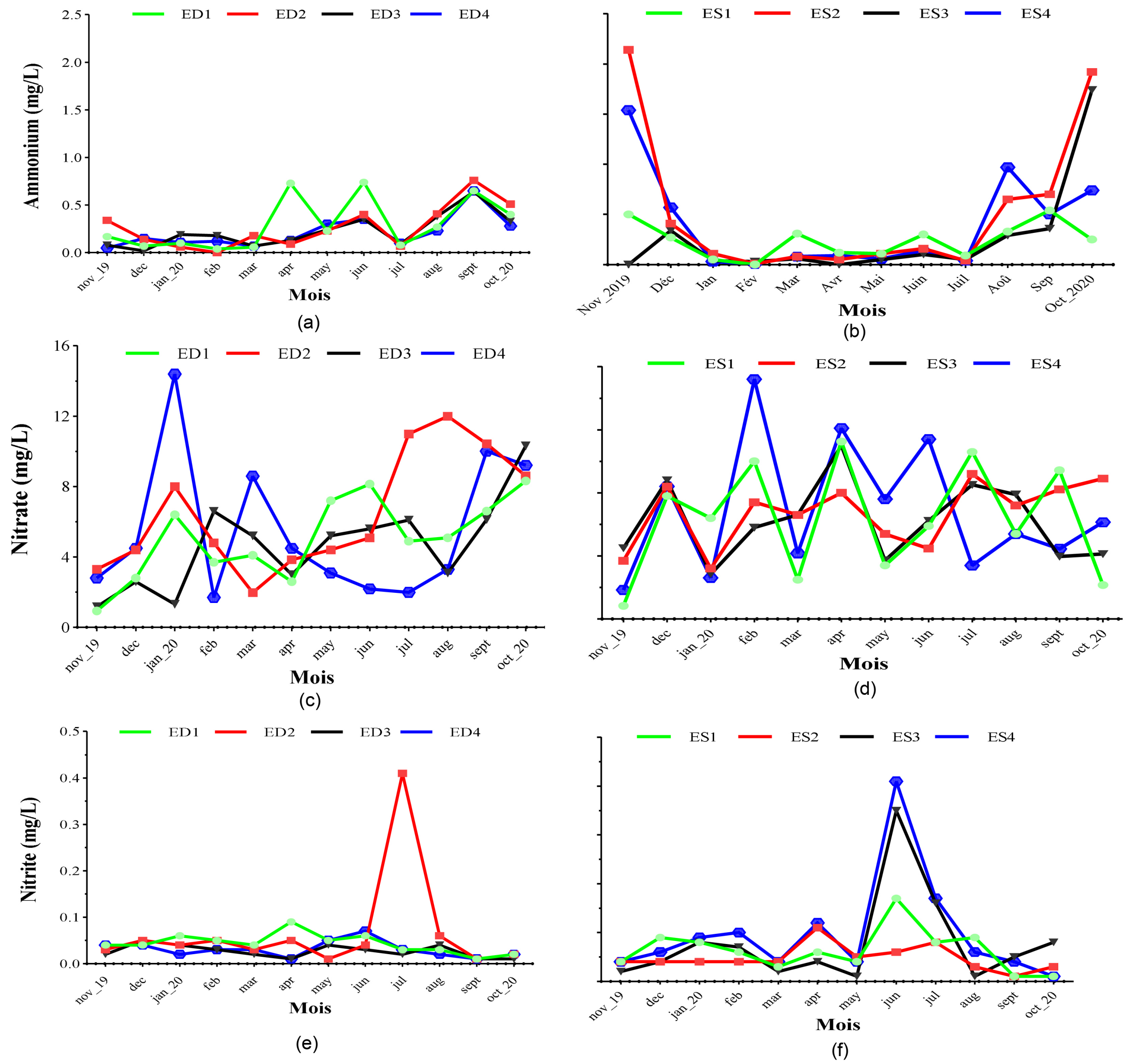


Figure 6. Spatial and temporal variations of NO_3^-, NO_2^- and NH_4^+, ((a), (c), (e): freshwater influenced sites; (b), (d), (f): marinewater influenced sites) during the study period.

most diverse with 30 taxa (66.5% of the total diversity) while Cladocerans represented by 15 taxa were the least diverse (33.5% of the total diversity).

