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Research Article

COMPARATIVE STUDY BETWEEN LOW AND HIGH-WATER QUALITY AND THE ZOOPLANKTON COMMUNITY OF THE NIGER RIVER, NIGER

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ABSTRACT

Seasonal variations in zooplankton abundance, diversity and the physicochemical properties of the Niger River were studied during 2018 and 2019.The aim of this study is to carry out a comparative study of water quality and the zooplankton community in the River Niger between the high-water period (February 2019) and the low-water period (April 2018). To do this, three water samples were taken at each period and at each station, in order to determine the physico-chemical parameters and then identify the zooplankton. Qualitative analysis of zooplankton revealed the presence of 48 taxa belonging to three main taxonomic groups: Rotifera, Cladocera and Copepoda. During low-water periods, the most frequent taxa were rotifers (74.89%), followed by copepods and copepodites (20.17%) and cladocera (4.93%). In contrast to high-water sampling, copepods and copepodites are the most important (53.2%), followed by rotifers (32.63%) and cladocerans (14.09%).Rotifers are the most abundant group and the most resistant to changes in environmental variables. The physicochemical parameters that significantly influence zooplankton populations are pH, dissolved oxygen, temperature, total phosphorus, silica and chlorophyll-a.

Keywords: Africa, Zooplankton diversity, Niger River, Water quality.

INTRODUCTION

Aquatic ecosystems are home to a diverse array of organisms interacting with each other and their environment. Depending on their life-history traits and ecological preferences, organisms are adapted to the biotic and abiotic factors determining their habitats within a range of variation (Mathivanan *et al.*, 2007). Thus, a disturbance of anthropogenic origin (i.e. human pressure) or natural origin (e.g. drought, flooding, silting...) that causes these factors to vary beyond this range can lead to changes in their distributions and/or abundance (Zhao *et al.*, 2012). The Niger River has a fairly varied biodiversity of vertebrates (Awaïs, 2007) and invertebrates (Alhou, 2007; Alhou *et al.*, 2014). This biodiversity is considerably and continuously affected by anthropogenic and climatic activities that degrade the quality of the waters and habitats on which plankton depend (Sako, *et al.,* 2019). Among this biodiversity, zooplankton is ecologically an important group of aquatic organisms (Berté *et al.,* 2019).

As consumers, predators and prey, zooplankton plays a central role in aquatic food webs and energy transfers in aquatic ecosystems (Fonty, 2021). Numerous studies have shown that zooplankton populations and communities have changed significantly over recent decades due to environmental factors linked to human activities and climate change, and this work highlights that zooplankton can be used as an indicator of the impact of these changes at a planetary level (Fofana *et al.*, 2019). An essential intermediary between primary producers (phytoplankton) and higher trophic levels (fish), these organisms form

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highly diversified biological communities, necessary for establishing models of how aquatic systems function, particularly with a view to managing fisheries resources (Perbiche *et al.,* 2012). There is growing interest in large river ecosystems, but knowledge of river zooplankton remains patchy, with little information on the factors that structure zooplankton communities in lotic rather than lentic environments (Jack and Thorp 2002). So, from a sustainable natural resource management perspective, it is important to study these ecosystems, in all their components, and to master their functioning. However, the study of aquatic organisms has often overlooked the microorganisms that constitute the primary and even secondary production of ecosystems.

The study of zooplankton can be considered from several points of view, each representing a different stage in the analysis of the functioning of a pelagic ecosystem (Le Coz, 2017). In a way, these different approaches are dictated by the means of investigation available at a given time and place. So far, a structural approach has been adopted, focusing on ecosystem constituents, their nature, abundance and distribution in space and time, as opposed to a functional approach that considers the dynamics of the system's (or selected sub-systems') behavior and development. To our knowledge, Souley *et al.,* studies (2021; 2022) constitute one of the first on zooplankton in the Niger River in Niger. This lack of knowledge could be the result of the perception that rivers are not suitable environments for zooplankton, due to residence times (Picapedra *et al.,* 2018). Zooplankton assemblages in freshwater lotic systems are generally dominated by rotifers, with relatively few cladocerans and copepods compared to lacustrine ecosystems (Shiel *et al.,* 1982). The aim of this study is to make a comparative study between the high-water period (February 2019) and the low-water period (April 2018) on water quality and the zooplankton community of the Niger River in Niger.

MATERIALS AND METHODS

Presentation of the study area

The study area is located in south-western Niger (Figure 1, Table 1), corresponding to western Niger (Garba, 1984). It lies between 11°45' and 15° north latitude, 0°45' and 4° east longitude. It is bordered to the west by Burkina Faso, and to the south by Benin and Nigeria. With a surface area of 50,000 km^2, the study area encompasses the Dosso, Tillabéri and Niamey regions. The River Niger is the third longest river in Africa (4,200 km), after the Nile and the Congo, and the longest river in West Africa. Its basin covers an area of almost 2.2 million km^2, including around 1.5 million km^2 of active watershed and 0.7 million km² of fossil watershed, dried up year-round (Souley *et al.,* 2021). The Niger River rises in the Guinean crest of the Fouta Djalon, a region of high plateaus with an average altitude of around 800 meters, and flows northeastwards, forming a vast plain in Mali, flooded during the rainy season, known as the interior delta or lacustrine basin (Olivry, 2022).

