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Spatial and Seasonal Variation of Microalgal Densities and Mean Chlorophyll *a* Content in the Waters of The Bandama River (Côte d'Ivoire)

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Abstract

The Bandama River is the only river entirely located within Côte d'Ivoire, covering areas with different climatic and biogeographic characteristics. Various activities such as fishing, livestock farming, agriculture, electricity production, and mining impact its biodiversity. This study aims to assess the abundance of microalgae inhabiting the waters of the Bandama River. The study required direct water sampling using 250 ml bottles. Sampling campaigns were conducted each season from February to October 2013. The highest algal densities were recorded in Lake Taabo. The species *Aphanocapsa elachista*, *Microcystis aeruginosa*, *Anabaena mucosa*, *Aulacoseira granulata* var. *angustissima*, *Dictyosphaerium* pulchellum, and *Pediastrum duplex* var. *gracillimum* were the basis of this abundance. The lowest densities were observed at the Yékolo station. Rivers recorded high densities and chlorophyll *a* content during the short dry season, while lakes showed peak values during the long rainy season. Cyanoprokaryota and Chlorophyta were the most represented groups, accounting for 65.04% and 17.89%, respectively. The diversity indices indicate that the algal community is diverse in both lacustrine and fluvial environments. This study contributes to evaluating the impacts of anthropogenic activities on microalgae in Côte d'Ivoire.

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Introduction

The Bandama River is the only river entirely located within Côte d'Ivoire (Iltis & Lévêque, 1982a et b). Due to its north-south orientation, it traverses areas with different climatic and biogeographic conditions. It is exposed to various anthropogenic pressures that may disrupt its ecological functioning. Indeed, human impact has significantly increased. The Bandama River basin is subject to intense industrial and agro-pastoral activities, including heavy fertilizer use. Mining and artisanal gold extraction are among the activities conducted in the river basin (Anonymous, 2010). There is a need to preserve this basin to ensure biodiversity conservation and sustainable resource management. This study aims to assess the abundance of microalgae in the Bandama River waters to better understand the impact of anthropogenic activities.

Materials and Methods

Study Area

The Bandama River, 1,050 km long, has a catchment area of 97,000 km². It is formed by the confluence of its main course (White Bandama) and its two major tributaries, the Marahoué (Red Bandama) and the N'Zi (Figure 1). Its average width is 100 m, and its average discharge is 171 m³/s with a slope of 0.46 m/km (Savané, 2010).

For this study, 10 sampling stations were selected along the longitudinal gradient of the river.

The stations are distributed as follows: stations B1 and B2 upstream of Lake Kossou; B4 and B5 on Lake Kossou; B6 on the Marahoué; B7 between Lake Kossou and Lake Taabo; B8 on Lake Taabo; and B3, B9, and B10 upstream and downstream of the N'Zi confluence, respectively (Figure 1).