The highest taxonomic richness was obtained in freshwater influenced sites with 40 taxa against 17 in marinewater influenced sites. The species *Penilia avirostris* (Cladoceran), *Rhabdonella conica* and *Synchaeta* sp. (Rotifers) were collected only in marinewater influenced sites while the species of Cladocerans: *Simocephalus vetulus*, *Diaphanosoma excisum*, *Diaphanosoma brachyurum*, *Alonella excisa*, *Alona costata*, *Alona elegans*, *Alona diaphana*, *Chydorus ovalis*, *Pleuroxus denticulatus*, *Pleuroxus trigonelus*, *Bosmina longirostris* and *Bosminopsis* sp., *Llyocryptus* sp. and Rotifers: *Rotaria rotatoria*, *Philodina roseola*,

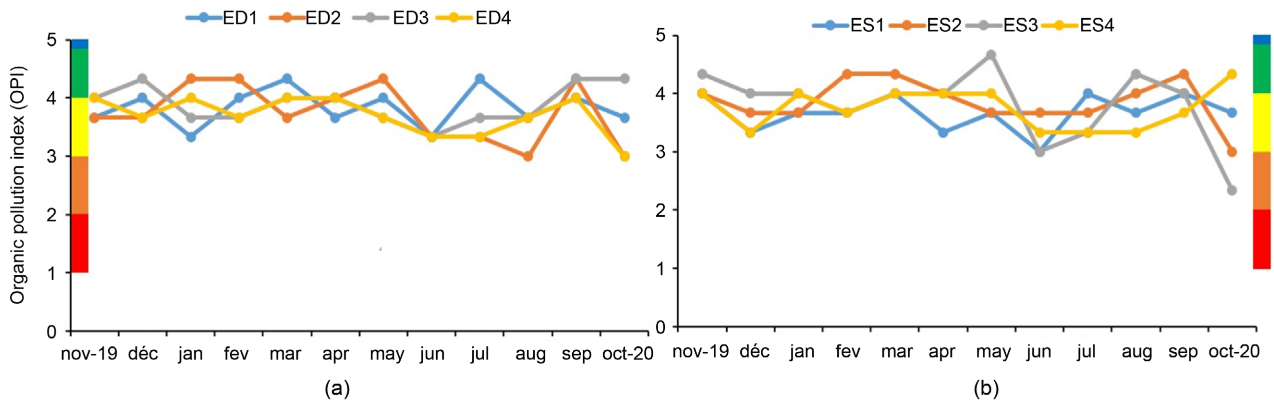


Figure 7. Spatial and temporal variation of OPI in freshwater influenced sites (a) and marinewater influenced sites (b) stations.

Brachionus angularis and *Brachionus caudatus* were collected only in freshwater influenced sites (**Table 1**).

The percentage of occurrence of taxa of the different groups collected (**Table 1**) shows that in freshwater influenced sites, 16 taxa were incidental (40% of the species richness) and 24 rare (60% of the species richness). In contrast, in marinewater influenced sites, it shows that 1 taxa (the Cladoceran *Penilia avirostris*) was incidental (5.88% of the species richness), 3 incidental (17.64% of the species richness) and 13 rare (76.47% of the species richness).

Rotifers showed the highest diversity of species (30), genera (15) and families (11) compared to Cladocerans which recorded 15 species, 9 genera and 5 families (**Figure 8(a)**). During the study period, the total abundance of organisms was 612 ind./L (**Figure 8(b)**). This abundance was dominated by Rotifers with 67% (407 ind/L) while Cladocerans represented only 33% (205 ind./L).

3.2.2. Quantitative Analysis

Spatially, Cladoceran and Rotiferan species richness was highest at stations ED1 (25 taxa) and ED4 (23 taxa) located in freshwater influenced sites and low at stations ES2 (4 taxa), ES3 and ES4 (3 taxa each) located in marinewater influenced sites (**Figure 9(a)**). At all stations, Rotifers presented a higher species richness than Cladocerans. Temporally, the highest species richness was obtained in April, June and September (16 taxa each), followed by August and October (12 taxa each); the lowest taxon richness was obtained in March (2 taxa) and May (1 taxa) (**Figure 9(b)**). The taxonomic richness of Cladocerans showed significant difference between fresh and marinewater influenced sites ($p = 0.02$).

