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Relationships between Phytoplankton Structure and Environmental Variables in an African Tropical Reservoir

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Abstract: ***Relationships between phytoplankton communities and environmental factors were studied from samples collected from July 2020 to February 2021 in the Korhogo reservoir. Taxonomic composition, diversity and abundance of phytoplankton were studied at 5 stations in relation to physical and chemical factors. Based on the values for trophic states, Korhogo Reservoir was eutrophic. Phytoplankton taxonomic identification revealed 78 taxa, mainly, Euglenophyta (47.43% of taxa), Chlorophyta (29.49% of taxa). The highest densities were recorded during the dry season, then, the lowest densities during the rainy season and mainly at the end of the rainy season with some specific taxa like Microcystis aeruginosa, Merismopedia tenuissima and Trachelomonas volvocinopsis. Shannon diversity index values (H') were generally high during the dry season, and low during the rainy season and particularly at the end of the rainy season, at all sampling sites. Regarding Evenness (E), the recorded values varied between 0.54 at station St2 at the end of the rainy season and 0.88 at station St5 during the dry season. No Significant differences (p>0.05) in these indexes were recorded between seasons and sampling sites. The redundancy analysis (RDA) demonstrated a little relationship between environmental variables and abundant taxa, suggesting that other parameters were responsible for this high abundance.***

Keywords: Phytoplankton abundance, diversity indexes, physicochemical parameters, reservoir

1. Introduction

Korhogo Reservoir is a shallow raw potable water reservoir. This reservoir, like 500 other small reservoirs, has been constructed on most river systems for water supplies and is presently considered to be threatened [1]. It has played an essential role in the development of the city. Unfortunately, the strong demographic growth and the extension of the city have led to the occupation of the banks of this lake, either for the creation of dwellings or for the development of market gardening. So this reservoir, surrounded by urban development, receives wastewater from many sources, examples being animal farming, urban and agricultural runoff, and sewage loading. This results in significant changes in the trophic state of the reservoir.

This situation becomes more worrying as the water of the reservoir is used to supply the population with drinking water after treatment in case of high demand. According to [2], the vulnerability of tropical lake ecosystems calls for greater vigilance and hydrobiological investigations. One of the indicators of the fluctuations in these hydrosystems is the phytoplankton. Phytoplankton represents an essential component of aquatic environments in terms of abundance and biomass. It constitutes, by its concentration on submerged substrates or in suspension in the water column, a nutritional source for many aquatic organisms, in particular zooplankton, insects and fish. Thus, according to [3], phytoplankton is usually at the base of the aquatic food web and is the most important factor for the production of organic matter in the aquatic ecosystem. Phytoplankton is also one of the most efficient indicators of changes in the ecological condition of an aquatic ecosystem, with a short life cycle and a wide spatial distribution [4]. In reservoirs, environmental factors, such as water temperature, pH, transparency and nutrient concentrations influence phytoplankton biomass, composition and succession in aquatic systems [5]. Water column instability also modulates phytoplankton species richness and diversity [6]. Additionally, phytoplankton is the first group affected by contamination; as such, it can provide important information that can be used to predict the environmental impact of pollution [7]. So, understanding the relationships between phytoplankton communities and environmental factors is therefore critical to understanding the functioning of shallow reservoirs like the Korhogo reservoir.

To this date, there is little information on relationships between phytoplankton communities and environmental factors in Côte d'Ivoire reservoirs. The known works were [8], [2], [9]. The purpose of this study is (1) to investigate the phytoplankton composition, structure and abundance in the Korhogo reservoir throughout different seasons, (2) to determine the influence of various environmental factors on phytoplankton abundance.