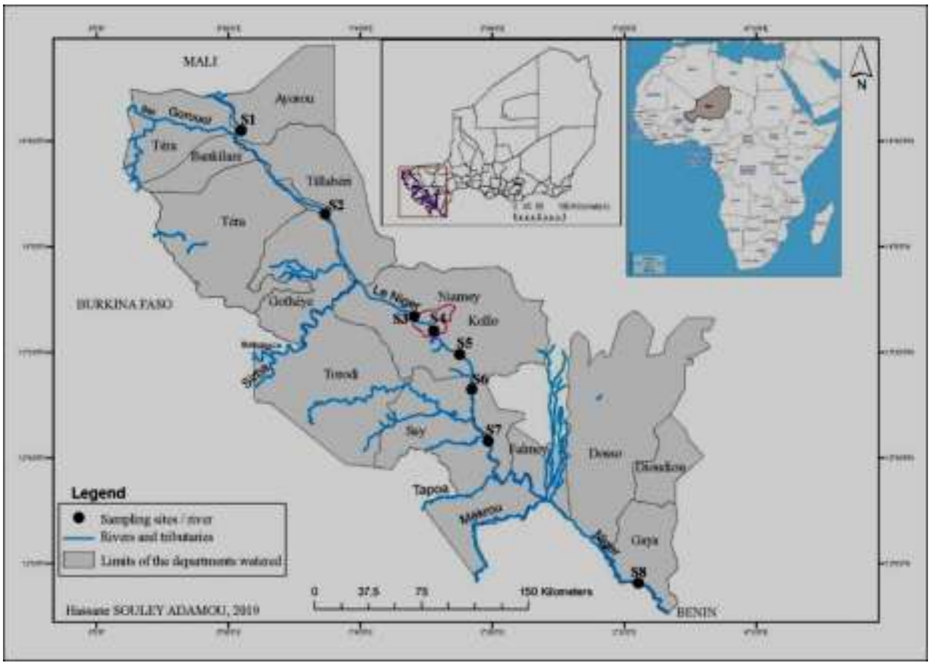

Figure 1.Map of Niger within the African continent (top right), the Niger River within the Niger territory (mid-topright), and sampling stations on the Niger River (black dots).

Table 1. Geographical location of sampling stations.

Code	Locality	Latitude N	Longitude E
S1	Ayorou	14,73429	0,91407
S2	Tillabéri	14,20678	1,44459
S3	Tondibiat	13,56218	2,00867
S4	Saga	13,47027	2,13075
S5	Kollo	13,32143	2,29288
S6	Say	13,10185	2,37167
S7	Kirtachi	12,77589	2,47214
S8	Gaya	11,87730	3,42149

Zooplankton sampling

For zooplankton sampling, 200 Litter of river water were collected in a bucket and filtered through 50-µm mesh plankton net. The retained zooplankton was stored in polyethylene bottles. Carbonated water was added with formaldehyde (final concentration 4%) to fix the organisms. Three samples were collected from each site in the middle of the river at the eight (8) stations.

Environmental variables measured

At each station and site, samples were taken from the middle of the river to measure environmental variables: temperature, dissolved oxygen, conductivity and pH were measured in situ using a HANNA 9829 multi-parameter probe. In addition, 500 ml of water were placed in polyethylene bottles and stored in a cooler at 4°C for laboratory analysis of nutrients. Phosphate (PO_4^{2-}) and silica (SiO_2) concentrations were determined by HPLC and Dionex. In the case of chlorophyll-a, a volume of 150 mL to 1L of water was filtered through a Whatman GF/C filter using a manual vacuum pump. After each filtration, the filter was immediately wrapped in aluminum foil and stored in a cooler (4°C) until laboratory analysis. For suspended particulate matter (SPM) analysis, water was collected in a bucket and a volume of 150 ml to 1L (depending on water turbidity) was filtered through a Whatman pre-oriented GF/C filter using a manual vacuum pump. Filters were stored in a cooling box for transport to the Department of Life and Earth Sciences (ENS) laboratory at the University of Abdou Moumouni in Niamey. Chlorophyll-a concentration was measured spectrophotometrically.

Laboratory analysis and identification

In the laboratory, one or two drops of erythrosine solution prepared at 0.8 g per 100 ml of water were added to each vial to stain and then facilitate the search for organisms and their identification. Sub-samples were taken from each vial after homogenization and placed in a counting wheel to identify and count organisms under a binocular magnifier (OLYMPUS SZX10, magnification 40× and 90×). Some identifications required microscopic analysis (400×) (LEICA DM IRB, NIKON Optiphot 2). The minimum number of individuals counted was 150 to 200 per sample. Organisms were identified using the keys of Koste (1978), Pontin (1978), Segers (1995), Nogrady and Perriot (1995), De Smet (1996), Alonso (1996), Nogrady and Segers (2002). Organisms were identified to the most precise taxonomic level possible and densities were expressed in ind/m3.