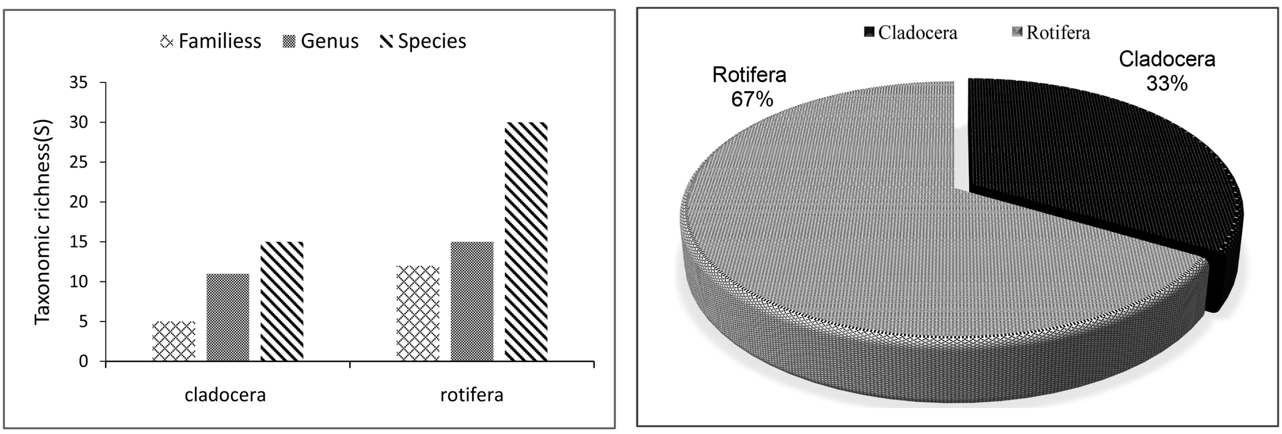
Spatially, Rotifers were most abundant in freshwater influenced sites at ED2 stations, dominated by the family Brachionidae (59 ind/L) with *Keratella tecta*; and ED4 dominated the family Brachionidae (41 ind/L) with *Keratella tecta* (**Figure 10(a)**). As for Cladocerans, the highest abundance was obtained at freshwater influenced station ED1, dominated by the family Chydoridae (26 ind/L) with *Alona costata* and *Pleuroxus trigonelus* species. Low abundances were obtained in marinewater influenced zones at stations ES3 (31 ind/L) and ES2 (47 ind/L) where the family Sididae dominated (13 and 24 ind/L respectively

Table 1. Abundance and occurrence of Rotifers and Cladocerans identified in the mangrove waters of Mouanko during the study period.

Groups	Families	Species	Freshwater influenced sites				Occurrence %	Marinewater influenced sites				Occurrence %
			ED1	ED2	ED3	ED4		ES1	ES2	ES3	ES4	
Cladocerans	Daphniidae	*Simocephalus vetulus*	3	6	-	-	4.16	-	-	-	-	-
	Sididae	*Diaphanosoma brachyurum*	-	-	14	-	6.25	-	-	-	-	-
		Diaphanosoma excisum	5	4	-	-	4.16	-	-	-	-	-
		Penilia avirostris	-	-	-	-	-	8	24	13	39	29.16
	Chydoridae	*Alonella excisa*	-	-	8	3	6.25	-	-	-	-	-
		Alona costata	6	-	3	3	8.33	-	-	-	-	-
		Alona diaphana	4	-	-	-	2.08	-	-	-	-	-
		Alona elegans	4	-	3	-	4.16	-	-	-	-	-
		Chydorus ovalis	3	-	-	3	4.16	-	-	-	-	-
		Kurzia longirostris	-	4	-	5	4.16	3	-	-	-	2.08
		Pleuroxus denticulatus	3	4	-	-	4.16	-	-	-	-	-
		Pleuroxus trigonelus	6	8	-	3	8.33	-	-	-	-	-
	Bosminidae	*Bosmina longirostris*	-	7	-	-	4.16	-	-	-	-	-
		Bosminopsis sp.	-	-	3	-	2.08	-	-	-	-	-
	Macrothricidae	*Ilyocryptus* sp.	-	3	-	-	2.08	-	-	-	-	-
Rotifers	Asplanchnidae	*Asplanchna* sp.	3	3	-	3	6.24	4	-	-	-	2.08
	Rhabdonellidae	*Rhabdonella conica*	-	-	-	-	-	-	9	11	-	6.25
	Trichocercidae	*Trichocerca chattoni*	4	-	7	4	8.33	4	-	-	-	2.08
		Trichocerca sp.	4	3	3	-	6.24	4	-	-	-	2.08
	Philodinidae	*Philodina roseola*	3	-	-	-	2.08	-	-	-	-	-
		Rotaria rotatoria	4	4	-	3	6.24	-	-	-	-	-
	Synchaetidae	*Synchaeta* sp.	-	-	-	-	-	-	-	-	4	2.08
	Brachionidae	*Brachionus angularis*	-	10	-	-	6.25	-	-	-	-	-
		Brachionus caudatus	-	7	-	4	6.25	-	-	-	-	-
		Brachionus sp.	3	3	-	-	4.16	-	-	-	-	-
		Keratella quadrata	4	6	-	-	4.16	-	-	-	-	-
		Keratella serrulata	-	-	-	3	2.08	3	-	-	-	2.08
		Keratella sp.	-	-	-	3	2.08	-	4	-	-	2.08
		Keratella tecta	3	25	18	18	18.75	-	-	-	-	-
		Keratella tropica	12	8	-	13	18.75	-	-	4	-	2.08
	Euchlanidae	*Dichronophorus grandis*	-	-	-	-	-	12	4	-	4	8.33
		Dichronophorus sp.	3	-	-	4	4.16	-	-	-	-	-
		Euchlanis dilatata	-	-	-	6	4.16	3	-	-	-	2.08