2. Materiel and Methods

2.1. Study area

The reservoir of Korhogo (Figure 1) is located at 9°27'.50'' - 9°28'.30''N and 5°38'.40'' - 5°39'20'', lies in an urban area of the city of Korhogo, in the north of Côte d'Ivoire that belongs to Sudanese zone. This zone has two main seasons:

a rainy season from May to October and a dry season from November to April, accompanied by the harmattan. These two main seasons can be further subdivided according to the rainfall or the extent of the drought [10]. The annual rainfall varies between 1000 and 1600 mm and the average annual temperature varies between 24°C and 36°C. The reservoir has a maximum depth of 5 m. Five stations (Figure 1, Table 1) were selected for the present study. These were chosen to take into account certain criteria such as the presence of invasive aquatic plants; the presence of areas subject to anthropogenic disturbances (wastewater discharges, agricultural activities, habitat) and accessibility to them.

2.2. Physicochemical parameters

The sampling campaign took place in July and October 2020 during the rainy season and February 2021 during the dry season. Some physicochemical measurements were made in the field immediately after each sample was collected. The multiparameter HANNA HI 9829 was used to assess water temperature, conductivity, pH and Dissolved Oxygen. The water transparency (ZSD) was measured in situ, using a white Secchi disk. For nutrients (orthophosphates and nitrates), subsamples of 30 ml were collected and refrigerated for later analysis using a spectrophotometer UV JASCO

2.3. Biological parameters

At each sampling period, water samples were taken between 06: 00 and 09: 00 am at the surface of the water using a plankton net with 10 µm mesh for qualitative studies. Other samples were taken at the surface of the water for quantitative analysis. Samples were preserved with 5% formalin in a 30 ml bottle. From which subsamples were taken for qualitative analysis. For diatoms, subsamples were prepared according to standardized protocols [11]. Observations were carriedout using an Olympus BX40 microscope, equipped with a Canon camera.

For taxonomic studies, the following literature was used: [12], [13], [14], [15], for Euglenozoa, [16] and [17] for Cyanoprokaryota, [18], [19] for Bacillariophyta, [20], [21], [22] for Chlorophyta.

For quantitative analysis, Malassez cell was used. For this study, the estimated counting error for each major algal species was ± 25%. Individuals were counted, and for filamentous and colonial algae, the number of cells of a standard individual was estimated. For non - diatoms algae, the density (cells/L) of each species was estimated. Diatom cells containing organic matter were counted to estimate absolute abundance. Other Counts of diatoms were made from material permanently mounted on microscope slides. The density (cells/L) of each diatom species was calculated by multiplying the relative abundance of each species estimated from the permanent - mount diatom count by the total number of diatoms containing organic matter (cells/L) determined from the Malassez cell.

Species richness (total number of algal species in a sample) and the Shannon - Wiener diversity index and evenness based on relative abundances of all algal taxa in samples were used as measures of community diversity.

2.4. Statistical analyses

Differences in physical - chemical parameters, phytoplankton density, Shannon diversity and evenness among sampling seasons and stations were tested using the Kruskal - Wallis test (significance level 0.05). However, the means and standard deviation of all measurements were recorded for each parameter. To investigate the effect of environmental factors on the phytoplankton communities, a ReDundancy Analysis (RDA) was performed on the dominant species (contribution >5%). The significance of the first four axes was tested using a Monte Carlo analysis with 499 permutations. ReDundancy Analysis was computed with the program CANOCO for Windows 4.5 [23]. The others were performed withSTATISTICA software 7.1.