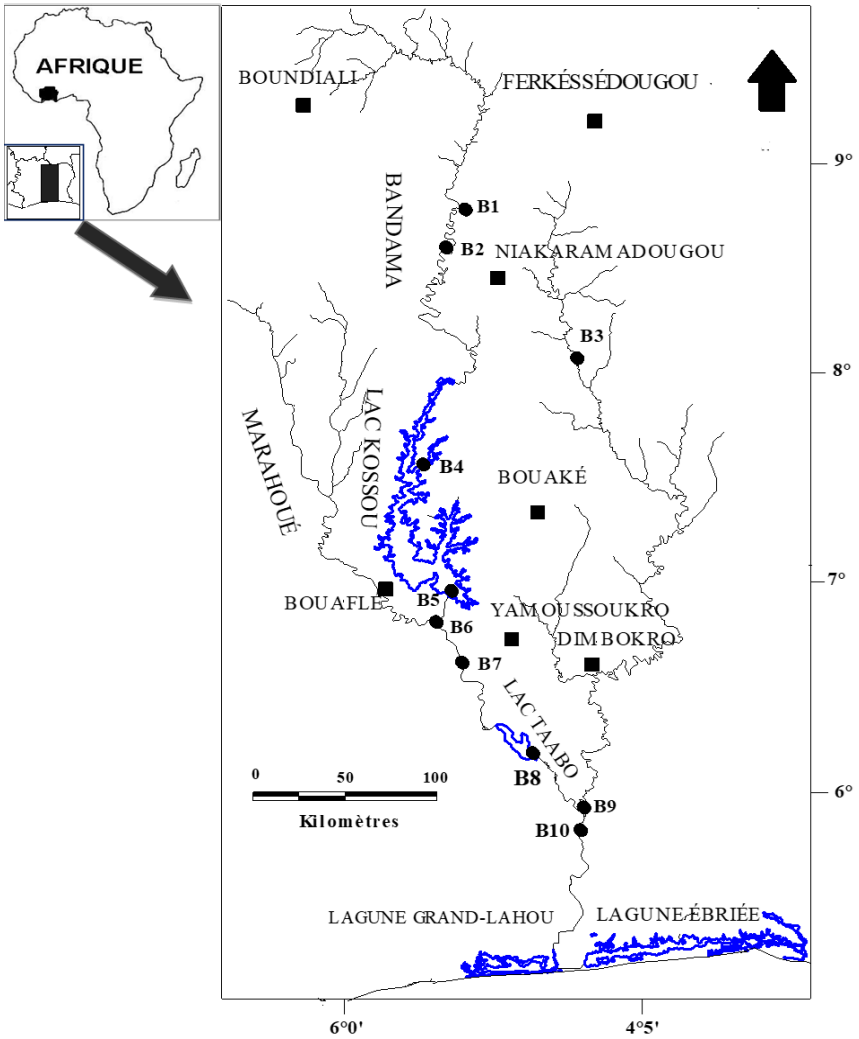

Figure.1 Location of sampling stations on the Bandama River (Côte d'Ivoire)

Microalgae Sampling

This study required direct water sampling using 250 ml bottles. Samples were fixed on-site with a formaldehyde solution at a final concentration of 5%. River water was also collected in 500 ml bottles and wrapped in aluminum foil for chlorophyll *a* analysis. Each bottle was labeled with the location, station, and sampling date.

Microalgae Counting

The quantitative study of microalgae used the Utermöhl (1958) counting method. Samples were manually homogenized and transferred into 2.5 cm sedimentation chambers (equivalent to 5 ml volume) for 24 hours.

Observations were made under a microscope at 40x magnification. Multiple fields (86 to 504) were examined, ensuring a statistically valid count of over 2,000 cells (Venrick, 1978). Microalgae density (D) was calculated using the formula (1):

$$D = \frac{A * Nb}{V * C_{40\times} * R^{2}_{40\times}} \quad (1)$$

Nb: Number of cells counted for a taxon under the microscope
a: Observed area under the microscope
C_{40x}: Number of fields observed at 40x magnification
R_{40x}: Field radius at 40x magnification (0.25 mm)
A: Sedimentation chamber area where cells accumulate (480.8 mm²)
V: Sample volume used for sedimentation (5 ml).

Chlorophyll *a* Analysis

Water samples (500 ml) were filtered through Whatman GF/F glass fiber filters (25 mm diameter, 0.7 µm pore size) using a vacuum pump. After filtration, filters soaked in 90% acetone were immediately wrapped in aluminum foil and stored at 4°C until laboratory analysis for chlorophyll pigment extraction.

After centrifugation at 3,000 rpm for 15 minutes, the supernatant was placed in a 15 cm optical path cuvette. Absorbance was measured at different wavelengths, first without acidification and then after acidification (Aminot and Chaussepied, 1983). Chlorophyll *a* (chl. *a*) content was calculated using formula (2):

$$\text{Chl.}\,a\,(\mu g/l) = \frac{26{,}7 \times (E_1 - E_2) \times V}{Vg \times l} \quad \text{où} \quad 26{,}7 = A \times K \quad (2)$$

$E_{1:}$ absorbance before acidification (DO_{665}-DO_{750})
$E_{2:}$ absorbance after acidification (DO_{665}-DO_{750})
V: Acetone volume (ml)
Vg: Filtered water volume
l: Optical path length of the cuvette (cm)
A: Chlorophyll absorption coefficient
K: Compensation coefficient for absorbance reduction

Statistical Analyses

Data analysis involved univariate analyses (Kruskal-Wallis test). The Kruskal-Wallis test is a non-parametric alternative to one-way ANOVA (inter-group). It was used to compare at least three samples and test the null hypothesis (significant at $p < 0.05$) that the samples came from the same distribution or distributions with the same median. The non-normal distribution of data and unequal sample sizes led to the use of the non-parametric Kruskal-Wallis test to assess parameter variability between sampling points and seasons. Statistical analyses were performed using STATISTICA version 7.1.