Statistical Analysis

Data were collected through sampling and processing in the laboratory. Data analysis focused on zooplankton community structure, including taxonomic richness, diversity and equitability within the sampled stations. The biological data obtained were used to determine taxonomic richness and calculate various diversity indices to characterize zooplankton composition and evolution. The density of organisms or the number of individuals per cubic meter (m3) was calculated. The Shannon-Wiener diversity index reflects the diversity of species in the environment. Its formula is:

$$H' = -\Sigma\ [(ni/N) \times \log_2 (ni/N)]$$

H' represents specific diversity in bits, ni the number of individuals of species i, N the total number of individuals considering all species and log2 the logarithm in base 2. Piélou's equitability index (Eq) measures the equitability (or equipartition) of the species in the stand in relation to a theoretical equal distribution for all species. It is obtained by the formula:

$$Eq = H' / \log_2 S$$

Where H' is the Shannon-Wiener index, log2 is the logarithm to base2 and S is the number of species present.

The Eq index ranges from 0 (dominance of a single species) to 1 (even distribution of individuals in the stands). The significance of differences between different stations was tested using minitab 18 software. Multivariate analyses were conducted to analyse the relationship between the distribution of the zooplankton communities and environmental factors for each sampling campaign separately and for all data considered together. Abundances were transformed to log (x + 1) to obtain a normal distribution. A Detrended Correspondence Analysis (DCA) was first conducted on the zooplankton data using CANOCO software version 4.5 (Jongman *et al.,* 1987; ter Braak, 1994) to determine the method of ordination to be used. Since the total inertia was less than 2.6, the species were considered to have a linear model and redundancy analyses (RDA) was performed. Abundance data of the identified taxa were centred and standardised. A Monte Carlo test (999 permutations) was applied to test statistical significance of the environmental variables in explaining the zooplankton distribution using a significance limit of $p < 0.05$.

Table 2. Average and extreme values of environmental parameters of the Niger River during low and high-water periods.

	Low-water			High-water		
Environmental Parameters	Min	Max	Moy	Min	Max	Moy
Temperature (°C)	24	32,9	29,08 ± 2,82	23	27,8	25,625 ± 1,47
Suspended matter (mg/L)	10,4	22,8	17,22 ± 4,24	10,77	22,35	16,06 ± 3,79
Conductivity (mg/L)	39	90,2	62,2 ± 20,16	30	71,2	49,02 ± 15,96
P^H	7,1	7,7	7,22 ± 0,24	7	7,5	7,22 ± 0,21
Dissolved Oxygen (mg/L)	5,1	10,2	8,36 ± 1,85	6,48	7,5	6,71 ± 0,66
Silica (mg/L)	6,47	11,07	7,87 ± 1,38	12,34	15,35	13,95 ± 1,03
Chlorophylla (mg/L)	10,70	61,38	30,41 ± 15,47	1,71	16,67	7,23 ± 4,87
Total phosphorus (mg/L)	17	104	44,37 ± 28,85	86	173	128,87 ± 33,29

RESULTS AND DISCUSSION

The values of the various physico-chemical parameters for the two periods at each station are summarized and presented in Table 2. Temperature was higher at all stations sampled during low-water periods. In fact, the temperature of the River Niger during low-water periods ranged from 24°C to 32.9°C and from 23°C to 27.8°C during high-water periods. The minimum temperature value (23°C) was recorded during high water and the maximum value (32.9°C) was recorded during high water, with respective mean values of 25.625 ± 1.47°C and 29.08 ± 2.82°C. There was a significant difference (p-value=0.006) between the two periods. During the low-water period, suspended matter was much higher at all stations except S6. During the sampling period, we observed a slight change in suspended matter between the two periods. The values recorded in April and February was 17.22 ± 4.24mg/L and 16.06 ± 3.79mg/L respectively. Based on these results, we concluded that the two-month difference in suspended matter concentration was not significant (p-value=0.452). Conductivity ranged from 39 mg/L to 90.2 mg/L in April and from 30 mg/L to 71.2 mg/L in February, with mean values of 62.2 ± 20.16mg/L and 49.02 ± 15.96mg/L respectively. Conductivity also showed no significant change (p-value= 0.063). The pH of the River Niger was more or less constant over the two months. Indeed, the pH values recorded at all stations during these two months are almost neutral, with an average value of 7.22 ± 0.24 (April) and 7.22 ± 0.21 (February). The latter showed that there was no significant difference (p-value=1.000). With regard to the concentration of dissolved oxygen in the river water, it is higher in low water than in high water, except at stations S4 and S5, where the concentration is slightly lower between these two periods. Overall, dissolved oxygen is higher in low water than in high water, with an average of 8.36±1.85mg/L and 6.71 ± 0.66mg/L respectively. The difference in oxygen concentration between the two periods was significant (p-value = 0.04). On the other hand, silica concentration was high at all stations and during both periods. The minimum value (6.47 mg/L) was recorded in low water and the maximum value (15.35 mg/L) in high water, with an average of 7.87 ± 1.38mg/L and 13.95 ± 1.03mg/L respectively. The difference in silica concentration between the two periods is significant (p-value=0.04). We also noted a much higher concentration of total phosphorus in the high-water period than in the low-water period at all stations sampled. In fact, total phosphorus varied from 86 mg/L to 173 mg/L in high water and from 17 mg/L to 104 mg/L in low water. There was also a highly significant difference (p-value=0.002) in phosphorus concentration between the two periods. Chlorophyll-a concentration is very high in all situations and in both periods, with a highly significant p-value (p-value = 0.003). Values recorded in high water ranged from 1.71mg/L to 16.67 mg/L, with an average of 7.23 ± 4.87mg/L, and values recorded in low water ranged from 10.70 mg/L to 61.38 mg/L, with an average of 30.41±15.47mg/. Overall, the difference in temperature, oxygen, silica, chlorophyll-a and phosphorus concentrations between the two periods was significant, while that of suspended matter, conductivity and pH was not.