3. Results

3.1 Physicochemical environment

The physicochemical parameters at different sampling

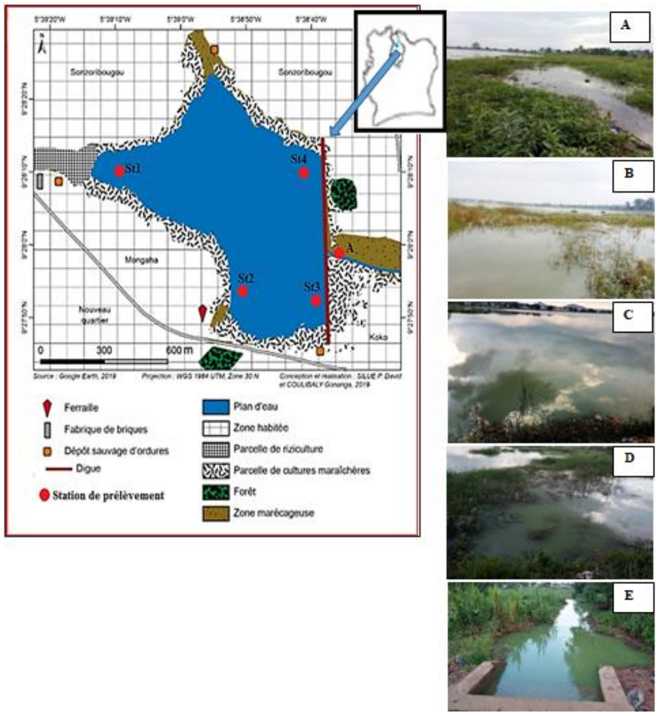

Figure 1: Korhogo reservoir showing the sampling sites. A: View of St1, B: View of St2, C: View of St3, D: View of St4, E: View of St5

Table 1: Coordinates of sampling sites

Stations	Coordinates
St1	9°28'06.35" N et 5°38'55.37" W
St2	9°27'56.39" N et 5°38'47.95" W
St3	9°27'54.59" N et5°38'41.07" W
St4	9°28'06.98" N et 5°38'42.27" W
St5	9°27'59.10" N et 5°38'35.02" W

Stations throughout the seasons are summarized in Table 2. The reservoir water temperature fluctuated between 26 ºC during the dry season at St5 and 27.9 ºC at St4during the rainy season. The conductivity exhibited a high fluctuation throughout the stations. The highest values (312 and 305 µS. Cm $^{-1}$) were obtained at St1, then the lowest values (114 and 126 µS. Cm $^{-1}$) at St5. The lowest value of dissolved oxygen (3.81 mg. L $^{-1}$) was measured during the rainy season at St1, then the highest (5.54 mg. L $^{-1}$) was in the rainy season at St5. The measured pH values were neutral to slightly alkaline. Its values varied between 6.8 and 8.29. The water transparency was essentially low (Z_{SD} min = 60 cm, Z_{SD} max = 90 cm). The highest water transparency value was measured during the dry season at St2. The Reservoir was characterized by high concentrations of nitrate. Except for St4, it highest values were obtained in the rainy season. The maximum concentration of nitrate was 4.85 mg. L $^{-1}$. Orthophosphates values determined in the reservoirs were generally slow throughout seasons and stations. The minimum value of these parameters was 0.44 mg. L $^{-1}$ then the maximum was 0.71 mg. L $^{-1}$.

Table 2: Limnological variables of the reservoir

Stations	Seasons	Temp (°C)	Cond (µs. m $^{-1}$)	OD (mg. L $^{-1}$)	pH	Trans (m)	NO_3^- (mg. L $^{-1}$)	PO_4^{3-} (mg. L $^{-1}$)
St1	SP	27.34	305	3.81	7.4	0.6	4.2	0.67
	SS	26.5	312	4.1	6.8	0.8	3.9	0.71
St2	SP	27.29	189.5	4.83	7.46	0.75	3.9	0.71
	SS	27	208	4.8	7.1	0.9	3.5	0.61
St3	SP	27.5	152	5.06	8.29	0.7	3.5	0.58
	SS	26.8	170	4.5	7.5	0.84	3.48	0.61
St4	SP	27.96	157.5	4.99	7.26	0.85	4.45	0.55
	SS	28	189	5.01	6.9	0.95	4.85	0.44
St5	SP	27.37	114	5.54	7.71	0.7	4.6	0.48
	SS	26	126	5.45	7.8	0.9	3.52	0.51

Temp: température, Cond: conductivity, OD: dissolved oxygen, Trans: transparency, NO_3^{-}: nitrates, PO_4^{3-}: orthophosphates, SP: rainy season, SS: Dry season, St: station

3.2 Phytoplankton composition

In the samples from the Korhogo Reservoir, a total of 78 taxa were identified belonging to 4 phyla, 5 class, 8 orders, 17 families, 27 genera. The Euglenophyta and Chlorophyta were the most diversified groups with 47.43 % and 29.49% respectively of total species, followed by the Cyanophyta with 11.54% and Bacillariophyta with 11.54% of total species (Figure 2).

