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RESEARCH ARTICLE

DIVERSITY AND SPATIO-SEASONAL DYNAMICS OF MICRO-ALGAE IN THE COMOE RIVER (CÔTE D'IVOIRE)

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ABSTRACT

Water remains the most essential natural resource for life. In Côte d'Ivoire, the catchment areas of rivers are the environments most exploited by human populations. These practices have consequences for the watercourses, which also receive various types of waste through run-off water. This study was initiated between February 2020 and January 2021, with a view to assessing the diversity and dynamics of micro-algae in the Comoé River. The composition, diversity, occurrence and spatio-seasonal abundances of micro-algae were studied. Physico-chemical variables were measured in situ and in the laboratory. Microalgae were collected using a plankton net and observed under optical and electron microscopes for identification. A total of 190 taxa were inventoried, divided into 79 genera, 39 families, 23 orders, 10 classes and 5 phyla. The most diverse phyla were Euglenophyta with 59 taxa, Chlorophyta with 55 taxa and Heterokontophyta with 51 taxa. The study revealed a positive upstream-downstream gradient in specific richness and diversity. According to their frequency of occurrence, there were 32 constant taxa, 72 accessory taxa and 86 accidental taxa. We also noted an increase in micro-algal abundance from the upper to the lower reaches of the river. High algal abundances were obtained in the dry seasons at most stations. The lowest abundances were observed at the Kafolo station and the highest at Kokonou and Grand-Bassam.

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INTRODUCTION

Water, a natural resource essential to life, is currently under serious threat. Indeed, the quality of water throughout the world is deteriorating sharply because of population growth and its development requirements (Taffouo *et al.,* 2017). The transformation of human society and its quest for greater daily well-being are at the root of phenomena such as untreated industrial waste, the intensive use of agricultural inputs and the irrational exploitation of aquatic resources (Noukeu *et al.,* 2016). These practices lead to the degradation of aquatic environments and a depletion of the resources they shelter (Noukeu *et al.,* 2016). As a result, eutrophication is intensifying, leading to a reduction in biodiversity and an increase in pollutant-resistant species (Roxane and Reinhard, 2015). As in most developing countries (Priso *et al.,* 2012 ; Dibong *et al.,* 2014), the Comoé River in Côte d'Ivoire is no exception to this sad reality. Numerous activities, in particular intensive agriculture using agricultural inputs, industrial and artisanal mining, the construction of navigation canals and unbridled urbanisation in the catchment areas are just some of the practices that can be observed along the Comoé River. Moreover, in recent years, the Comoé basin has been subject to heavy flooding, draining industrial, agro-pastoral and domestic waste into the riverbed (Ahouansou, 2008).

This situation could lead to changes in the physico-chemistry of the water and impact on the life of organisms in the environment, including micro-algae. Under favourable environmental conditions (pH, temperature, levels of nutritive salts, dissolved oxygen, etc., Zinsou *et al.,* 2016), micro-algae can develop and, depending on the case, be beneficial or harmful to humans (Reichwaldt and Ghadoua, 2012). However, work on the micro-algal component of the Comoé River is limited to that of Iltis (1982a) at the Gansé station and Adon *et al.* (2018) at the river mouth. Faced with this lack of information, it became necessary for us to provide scientific data on micro-algae with a view to monitoring the ecological quality of the said river. The aim of the present work is therefore to study the diversity and dynamics of micro-algae in the Comoé River.

MATERIALS AND METHODS

Study area: This study covers the section of the Comoé River (Figure 1), from Kafolo (Ivorian-Burkinabe border) to Grand-Bassam (river mouth). The Comoé River rises in the cliffs of Banfora (Burkina Faso) at an altitude of 420 m (Vanden Bossche and Bernacsek, 1990).