We recorded 48 zooplankton taxa between the two sampling periods (Table 2). During low-water periods, rotifers were the most abundant group (74.89%), followed by copepods (20.17%) and cladocerans (4.93%). At high water, however, the largest group was copepods (53.27%), followed by rotifers (32.63%) and cladocerans (14.09%). In addition, we recorded a high abundance and richer species composition of rotifers in the upper-water zooplankton.

Although cladocerans were still less abundant between the two periods, we noted an increase from 4.93% to 14.09%. In terms of abundance, a total of 327070.39 ind/mL was recorded in the low-water period, including 244948.78 ind/L of rotifers, 65984.97 ind/L of copepods and 16136.64 ind/L of cladocerans. At high water, 43344.85 ind/L were recorded, including 23089.97 ind/L copepods, 14144.35 ind/L rotifers and 6110.53 ind/L cladocerans. Figure 2 shows the spatio-temporal variations in zooplankton community abundance for the two periods (high and low water) sampled. Rotifers were more abundant in low-water periods than in high-water periods and at all stations, with enormous abundance at stations S5 and S8 (Figure 2a). Copepods were more abundant at stations S1, S2, S3, S4 and S5, and were particularly visible at stations S4 and S5 during the low-water period, but were much more abundant at stations S5, S6, S7 and S8 during the high-water period (Figure 2b). As for cladocerans, they are most abundant during low-water periods and at all stations except S6 and S8 (Figure 2c). Generally speaking, zooplankton organisms are more abundant at low water than at high water (figure 2d), particularly at stations S4, S5 and S8.