Spatial distribution of taxa showed that the highest number (48 taxa) was counted at St1 followed by St2 (44 taxa), then St4 (38 taxa). St3 and St5, with 28 taxa and 25 taxa respectively, had the lowest species richness. In the temporal survey, species richness was weakly represented during the rainy season. The lowest species richness (42) was obtained in October at the end of the rainy season and the highest (76) was registered in February during the dry season. Overall, species richness not differs significantly between sampling sites and throughout seasons.

3.3 Phytoplankton abundance

Figure 3 shows the absolute densities of microalgae collected in the reservoir. Generally, the highest densities were recorded during the dry season. On the other hand, the lowest densities were obtained during the rainy season and mainly at the end of the rainy season. The highest density, 9425000 cells. ml $^{-1}$, was recorded at St3. This was followed by St2 with 8262500 cells. ml $^{-1}$. The lowest densities were obtained in St1 (2495235 cells. ml $^{-1}$) and St3 (2530000 cells. ml $^{-1}$). At the spatial level, no significant difference was found. However, at the seasonal level, a significant difference ($p<0.05$) was found. The man withney test allows distinguishing the dry season samples with high densities from the rainy season samples with relatively low dry season samples with high densities from the rainy season samples with relatively low densities.

The relative density of microalgae is presented in figure 4. The predominance of relative density of Cyanoprokaryota at stations St2 and St3 throughout all seasons was noted. At the stations St4 and St2, this predominance was marked respectively during the dry season and the end of the rainy season and the dry season. This abundance was provided by taxa such as *Microcystis aeruginosa*, *Merismopedia tenuissima* and *Oscillatoria limosa*. With the exception of station St5, where the relative density of individuals constituting the phylum Euglenophyta occupies first place with species such as *Trachelomonas volvocinopsis*, *Lepocinclis oxyuris* var. *oxyuris* fo. *minima*, these occupied second place in the other stations in all seasons. The relative densities of individuals of the Chlorophyta and Bacillariophyta phyla remain low with percentages below 15%. at all stations and seasons.

3.4 Diversity indexes

Values of diversity (H') and evenness (E) indexes are shown in Figure 6. Shannon diversity index values (H') ere generally high during the dry season, and low during the rainy season and particularly at the end of the rainy season, at all sampling sites. The highest value (3.4 bits/cells) was recorded at station St5 and the lowest value (1.78 bits/cells) at station St3. Regarding Evenness (E), the recorded values varied between 0.54 at station St2 at the end of the rainy season and 0.88 at station St5 during the dry season. No Significant differences ($p>0.05$) in these indexes were recorded between seasons and sampling sites.

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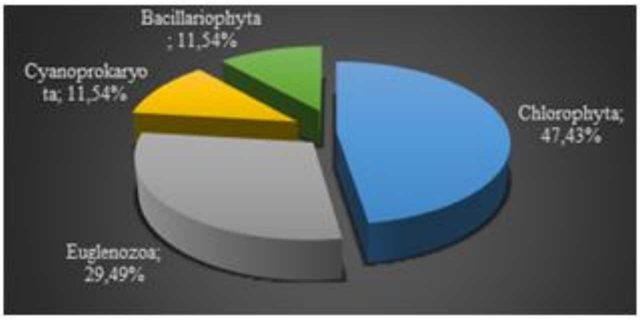