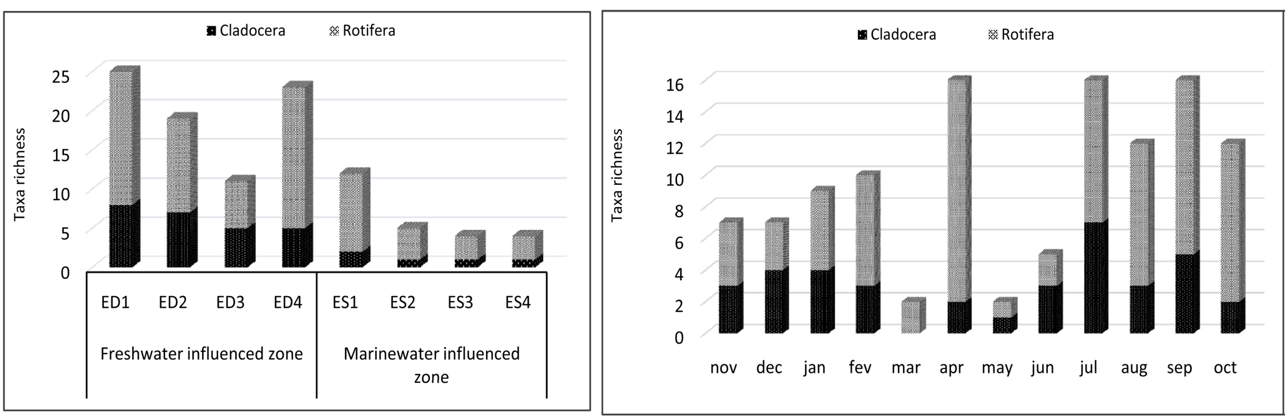
Continued

		Euchlanis sp.	-	-	-	6	4.16	-	-	-	-	-
	Notommatidae	*Cephalodella gibba*	-	-	-	4	2.08	-	-	-	-	-
		Cephalodella sp.	3	-	-	3	4.16	-	-	-	-	-
	Lecanidae	*Lecane bulla*	3	10	3	8	14.58	8	-	3	3	8.33
		Lecane clara	3	-	3	-	4.16	5	-	-	-	2.08
		Lecane leontina	4	6	-	7	10.41	-	-	-	-	-
		Lecane sp.	6	-	-	-	4.16	3	-	-	-	2.08
	Lepadellidae	*Lepadella rottenburgi*	-	3	-	-	2.08	-	-	-	-	-
		Lepadella sp.	9	-	7	3	12.5	-	-	-	-	-
	Mytilinidae	*Mytilina* sp.	-	-	-	3	2.08	-	-	-	-	-
	Collurellidae	*Colurella obtusa*	4	-	-	6	6.25	4	-	-	-	2.08
		Colurella sp.	-	-	-	-	-	-	6	-	-	4.16
Total	**17**	**45**	**109**	**124**	**72**	**118**		**61**	**47**	**31**	**50**	
	Taxonomic richness				**40**					**17**		



(a) (b)

Figure 8. Taxonomic richness (a) and abundance (b) of Cladocerans and Rotifers collected in the waters of Mouanko mangroves.



(a) (b)

Figure 9. Spatial (a) and temporal (b) variations in species richness during the study period.