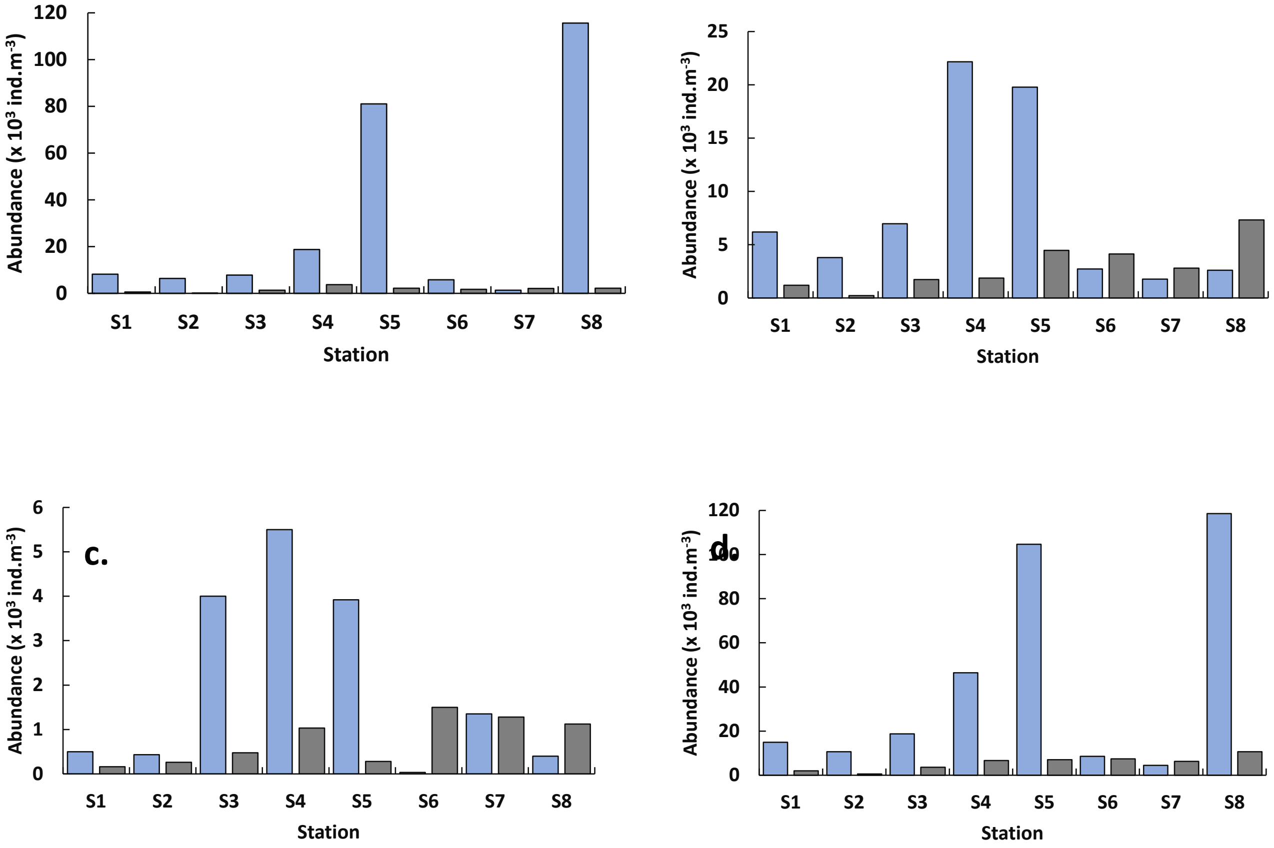

Figure 2. Species abundance by station. a. Rotifers; b. copepods; c. cladocerans; d. total abundance by station. Low-water abundance in blue, high-water abundance in gray.

Specific richness of the zooplankton community

The Figure 3 shows the variation in taxon numbers and calculated indices over the two sampling periods. The number of taxa (N) varied from 14 at S7 to 20 at S4 during low-water sampling and from 8 at S2 to 21 at S3 and S4 during high-water sampling. The Shannon-Weaver diversity index (H') varied from 2.2 at S5 to 3.3 at S4 during low-water sampling, and from 2.4 at S5 to 3.55 at S4 during high-water sampling. Spatial variation in H' values over the two sampling periods was similar ($p < 0.05$): there was an increase in H' from S2 to a maximum at S4, followed by a decline to a minimum at S5 and a second increase to high values at S7, with a final drop at S8. Equitability (Eq) was minimum at station S6 (0.2) and maximum at station S7 (0.7) during low-water sampling, and minimum at station S3 (0.4) and maximum at station S2 (0.7) during high-water sampling. There was no spatial trend in Eq values, nor did they follow the same pattern during the two sampling periods ($p > 0.5$). Considering all stations, the mean number of taxa, H' and Eq values were not significantly different between the two sampling periods.

The results of the canonical redundancy analysis carried out between physico-chemical parameters and the main taxon groups at the different stations are shown in figure 4. These RDA results reveal that the correlation between environmental factors and zooplankton groups is mainly explained by the first two axes (32.8% of total variance) with 27.5% for the first axis and 5.4% for the second axis. Figure 4a explains the distribution of the different stations according to taxa. As can be seen in Figure 4a, stations S1S and S8O are positively correlated with the first axis, while stations S6S and S4O are negatively correlated with the first axis. In the light of figure 4a, we decided to investigate the correlation between species groups and environmental variables, as shown in figure 4b. This summarizes the correlation of environmental variables with zooplankton groups. Axis 1 is positively correlated with oxygen and to a lesser extent chlorophyll-a, and negatively with pH, conductivity and total phosphorus. Axis 2 is strongly and negatively correlated with temperature, silica and suspended matter. The three zooplankton groups obtained during our study are influenced by various environmental variables. Rotifers correlated significantly and positively with chlorophyll-a and O_2, and negatively with pH. Copepods, on the other hand, react positively with pH. Finally, cladoceransare positively influenced by temperature and especially by silica and suspended matter.

Table 3.List of zooplankton taxa recorded during low-water and high-water sampling periods in the River Niger.

Taxon	Low-water	Hight-water
Rotifera		
Asplanchnabrigthwelli i Gosse, 1850	+	+
Brachionus angularis Gosse, 1851	+	+
Brachionusbidentatus Kertesz, 1894		+
Brachionuscalyciflorus Pallas, 1766		+
Brachionuscaudatus Barrois&Daday, 1894	+	+
Brachionusdiversicornis (Daday, 1883)	+	
Brachionusfalcatus Zacharias, 1898	+	+
Brachionusleydigi Cohn, 1862	+	+
Brachionuspatulus O.F. Muller, 1776		+
Brachionusquadricornis (Schrank, 1803)	+	+
Brachionusquadridentatus Hermann, 1783	+	+
*Brachionusurceolaris*Müller, 1773	+	+
Cephalodella sp.	+	+
Filinialongiseta (Ehrenberg, 1834)	+	+
Filiniaopoliensis (Zacharias, 1898)	+	+
*Hexarthra*sp.	+	+
Keratellacochlearis (Gosse, 1851)		+
Keratellalenzi Hauer, 1953		+
Keratella quadrata (O.F. Muller, 1786)	+	
Keratellatropica (Apstein, 1907)	+	+
Lecanehastata (Murray, 1913)	+	+
Lecaneleontina (Turner, 1892)		+
Lecaneludwigii (Eckstein, 1833)		+
Lecanequadridentata (Ehrenberg, 1830)	+	+
Lecanelunaris (Ehrenberg, 1832)	+	+
Lecanepapuana (Murray,1913)		+
*Lecane*sp.	+	+
Lepadella patella (Müller, 1773)	+	+
Macrochaetussericus (Thorpe, 1893)		+
Mytilinaventralis(Ehrenberg, 1830)	+	+
*Polyarthra*sp.	+	+
Platyiasquadricornis(Ehrenberg, 1832)	+	
Synchaetalongipes Gosse, 1887	+	+
Synchaeta sp.	+	
Trichocerca sp.	+	+
Copepoda		
Mesocyclopskieferi Van De Velde, 1984		+
Tropodiaptomusorientalis (Brady, 1886)		+
Tropodiaptomusstuhlmani (Mrázek, 1895)		+