Figure 1: Spectrum of phytoplankton phyla in Korhogo reservoir

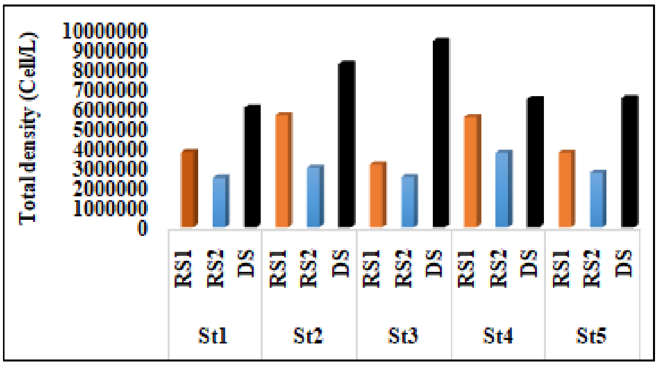


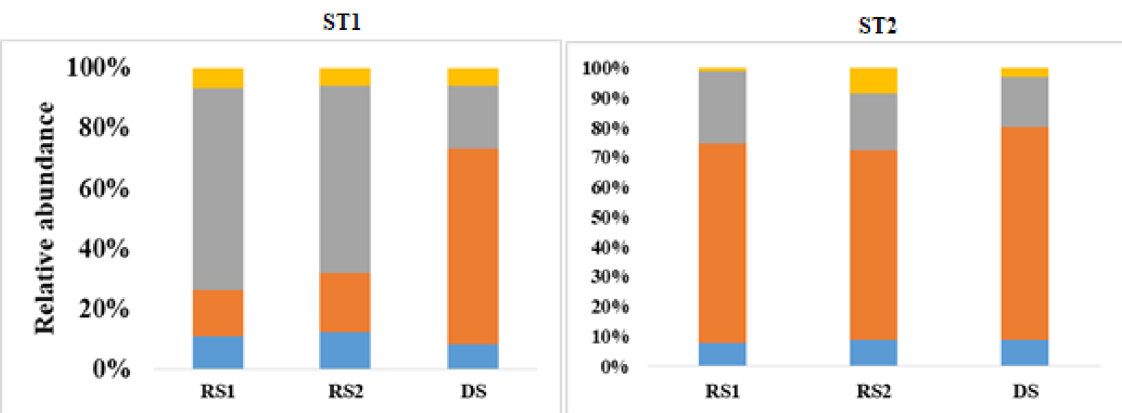
Figure 3: Temporal patterns of total density in four stations of Korhogo Reservoir. RS: rainy season; DS: Dry season

3.5. Relationships between phytoplankton and environmental variables: ReDundancy Analysis (RDA)

As shown in Figure 5, RDA was performed using 18 taxa (abundance ≥ 2%) and 7 environmental variables to study the relationship between phytoplankton and environmental variables. Axes 1 and 2 which express 38.40% of the total variance were used to express results. Axis 1 which accounts for 20.9% of total inertia was positively and strongly correlated with water transparency and weakly with temperature. This axis 1 was negatively and strongly correlated with pH, moderately with dissolved oxygen and the concentration of orthophosphates and weakly with the concentration of nitrates. The abundance of species such as *Oscillatoria limosa* (Osl), *Micrasterias truncata* var. *pusilla* (Mit) and *Chroococcus turgidus* (Crt) in the dry season was influenced by water transparency. The densities of taxa suchas *Microcystis aeruginosa* (Mia), *Trachelomonas volvocinopsis* (Trv), *Phacuslongicauda* var. *rotunda* (Phr), *Lepocinclis oxyuris* var. *oxyuris* fo. *minima* (Lex) and *Euglena spirogyra* (Eui) were more influenced by pH. The second axis which expresses 17.5% of the total variance was negatively and weakly correlated with the water conductivity and separates most of the samples of the dry season from those of the rainy season, characterizing the densities of microalgae such as *Phacus pleuronectes* (Php), *Microcystis wesenbergii* (Miw) and *Aphanocapsa roseana* (Apr).