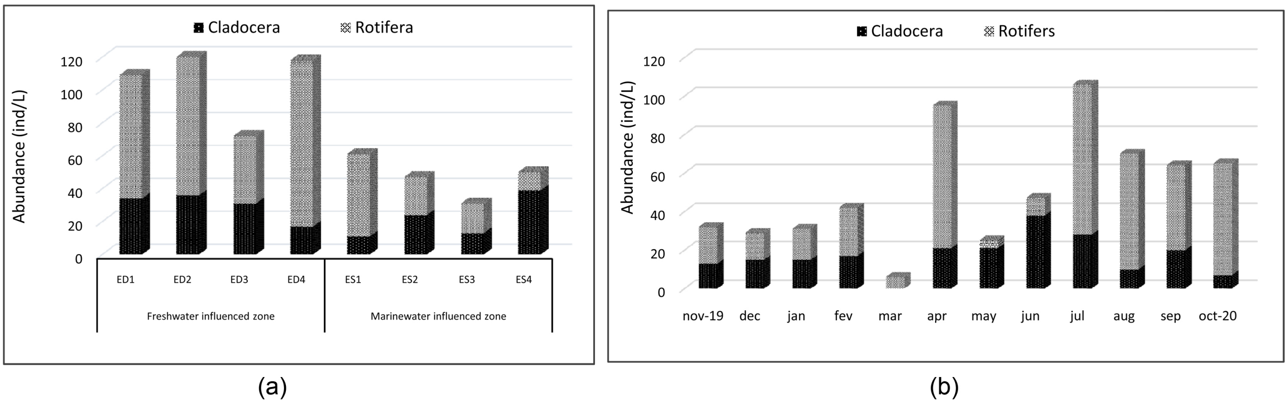


Figure 10. Spatial (a) and temporal (b) variations in the abundance of cladocera and Rotifers during the study period.

at each station) with the species *Penilia avirostris* (13 and 24 ind/L at each station). Rotifers were more abundant than Cladocera at all stations except at ES4.

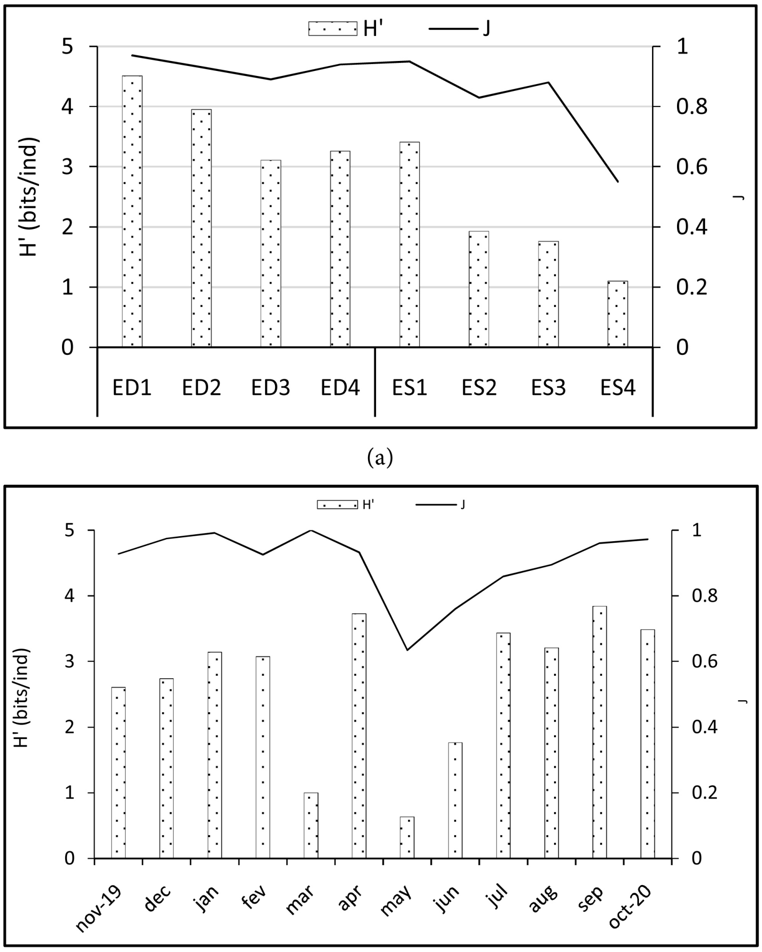
Temporally, the highest abundances were recorded in July (106 ind/L), dominated by the family Brachionidae (51 ind/L) with the species *Keratella tecta* (36 ind/L), followed by the month of April (95 ind/L), dominated by the family Brachionidae (30 ind/L) with the species *Rhabdonella conica* (16 ind/L) (**Figure 10(b)**). In contrast, the lowest abundances were recorded in March (6 ind/L) with the single family Brachionidae and the species *Keratalla tropica* and *Brachionus caudatus* (3 ind/L each). The abundance of Cladocerans and Rotifers showed no significant differences, neither spatial nor temporal ($p > 0.05$).

3.2.3. Diversity Index

Spatially, the Shannon and Weaver diversity index (H') varied from 1.1 bits/ind (ES4) to 4.5 bits/ind (ED1). In freshwater influenced stations this index was high with an average of 3.95 ± 0.6 bits/ind, and low in marinewater influenced stations with an average of 2.05 ± 0.97 bits/ind (**Figure 11(a)**). Pielou equitability (J) fluctuated between 0.55 (ES4) and 0.97 (ED1). Stations located in zone under fresh-water influenced were clearly more equi-related (0.93 ± 0.03) than those located in marinewater influenced sites (0.8 ± 0.17) (**Figure 11(a)**). Temporally, the Shannon and Weaver diversity index (H') ranged from 0.63 bits/ind (may) to 3.84 bits/ind (September) with an average of 2.71 ± 1.05 bits/ind (**Figure 11(b)**). The Pielou equitability index (J) varied between 0.63 (may) and 1 (March) with a mean of 0.9 ± 0.1 (**Figure 11(b)**). The Kruskal Wallis test showed no significant difference ($p > 0.05$) in spatiotemporal data.