Cyclopoids copepodites	+	+
Calanoids copepodites		+
Harpacticoids copepodites	+	+
Nauplii	+	+
Cladocera		
Alona affinis (Leydig, 1860)		+
Alonaguttata Sars, 1862		+
Alonarectangula G.O. Sars, 1862	+	+
Alonella excisa (Fischer, 1854)		+
Alonella nana (Baird, 1843)		+
Bosminalongirostris (O.F. Müller, 1785)	+	+
Ceriodaphniaquadrangula (O.F. Müller, 1785)	+	
Camptocercusuncinatus Smirnov, 1998	+	+
Chydorussphaericus (O.F. Müller, 1776)	+	+
Diaphanosomaexcisum G.O. Sars, 1885		+
Kurzialongirostris (Daday, 1898)		+
Moinamicrura Kurtz, 1875	+	+
Pleuroxustruncatus (O.F. Müller, 1785)		+

Physico-chemical indicators of water quality in a lotic ecosystem can tell us something about the degree of pollution in this biotope. Suspended particulate matter (SPM) show a slight variation between the two periods (Table 2). Levels ranged from 16.06 ± 3.79 mg/L at high water to 17.22 ± 4.24 mg/L at low water. These results contradict those obtained by Reggam*et al.,* (2015) in the Oued Seybouse water body (north-east Algeria), where they recorded a large difference in suspended matter between two high-water and low-water samples (1.00 mg/L and 580 mg/L) respectively. This large difference could be explained by the fact that the Seybouse water body has experienced intense watershed erosion, following torrential rains. In fact, suspended solids content is linked to the nature of the terrain crossed and the composition of the discharges (Mouni *et al.,* 2009). The mean temperature shows a highly significant difference between high and low water, at 25.625 ± 1.47°C and 25.625 ± 1.47°C respectively 29, 08 ± 2,82°C. This situation corroborates that found in the Ouémé delta river of Benin by Zinsou *et al.,* (2016), where they found a minimum value of 22°C and a maximum value of 30.5°C when the water is somewhat calm. This increase in temperature between the two periods could be explained by the low cloud cover at low water, which results in strong sunlight at the water surface. On the other hand, conductivity did not vary significantly between the two sampling periods (49.02 ± 15.96 mg/L and 62.2 ± 20.16 mg/L). The values found are lower than those found in eutrophic lakes such as Lake Nkolbisson (Ndjama *et al.,* 2017). In this lake, the minimum values recorded were 90 µs.cm^{-1}and the maximum values were 260 µS.cm-1. This slight change is thought to be due to the discharge of agricultural residues, as the study area is an irrigated perimeter with intense agricultural activity. In fact, the conductivity value is a function of dissolved salts on the one hand and fertilizer leaching by irrigation water on the other (Boukhechba *et al.,* 2023). Several factors affect the concentration of dissolved oxygen in water, namely temperature, atmospheric pressure, salinity and photosynthetic activity. Dissolved oxygen can originate either from the atmosphere by diffusion, or from the photosynthesis of autotrophic organisms (Boukhechba *et al.,* 2023). The concentration of dissolved oxygen in the river between the two periods is characterized by a change with an average value of 6.71 mg/L (high water) and 8.36 mg/L (low water). These results are in line with those of Safia *et al.,* (2020), who showed that the river is more oxygenated when the water is less calm. The increase in oxygen content in low water could be explained by the high light intensity, which leads to a fairly high photosynthetic activity of phytoplankton. Despite the river's torrential flooding and leaching, mean phosphorus values show maximum levels during high-water periods. Our results are in line with those found by Laplace-Treyture, (2020) where he recorded the high phosphorus value (1009 mg/L) at high water in the Gaschet water body. This concentration in high water could be explained by the fact that urban domestic waste discharged directly into the water by the population and runoff water inputs contain a significant quantity of phosphorus. According to Jen (2002), domestic wastewater contains many detergents that are sources of phosphorus. Chlorophyll-a concentration shows a significant difference between the two periods, being higher in all low-water stations. Our results contradict those obtained by Hu *et al.,* (2023), who found the maximum mean value in high water (20.86 mg/L). This difference could be explained by the greater concentration of light in our environment during low-water periods than during high-water periods. Indeed, the more phosphorus and light there is in the water, the more nutrients phytoplankton have to multiply and the more chlorophyll-a is abundant (Derolez *et al.,* 2023). Paradoxically, in our environment, the concentration of phosphorus is higher in high water than in low water, which shows that photosynthesis in phytoplankton is largely dependent on light. The pH values of the river water were generally neutral during our sampling at all the stations studied, and we didn't notice any variation. between the different sampling stations. These results contradict those obtained by Chiali and Cherifi, (2019) in the Sidi M'hamed Benali lake in Algeria, where they recorded a basic pH. This basicity of the environment could be linked to the high concentration of dissolved products in the water and the fact that it is a lotic environment that does not undergo leaching, even when rainfall is abundant. The pH depends largely on the type of environment, the buffering effect of the land it crosses and the nature of the discharges (urban, industrial and agricultural) (Medjani, 2016). On the other hand, silica concentration underwent a significant change from high to low water, with respective averages of 13.95±1.03mg/L and 7.87 ± 1.38mg/L.