4. Discussion

Based on the threshold values for different trophic states suggested by [24], the measured Secchi disk transparency for the Korhogo Reservoir and the nutrient charges place it in a eutrophic category. Most environmental parameters (temperature, pH, dissolved oxygen, water transparency, nutrient concentrations) were similar between sampling sites, except for the conductivity. According to the catchment's morphology and the characteristics of the surrounding area, it can be assumed that the Korhogo reservoir receives a high nutrient input, with phosphorus present in much lower concentrations thannitrates. This increase in the concentration of these nutrients seems to be associated with the practice of market gardening with the use of fertilizers around the reservoir. According to [25], agricultural activities generally lead to an increase in nutrients in the water. It would also be explained by nutrient loads from untreated urban domestic effluent to the reservoir.



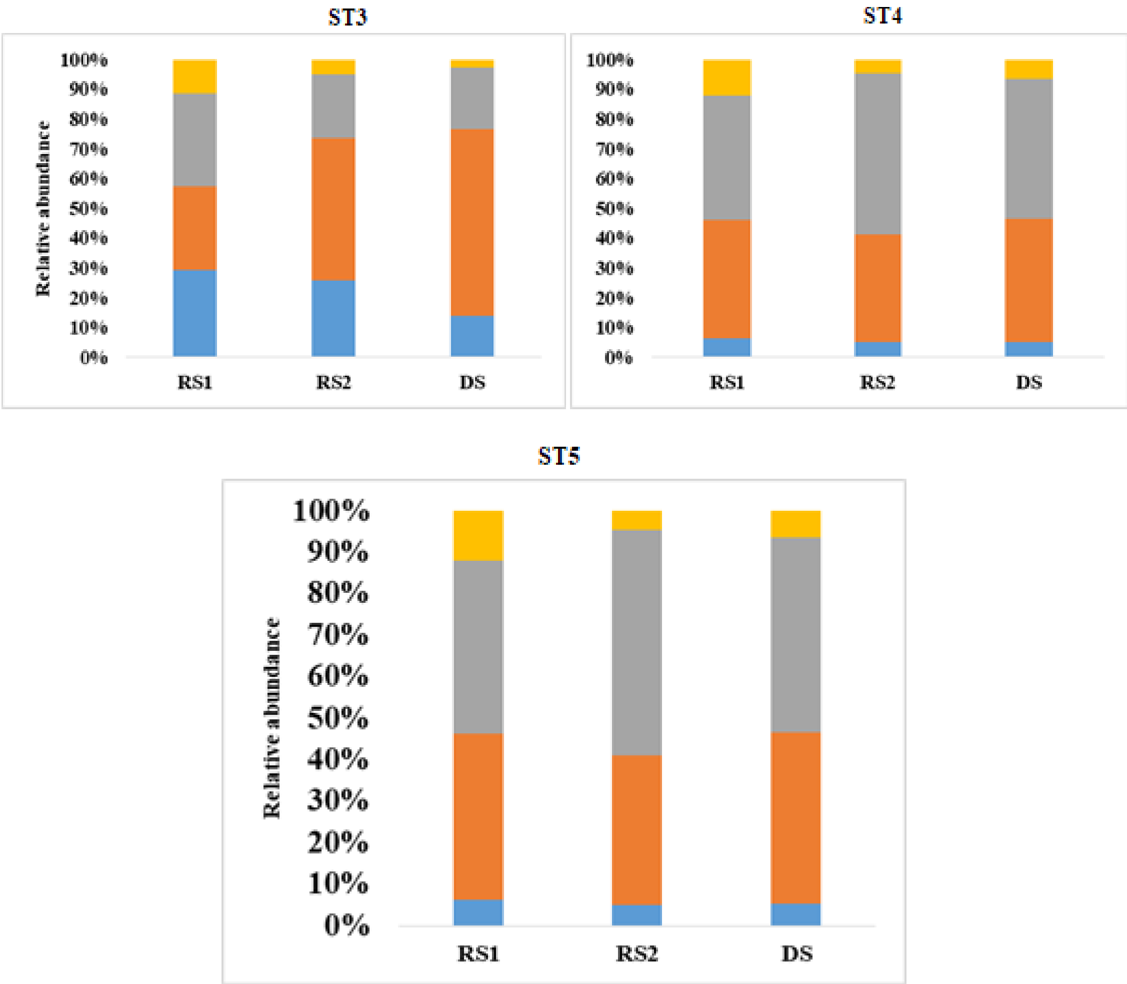


Figure 4: Temporal patterns of relative abundance in four stations of Korhogo Reservoir. RS: rainy season; DS: dry season

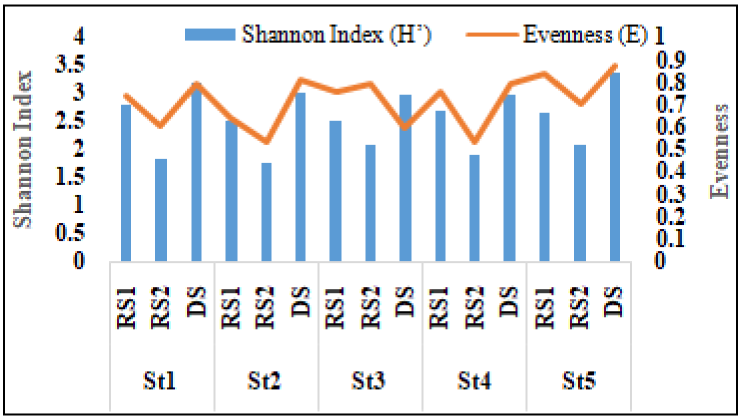


Figure 5: Seasonal variation of Shannon and evenness indexes in Korhogo reservoir
H': Shannon index; E: Evenness index; RS1: Midle rainy season, RS2: End rainy season; DS: Dry Season

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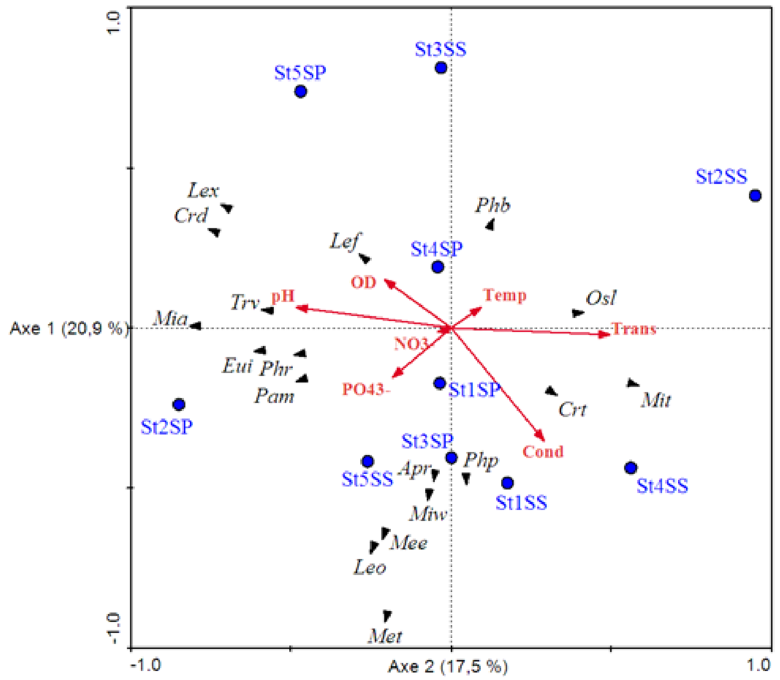

Figure 6: Ordination according to the RDA of 18 dominant taxa and 7 environmental variables. (T: temperature, Cond: conductivity; DO: dissolved oxygen; NO^{3-}: nitrate; PO_4^{3-}: Orthophosphate; Trans.: transparency; St: station, SS: dry Season, SP: rainy season

The low phosphorus concentrations can be associated with the very high density of cyanobacteria in the environment. Indeed, these algae have the ability to store phosphorus in the form of polyphosphategranules according to the luxury consumption phenomenon ([26], [27]).