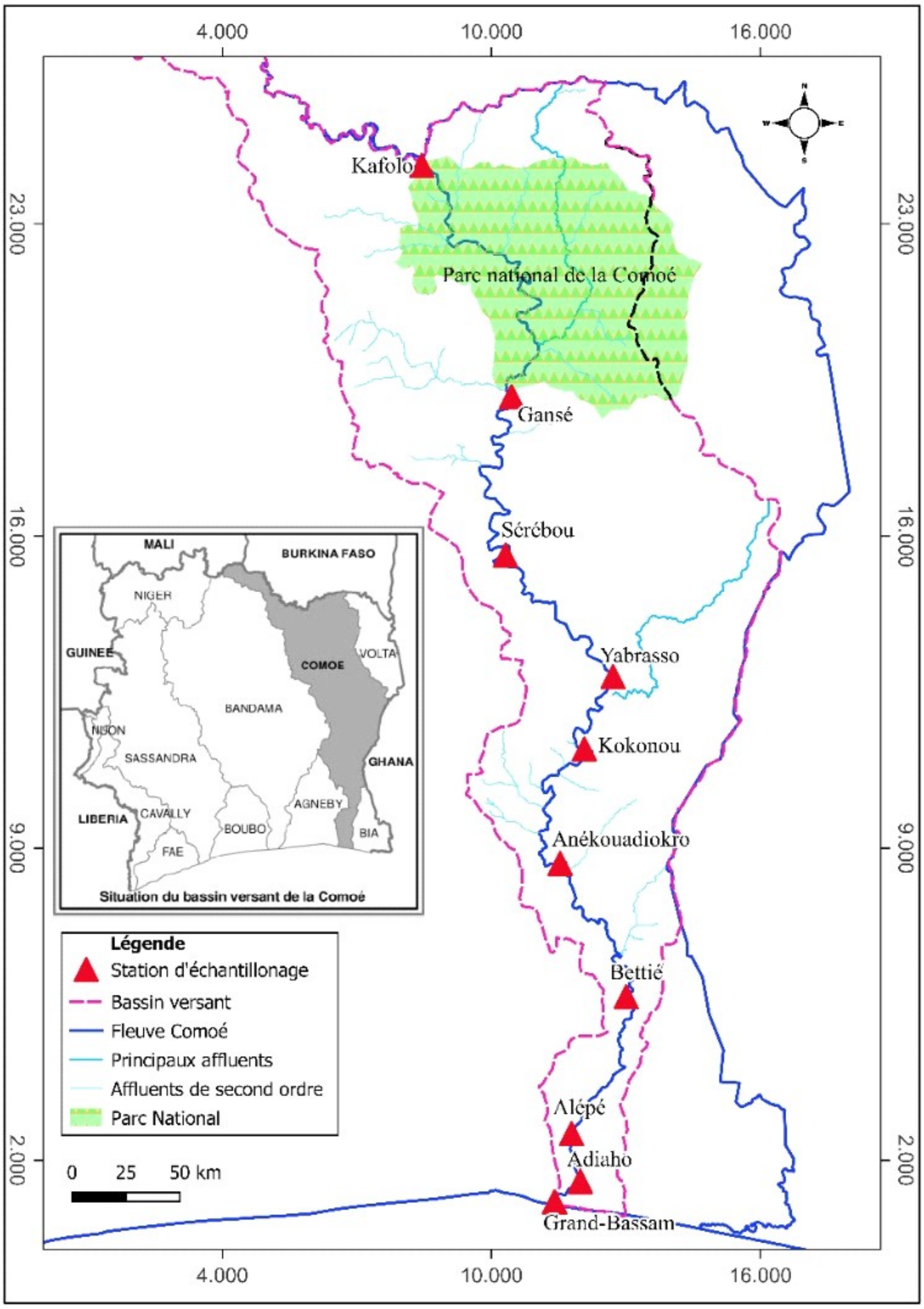

Figure 1. Map of Comoé river catchment with sampling stations

With a low average gradient (0.25 m/km), this river drains a catchment area of 78,000 km², of which 57,300 km² is in Côte d'Ivoire, and flows into the Ébrié lagoon at Grand-Bassam (Iltis and Lévêque, 1982). It is the longest river in Côte d'Ivoire (1160 km in total, including 150 km in Burkina Faso). The Comoé has three hydrological regimes in relation to the different climatic regimes to which it is subjected (Iltis and Lévêque, 1982) :