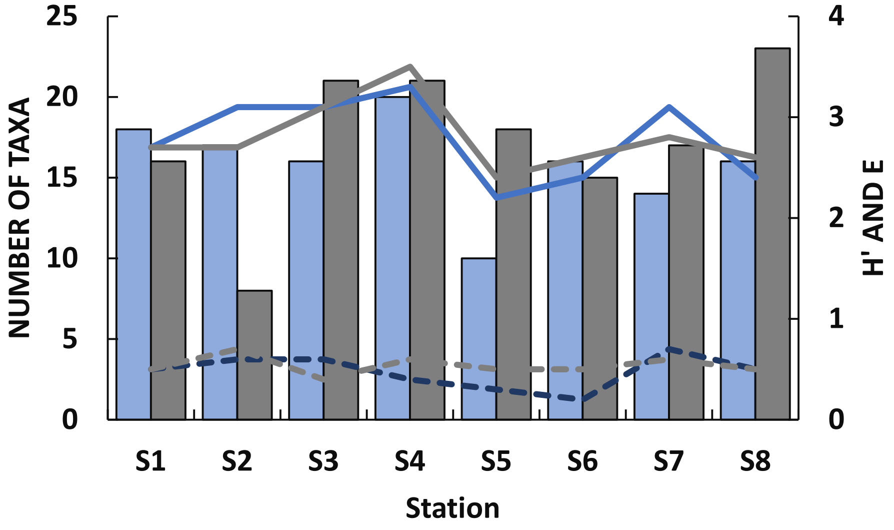

Figure 3. Number of taxa (The blue bars represents low-water sampling, while the grey bars represent high-water sampling.), Shannon-Weaver diversity index (H′, full line) and Evenness (E, dashed line) at the 8 Niger River stations (S1 to S8).

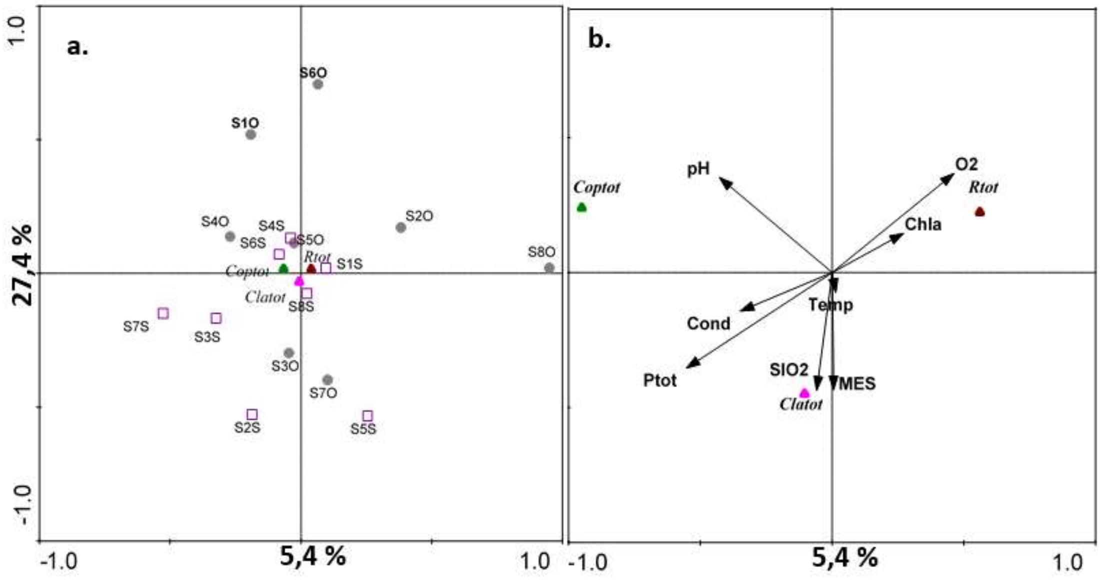

Figure 4. Redundancy analysis (RDA) of zooplankton groups as a function of environmental variables. a. station distribution, b. species correlation. S1S to S8S represent the eight stations sampled in low-water, S1O to S8O represent the eight stations sampled in high-water, rtot: rotifers, coptot: copepods and clatot: cladocerans.