3.2.4. Influences of Environmental Variables on the Distribution of Zooplankton Populations

The results of the Canonical Correspondence Analysis (CCA) showed that the correlations between the environmental factors and the taxa during the study period was distributed on two axes, axis 1 (54.07%) and axis 2 (17.28%) which cumulate 71.35% of the total variance (**Figure 12**). The factorial axis 2 separates the marinewater influenced stations forming group 1, with the fresh-water



(a)

(b)

Figure 11. Spatial (a) and temporal (b) variations of Shannon and Weaver (*H'*) and Pielou (*J*) equitability indices in mangrove waters during the study period.

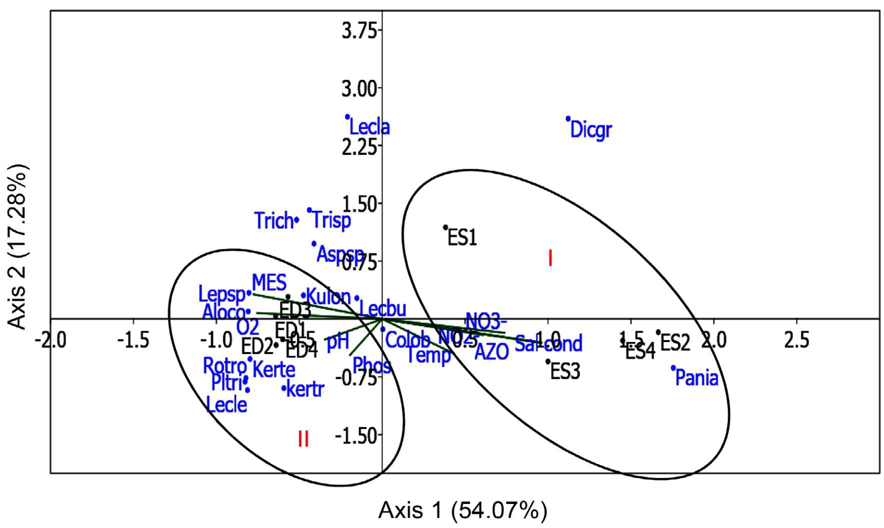


Figure 12. Canonical CorrespondenceAnalysis (CCA) showing the relationships between environmental variables, sampling sites and taxa at the eight sampling stations in the Mouanko mangrove waters.

Legend: Environmental variables: Temp = Temperature, NO^{2-} = Nitrite, NO^{3-} = Nitrate, O2 = Dissolved oxygen, Cond = Electrical conductivity, phos = Phosphate, AZO = ammoniac nitrogen, Sal = salinity, pH = hydrogen potential, MES = Suspended solids; Biological variables: Pania = *Peniliaavirostris*, Dicgr = *Dicronophorusgrandis*, Colob = *Colurellaobtusa*, Lecla = *Lecaneclara*, Trich = *Trichocercachattoni*, Trisp = *Trichocerca* sp., Aspsp = *Asplanchna*sp., Lepsp = *Lepadella* sp., Kulon = *Kurzialongirostris*, Lecbu = *Lecane bulla*, Aloco = *Alonacostata*, Rotro = *Rotariarotatoria*, Kerte = *Keratella tecta*, Kertr = *Keratellatropica*, Pltri = *Pleuroxustrigonelus* et Lecle = *Lecaneleontina*.

influenced stations, represented by group 2.

The first group, positively correlated with axis 1. Comprising the taxa *Penilia avirostris*, *Dicronophorus grandis* and *Colurella obtusa*, it was characterized by salinity, electrical conductivity, ammonia nitrogen, temperature, nitrates and nitrites. The second group which includes the taxa *Alona costata*, *Lecane bulla*, *Lecane clara*, *Lecane leontina*, *Trichocerca chattoni*, *Trichocerca* sp., *Asplanchna* sp., *Lepadella* sp., *Kurzia longirostris*, Rotaria *rotatoria*, *Keratella tecta*, *Keratella tropica* and *Pleuroxus trigonelus* was negatively associated with axis 1 and SS, dissolved oxygen and pH. Thus, the high average values of salinity, electrical conductivity, ammonia nitrogen, nitrates and nitrites obtained in the brackish water stations negatively influenced the presence of Cladocera and Rotifers in this part of the mangrove waters.