Results and Discussions

Microalgae Population Density

The spatial distribution of absolute microalgae densities in the Bandama River is presented in Table I. Station B8 (Lake Taabo) had the highest density (10,075,054 cells/l), followed by stations B5 (Lake Kossou), B4 (Lake Kossou), and B10 (Tiassalé) with 7,520,000 cells/l, 6,926,000 cells/l, and 3,017,000 cells/l, respectively. Station B3 (Yékolo) had the lowest density (144,000 cells/l). The relative density of microalgae groups is shown in Figure 2. Cyanoprokaryota were the most abundant, followed by Heterokontophyta and Chlorophyta. Euglenophyta and Dinophyta accounted for less than 5% of the community. In the fluvial stations (B1, B2, B3, and B9), Heterokontophyta dominated (35%, 45%, 69%, and 35%, respectively). In lacustrine stations (B4, B5, and B8) and mid-course stations (B6 and B7) between the two lakes, Cyanoprokaryota were dominant. Downstream station B10 was dominated by Chlorophyta (59.89%). Seasonal variations in algal densities (Table I) show that fluvial stations recorded high values during the short dry season and long dry season. Lakes recorded peak densities during the long rainy season. Stations B1 and B2 had the highest densities during the short dry season (256,000 and 351,000 cells/l, respectively), followed by the long rainy season (221,000 and 104,000 cells/l, respectively). The lowest densities occurred during the short rainy season (48,000 cells/l for B1 and 26,000 cells/l for B2). The long dry season showed intermediate values (128,000 cells/l for B1 and 75,000 cells/l for B2).

Table.1 Spatio-seasonal variation of absolute microalgae densities in the Bandama River (Côte d'Ivoire)

Sections of the river	Sampling stations	Sampling seasons			
		GSP	GSS	PSS	PSP
Upstream	B1	221000	128000	256000	48000
	B2	104000	75000	351000	26000
	B3	16000	63000	51000	14000
Lake of Kossou	B4	3623000	1240000	1645000	418000
	B5	3142700	1591000	2195000	591300
Between the Lakes	B6	47000	671000	541000	39000
	B7	944000	527000	952000	316000
Lake of Taabo	B8	3428000	2742054	1242000	3263000
Downstream	B9	90000	588000	207000	74000
	B10	418000	804000	1280000	515000

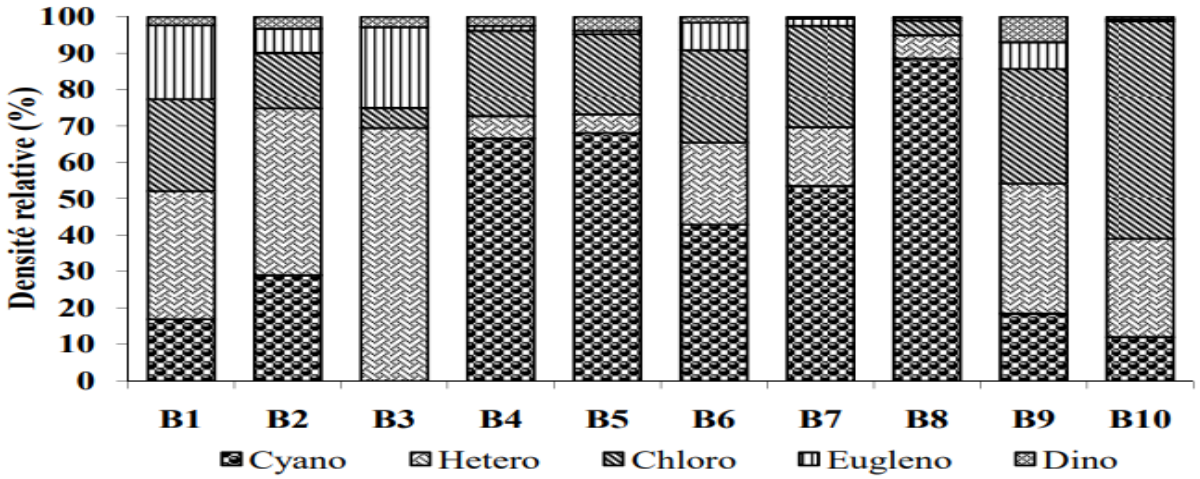

Figure.2 Spatial variation of relative microalgae densities. Cyano: Cyanoprokaryota, Hetero: Heterokontophyta, Chloro: Chlorophyta, Eugleno: Euglenophyta, Dino: Dinophyta.