These results are in line with those found by Soro *et al.,* (2021) in the waters of Haut-Bandama (Côte d'Ivoire) and also found by Madjida, (2023) in waters from the Oued Kebir-Rhumel basin (Algeria). This concentration of silica during the flood season could be due mainly to the dissolution of metamorphic rocks in the watersheds. But compared to the results obtained in Park W by Idrissou *et al.,* (2019), where he showed that the parameters, pH of the Niger River during both low-water and high-water periods meets international standards for surface waters. The present study collected three groups of zooplankton: rotifers, copepods and cladocerans. In contrast to the results found by Ramachandra *et al.,* (2006), who found up to six groups of zooplankton: protozoa, rotifers, crustaceans, cladocerans, copepods and ostracods. This difference could be explained by the lack of material used during our study. The distribution of zooplanktonic organisms depends on a range of environmental factors, including water temperature, light penetration, water chemistry (particularly pH, dissolved oxygen, salinity, toxic contaminants), food availability (algae, bacteria) and predation by fish and invertebrates (Onyema and Ojo, 2008). Rotifers are abundant, and their density is much greater at low water than at high water in all stations. These results are in line with those of Adandedjan, (2017) but contrary to those of Ayoagui and Bonecker (2004). However, they all agree that this phenomenon is linked to the low cladoceran population, which frees rotifers from the competition exerted by the latter, but this high abundance and absolute dominance could be explained by the fact that rotifers are a group of zooplankton that live in a polluted environment and have several habitats. In fact, as water quality deteriorates, populations and species richness decline, but somewhat less so for Rotifers, which are more tolerant of environmental variations (Hannson *et al.,* 2007). Copepods and cladocerans are more abundant in low water, except at stations S6, S7 and S8 (Figure 2b and 2c). These results corroborate those found by Soro *et al.,* (2020), who noted an abundance of copepods and cladocerans at some stations, and a decrease at others when the water was a little calmer. The low abundance of copepods and cladocerans at these low-water stations could be the result of a combination of factors can be explained by the fact that the discharge of residues from agricultural activities is much more intense, resulting in the death of certain organisms that are not resistant to pollution, namely copepods and cladocerans. Indeed, Monney *et al.,* (2016) have shown that the abundance of zooplankton populations increases with distance from discharge points in the coastal rivers of southeastern Côte d'Ivoire. Cladocerans were negligible at all sampling stations during both periods. In fact, cladocerans are less frequent and are found in calmer areas of a body of water Cherrahi and Ben Mahmoud, (2020). Redundancy analysis (RDA) has identified three groups of species, each belonging to a different zoological group. Each group is characterized by a number of environmental parameters and the times that favor its development. Rotifers correlate positively with dissolved oxygen and chlorophyll-a, confirming the decrease in rotifer levels in high-water months through lower oxygen and chlorophyll-a levels. This result was observed by Safia *et al.,* (2023) in the Boukerdane dam in Algeria. Copepods are correlated with the pH of the environment, which would explain their slightly constant rate. In fact, the pH recorded during our study was almost neutral during both periods and at all sampling stations. According to RDA analysis, cladocerans stick with temperature, suspended matter, especially silica, and stick slightly with phosphorus and conductivity. These responses are in line with those found by Vesnina *et al.,* (2023). This would explain the low rate of cladocerans during our study, despite the high concentration of silica in September, as they are very sensitive to agitation. According to the Shannon index, zooplankton diversity is higher during low-water periods. Our result contradicts that obtained in coastal rivers in southeastern Côte d'Ivoire (West Africa) by Monney *et al.,* (2016). This contradiction could be explained by the materials used during sampling and organism identification.

CONCLUSION

The average values for the various physico-chemical parameters reveal that the water quality at the sampled stations is acceptable, enabling them to purify themselves and fulfill their ecological role in the biosphere that is the River Niger. In fact, all the values recorded are approximately in line with internationally accepted standards for natural waters. However, the present study shows the negative impact of waste discharge on water quality and zooplankton diversity and abundance. The river's physico-chemical characteristics determine a zooplanktonic biodiversity marked mainly by the presence of rotifers, cladocerans and copepods. However, rotifers are qualitatively and quantitatively the most abundant group in the river. Moreover, the spatiotemporal distribution of zooplankton is dependent on physico-chemical parameters, in particular pH, dissolved oxygen, temperature, total phosphorus, silica and chlorophyll-a are the environmental variables that most influence group distribution. Given the importance of zooplankton in the aquatic food web, regular monitoring should be considered for the River Niger to answer these questions.

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