4. Discussion

4.1. Physico-Chemical Variables

The mean water temperatures at the two study sites fluctuated around an average of 28.5˚C ± 1.5˚C. These results are in line with those of [31] (28.66˚C ± 0.15˚C and 29.49˚C ± 0.16˚C) in the mangrove waters of Mbiako and Tiko in Cameroon respectively; [32] (29.67˚C ± 0.76˚C) in the mangrove waters of Mouanko and Manoka in Cameroon. These values do not exceed 30˚C, and are therefore in conformity with Cameroonian standards for surface water [33]. The mean suspended solids value (14.42 ± 16.8 mg/L) obtained in these waters are mainly due to mangrove foliage falling, decomposing and leaving debris in the water. This result is comparable to that of [34] who showed that the vegetation in the mangrove contributes to increase the rate of suspended matter in the water. Nevertheless, the very high content observed at station ED1 in April (126 mg/L) could be justified by exogenous inputs from rainwater.

In freshwater influences sites, the dissolved oxygen saturation rate hovered around an average of 72.33% ± 14.7%. This result is close to those generally obtained in forest and peri-urban streams (above 73%) [35] [36]. In contrast, in marinewater influenced sites, this mean value was 66.73% ± 13.42%, close to that obtained by [32] (64.80% ± 7.94%) in the mangrove waters of Mouanko and Manoka in Cameroon. This low oxygenation in marinewater influenced sites of mangroves would be due to the fact that they are constantly subjected to tidal phenomena. In 2004, Villanueva revealed that the arrival of water poor in oxygen in the mangroves by the tide is at the origin of the low oxygenation of the waters of this ecosystem [37]. The average pH value (7.64 ± 0.71 UC) obtained in the mangrove waters during this study is slightly basic. This basicity could be due to inputs of alkaline ions from the sea water to the mangrove water via the tides. Indeed, according to [38], the pH of the marine environment is generally basic (varies between 7.5 and 8.4 UC). However, the high values of this parameter recorded in the month of October (around 9 CU) could be due to the abundance of oyster shells in the waters linked to the intensive fishing of oysters by local residents. According to [39], the high amount of shell material influences the pH through the release of carbonate and the neutralization of H^+ ions that make the waters basic. The salinity values of the water at the two sites remain largely lower than those recognized for sea water in Cameroon [33] (23‰ and 24‰) throughout the study period. This may be as a result of the estuarine position of the two sites which benefit from high rainfall and freshwater inflows from rivers such as the Sanaga, Kwa-Kwa and Wouri which dilute the salinity of seawater. The low average values of the forms of nitrogen in the water could be linked to the purification capacity of the mangrove areas because they are subject to domestic and agricultural pollution brought by the tides, rivers and run-off water. According to [40], this can be explained by the high bioremediation capacity of these environments. Nonetheless, the nitrite peak observed in June at the ED2 station (0.41 mg/L) could be due to bacterial action, by transforming ammonia from organic waste (leaves and mangrove tree trunks, excreta and animal corpses) observed at this station, produces nitrite. [41] points out that nitrosomonas use ammoniacal elements (NH_4^+ and NH_3) and transform them into nitrite. The orthophosphate values recorded in the mangrove waters of Mouanko are very low (0.04 ± 0.12 mg/L) compared to those obtained in the Kondi stream located in the urban area (1.5 ± 1.43 mg/L) [13]. This low value could be due to the low anthropization of the area as well as the low practice of agricultural activities and uses of phosphorus materials. According to [40], orthophosphates can be contributed by pesticides used in agricultural activities and by domestic detergents.

The moderate level of organic pollution revealed by the IPO in the mangrove waters of Mouanko (3.78 ± 0.4) could be due to the bio-purifying nature of the mangrove. Indeed, mangroves play a role similar to that of filtering plants with regard to forms of nitrogen, orthophosphates, etc. [40].

The low levels of organic pollution indicator parameters (Nitrates, Nitrites, Ammonium and Phosphate), the high average values of dissolved oxygen and the low temperatures of the waters of the Mouanko mangroves show the low anthropic impact of this ecosystem [36] [41] [42] and confer on the waters of these mangroves an ecological quality that is moderately good, with characteristics that are favourable to the development of aquatic communities [43].

4.2. Fauna of Cladocera and Rotifers in the Mangrove Waters of Mouanko

During This study, 45 taxa of Cladocerans and Rotifers were collected. This taxonomic richness is largely suprior to that obtained by [44] (0 taxon) in the Sundarbans estuarine system in India. However, it is still lower than the 61 species obtained by [11] in the Upper Bandama Basin in northern Ivory Coast. These differences in taxonomic richness between these different environments could be related to the difference in mesh size of the net used by [44] (100 µm) and [11] (30 µm). They may also be due to the types of environment, physicochemical properties of the water, regional climate to and hydrology of the water bodies [45]. This specific richness was lower marinewater influenced sites (17 taxa) than in fresh-waters influenced sites (40 taxa). This would be due to the high levels of electrical conductivity and salinity recorded in marine environment. According to [46], when the electrical conductivity and salinity of the water increases, the high osmotic pressure created can induce migration or mortality of organisms.