Spatio-seasonal variation of mean chlorophyll *a* content

Figure 3 shows the spatio-seasonal variation of chlorophyll *a* content in the Bandama River. Chlorophyll *a* content did not vary significantly between stations ($p > 0.05$). The highest concentration (33.38 µg/l) was recorded at station B10 during the short dry season, while the lowest (0.92 µg/l) was observed at station B3 during the short rainy season. Table II presents mean chlorophyll *a* values for different river sections. The downstream section had higher biomass (16.34 ± 11.15 µg/l) compared to the upstream section (5.8 ± 5.12 µg/l). Overall, lakes had higher biomass (12.46 ± 9.23 µg/l) than fluvial environments (10.09 ± 5.54 µg/l). Chlorophyll biomass followed microalgal density trends.

Determinants of Chlorophyll Biomass

Table III of the stepwise regression shows that temperature and nutrients (nitrites, nitrates, orthophosphates, and ammonium) positively influence chlorophyll biomass (positive regression coefficient t). A high absolute t-value and low p-value suggest that the corresponding parameter has a strong impact on chlorophyll biomass. Thus, only nitrites, nitrates, ammonium salts, and silica most significantly influence chlorophyll biomass.

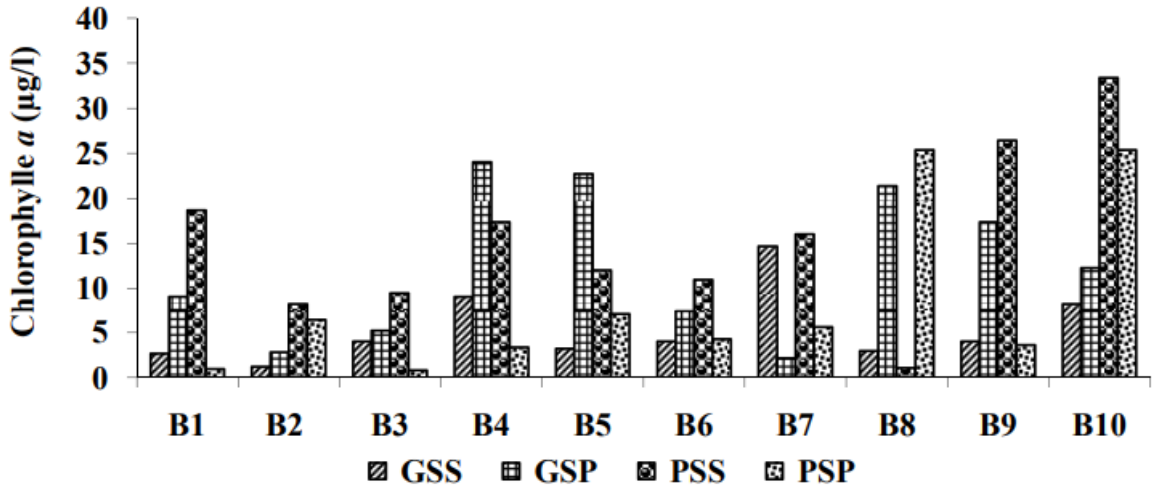

Figure.3 Spatio-seasonal variation of chlorophyll *a* content at stations (B1 to B10) in the Bandama River (Côte d'Ivoire)

Table.2 Mean chlorophyll *a* content in different sections of the Bandama River (Côte d'Ivoire)

Sections of the river		Chl *a* (µg/l)	Moy.
River	upstream	5,8 ± 5,12	
	Between the Lakes	8,14 ± 5,18	**10,09 ± 5,54**
	downstream	16,34 ± 11,15	
Lakes	Lake of Kossou	12,35 ± 8,21	
	Lak of Taabo	12,68 ± 12,46	**12,46 ± 9,23**

Table.3 Stepwise multiple regression coefficients (parameters) relating physicochemical parameters to chlorophyll biomass in the Bandama River (Côte d'Ivoire)