Phytoplankton taxonomic identification revealed seventy - eight taxa in the Korhogo reservoir. Overall, the phytoplankton community can be considered rich, considering the short sampling period. This richness could be explained by the stagnant nature of the reservoir. Indeed, the stagnant character of the hydrosystem favors biological processes such as complete cycles of reproduction and the development of algae [8]. In these waters, a majority association of Euglenophyta (47.43%) and Chlorophyta (29.49%) was observed. This dominance of Euglenophyta and Chlorophyta would be characteristic of environments rich in putrescible organic substances with the discharge of large quantities of untreated domestic wastewater found in the reservoir. According to [28], representatives of these phyla, specifically the genera *Scenedesmus* and *Euglena*, are known to have a predilection for eutrophic environments *sensu lato*. This higher diversity of Chlorophyta and Euglenophyta has also been noted in phytoplankton by [29] in the Lac de Guiers in Senegal, [30] in the waters of floodplain lakes in Brazil and [3] in the Adzopé reservoir and [31] in ponds south of the Togodo wildlife reserve in southern Togo, as well as [9] in Lake Guessabo in Côte d'Ivoire and finally in the Bacon reservoir in south - eastern Côte d'Ivoire [32]. The diversity index values recorded would indicate that the phytoplanktonic population in the reservoir studied was relatively diverse. According to [33], in exceptionally diverse environments, the Shannondiversity index hardly exceeds 4.5. Moreover, these values would reflect the existence of suitable conditions for the development of phytoplankton. Low diversity characterises a young population with high multiplication power and a predominance of one species, whereas high diversity characterises senescent populations with a complex specific composition [34]. Thus, the low values recorded, mainly during the rainy season, could be explained by the effect of heavy rainfall, which would cause a dilution effect, given the shallow depth and size of the hydrosystem. This phenomenon would reflect episodes of the dominance of a few species, mainly *Microcystis aeruginosa*, *Merismopedia tenuissima* and *Oscillatoria limosa*, 3 of the 78 taxa encountered, whose pillulation (92%) in st3 at the end of the rainy season contributes to lowering the index. This decrease in diversity during the rainy seasons was reported by [32] on the Bacon reservoir. The high value (3.4 bits/cell) recorded at station St5 could indicate the absence of outbreaks of a few isolated species, but rather of several taxa. This phenomenon would reflect episodes of dominance of a few species, mainly *Microcystis aeruginosa*, *Merismopedia tenuissima* and *Oscillatoria limosa*, 3 of the 78 taxa encountered, whose pillulation (92%) in st3 at the end of the rainy season contributes to lowering the index.

At stations St2 and St3, almost in all seasons, the abundance of Cyanobacteria was predominant despite their lower numbers than Euglenophytes. Generally, the little relationship between environmental variables and these taxa abundances demonstrated by the RDA, suggests that other parameters were responsible for this high abundance. So, therefore, this predominance could be attributed to strategies developed by Cyanobacteria to avoid being targeted by grazers (zooplankton and phytophagous fishes) like associating in large colonies [35], production of toxins [36] and release of chemical compounds [37]. [38] suggests that such strategies would contribute to increasing the competitive advantage of Cyanobacteria over other algal phyla in achieving dominance of an aquatic environment.

Specifically for *Microcystis aeruginosa*, the strong positive correlation of densities with pH suggests that the growth of these Cyanobacteria would be influenced by the pH generally associated with high temperatures in the tropical regions. This observation corroborates that of Blais [38], who indicates that these taxa proliferate in high pH biotopes.

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