Of the two zooplankton groups studied, Rotifers constitute 66.5% of the total diversity against 33.5% for Cladocera. This high diversity of Rotifers could be explained by their opportunistic trait that aids their resistance to environmental variations. According to [47], Rotifers form a highly diverse and cosmopolitan group in the animal kingdom. They are more adaptable to environmental changes and their short reproductive cycle largely compensates for their low relative fecundity [48]. In addition, they better escape fry grazing due to their small size [47].

Rotifers (67%) were the most abundant in our freshwater influenced stations. This high abundance of rotifers in this environment may well be due the fact that they represent the most important zooplanktonic group in freshwater [49] [50]. Temporally, the high abundance of the population in the months of April and July is justified by the fact that during this period, rainwater carries new nutrients (bacteria and organic detritus) into the mangroves and dilutes the salt water brought by tidal movements, thus making the environment favorable to the development of zooplankton [50]. On the other hand, during the months of November - February (dry season) the rise of the sea water thanks to the movements of the tides, floods the mangroves thus rendering the environment unsuitable for the development of a great number of individuals. Moreover, the low abundance of cladocerans (33%) could be as a result of the strong predation pressure exerted by fry and planktivorous fish. [51], emphasizes in this opinion that planktivorous fish preferentially consume cladocerans, because they are large prey, with reduced mobility, rich in energy and can be found without difficulty. The decrease in abundance of organisms in March is thought to be due to a transition between the dry and wet seasons. During this transition, the change in water quality would lead to a decrease in populations and species richness, but a little less for Rotifers which are more tolerant to environmental variations. This seems to confirm the hypothesis of a seasonal succession, under the influence of predation by fish fry, degrading water quality and competition between species [52]. Among the taxa collected, *Penilia avirostris* present only in marinewater influenced areas showed the highest abundance. This marine species would have migrated from the ocean to the mangroves thanks to tidal phenomena. According to [53], it is the only cosmopolitan marine cladocera frequently found in warm coastal waters.

The CCA results show that the variables strongly associated with the distribution of taxa are salinity, electrical conductivity, suspended solids and dissolved oxygen. The first group characterized by high salinity and electrical conductivity presented only 3 taxa. This would mean that the high values of salinity and electrical conductivity would disadvantage the development of continental Cladocera and Rotifers. On the other hand, the 13 taxa obtained in the second group would be due to low values of salinity and conductivity. Similar results have already been observed by [54] in the Ebrié lagoons in Ivory Coast. According to [55], salinity plays a crucial role in the estuarine environment by controlling the composition and diversity of certain organisms.

The strong spatio-temporal fluctuations of the Shannon and Weaver index (H) and of the Pielou equitability coefficient reveal a great instability in the structuring of the communities studied, thus showing the variability of the environmental conditions that prevailed in this ecosystem throughout the study. In addition, the low values of the equitability index recorded at station ES4 might be due to the high relative abundance of the species *Penilia avirostris*, which accounts for nearly 80% of the individuals at this station. Indeed, according to [56] [57] the Piélou index is low when one or a few taxa have a very high relative abundance. Similarly, the low diversity obtained in March, May and June is due to the instability of the environment linked to tidal movements that impact the stations by increasing the salinity and electrical conductivity of the water and causing the leaching of zooplanktonic organisms. [58] emphasizes in this regard that floods create conditions of instability that cause the drift of zooplankton populations. In general, salinity and electrical conductivity of the water seem to be the most important ecological parameters in determining the structure of the zooplanktonic community, as has been demonstrated in different estuarine or lagoon environments [59] [60].

5. Conclusion

The study of the influence of abiotic variables on the diversity and spatio-temporal distribution of Cladocerans and Rotifers in the mangrove waters of Mouanko show that the waters are warm, slightly basic, moderately oxygenated and highly mineralized. The low levels of ammoniacal nitrogen, nitrites and orthophosphates indicate the low organic pollution of the environment. Faunal analysis shows a predominance of Rotifers (30 taxa or 66.5% abundance) over Cladocera (15 taxa or 33.5% abundance). Species richness and zooplankton abundance were higher in freshwater influenced sites than in marinewater influenced sites. Salinity, electrical conductivity, flooding and free movement of mangroves and the different anthropogenic activities practiced in the surroundings are globally, factors that influence the distribution of Cladocerans and Rotifers in mangroves sites.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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