Dependent parameter	Indépendents parameters	t	R^2	F	p	Bêta (*B*)
Chl a	pH	-0,667	0,052	0,445	0,523	-0,229
	Temp	0,141	0,0024	0,0199	0,891	0,049
	CND	-0,828	0,079	0,686	0,431	-0,281
	OD	-0,536	0,034	0,287	0,606	-0,186
	Transp	1,012	0,1135	1,0243	0,341	0,336
	NO_3^-	1,747	0,276	3,05	0,118	0,525
	NO_2^-	2,254	0,388	5,08	0,054	0,623
	PO_4^{3-}	1,003	0,111	1,006	0,345	0,334
	NH_4^+	1,935	0,318	3,747	0,088	0,564
	Si	-1,762	0,279	3,105	0,116	-0,528

t = regression of coefficient, R^2 = determination of coefficient, F = inclusion coefficient, p = probability and Bêta (*B*)

Discussion

Microalgae Density

Spatially, the highest densities were recorded at station B8 (Lake Taabo). This high density does not reflect taxonomic diversity, as Lake Kossou was the most diverse. The dominance is due to a high number of individuals or cells forming colonies belonging to a few species. Lake Taabo was the only station with over 80% Cyanoprokaryota, known for their colonial or filamentous forms. The low algal densities at station B3 (fluvial and upstream) during rainy seasons may be due to low nutrient concentrations. The high algal density downstream, especially during the long rainy season, may be influenced by Lake Taabo. During this season, dam gates open, releasing nutrients and algae, leading to algal proliferation downstream. The high density at Zambakro station (B7) may result from receiving water from Lake Kossou and the Marahoué.

Low densities were observed in fluvial environments, consistent with Ouattara *et al.* (2001), who found phytoplankton abundance to be low in lotic systems. In most stations, particularly lakes (Kossou and Taabo), Cyanoprokaryota dominated due to their ecological plasticity (Lévi *et al.,* 2006). They adapt to extreme environmental conditions and colonize most freshwater ecosystems (Lavoie *et al.*, 2007). Their ability to store excess nutrients ensures growth during nutrient deficits (Reynolds *et al.,* 1987). Heterokontophyta, particularly *Aulacoseira granulata* var. *angustissim*a, dominated fluvial sections due to their rapid colonization of surfaces, with water flow detaching them into the water column (Niamien-Ébrottié, 2010).

These findings align with Iltis (1982a and b) in Ivorian rivers, Ouattara (2000) in the Agnéby River, and Dibong and Ndjouondo (2014) in Cameroonian rivers. Densities peaked during the short dry season in fluvial stations, likely due to accelerated nutrient mineralization from high temperatures and reduced runoff. Similar results were reported by Niamien-Ébrottié (2010). Cyanoprokaryota, including potentially toxic species like *Anabaena mucosa*, *Aphanocapsa elachista*, and *Microcystis aeruginosa*, proliferated during this season. Rainy seasons favored Chlorophyta, such as *Crucigeniella apiculata*, *Pediastrum gracillimum*, and *Spirogyra* sp., due to higher phosphate and ammonium levels from agricultural runoff (Biggs, 2000).

Chlorophyll Biomass

Chlorophyll biomass followed microalgal density trends, with higher values in stations with high cell densities. High chlorophyll biomass was linked to favorable conditions like temperature and nutrients (Zongo, 1994). Photosynthetic activity is influenced by temperature, nutrients, light, and water movement (Dufour, 1982). Low chlorophyll at Yékolo (fluvial and upstream) may reflect low nutrient levels. The highest chlorophyll *a* (33.38 µg/l) at Tiassalé (downstream) was attributed to large-sized Chlorophyta like *Desmodesmus quadricaudatus*, *Hyalotheca dissiliens*, *Pediastrum duplex* var. *gracillimum*, and *Pediastrum simplex*. Seasonally, chlorophyll *a* peaked during the short dry season due to nutrient enrichment from organic matter decomposition at high temperatures (Granéli *et al.*, 1999).

In conclusion, the highest algal densities were recorded in Lake Taabo, driven by *Aphanocapsa elachista*, Microcystis aeruginosa, Anabaena mucosa, *Aulacoseira granulata* var. *angustissima*, *Dictyosphaerium pulchellum*, and *Pediastrum duplex* var. *gracillimum*. The lowest densities occurred at Yékolo. Rivers showed high densities and chlorophyll *a* during the short dry season, while lakes peaked during the long rainy season. Cyanoprokaryota (65.04%) and Chlorophyta (17.89%) dominated.

Conflict of interest statement

Authors declare that they have no conflict of interest.

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