- The transitional tropical regime in the upper reaches of the basin: This regime comprises a single flood from August to October and a long low-water period from January to May.
- The attenuated equatorial transitional regime in the middle course : with two rainy seasons, this regime has two floods in June-July and September-October.
- The transitional equatorial regime, in the lower course : two periods of high water are observed, with the highest flood in June-July and the second in October-November (Yao, 2006).

Sampling and data analysis techniques

Four sampling campaigns were carried out according to climatic rhythms at each of the ten (10) stations selected, taking into account their accessibility and any anthropogenic pressures (Table 1). Sampling was carried out in July, September and November 2020 and in January 2021. For each campaign, samples were taken between 8 and 10 o'clock in the morning. Parameters such as temperature, pH, conductivity and dissolved oxygen were measured in situ using a HANNA HI 9829 portable multiparameter. A 29 cm diameter Secchi disc was used to measure water transparency. As for nutrient salts, water samples for the analysis of chemical parameters were taken 50 cm below the surface, collected in 1-litre plastic bottles and stored in coolers. In the laboratory, phosphates were measured by colorimetry in accordance with French standard T 90 023 (Grasshoff *et al.,* 1983). Nitrates were measured using the cadmium reduction method (Tréguer et Le Corre, 1975).

Microalgae were collected for the qualitative study using a 20 µm mesh plankton net in which 100 L of water was filtered using a 10-litre bucket. Samples for the quantitative study were taken using a Niskin-type hydrological bottle. Pill boxes with a capacity of 40 mL were used to collect and preserve the samples. A few drops of 5% formalin were added to the samples to fix and preserve the organisms contained in them. Observations were made using an Olympus CKX41 light microscope and a Zeiss Supra 40 VP scanning electron microscope (SEM). Taxa were identified using determination keys and/or various works on microalgae: Bourrelly (1961a), Ouattara (2000), Komárek et Anagnostidis (2005), John *et al.* (2004), Sophia *et al.* (2005), Ciugulea *et al.* (2008). Updated information on the various taxa was obtained from Guiry and Guiry (2023). Microalgal cells were counted using a Malassez cell (Groga *et al.,* 2017, Kouadio, 2022) mounted on an Olympus-type optical microscope.

The abundance of microalgae was then determined using the following formula :

$$N = (n*F) /V \quad (1)$$

N: cell concentration or abundance (cells/mL)
n: number of cells counted
V: volume of a cell
F: dilution factor

The Shannon diversity index was calculated:

$$H' = - \sum (Pi)\times Log_2 i) \quad (2)$$

Pi : proportional abundance or percentage importance of the species.
Pi : ni/N
S: total number of species.
N: total number of individuals of all species in the sample.
Ni : number of individuals of one species in the sample.
The Piélou equitability index was also determined:

$$E = H'/ Log_2 Rs \quad (3)$$

E: equitability index
H': Shannon diversity index
Rs: number of species.

Statistical processing: Non-parametric Kruskal-Wallis tests were used to test the variance of physico-chemical parameters between the various sampling points on the river. These tests are significant for $p < 0.05$. All these analyses were carried out using R software version 4.2.1.

RESULTS

Spatial variation in physical and chemical parameters: The spatial variation in the abiotic parameters studied is shown in Figures 2 to 7. Parameters such as dissolved oxygen, nitrates and orthophosphates varied significantly from one station to another ($p<0.05$). On the other hand, temperature, transparency, conductivity and pH did not vary significantly between stations ($p > 0.05$). Temperature ranged from 26.36°C to 33.4°C (Figure 2), with an average of 28.93°C. The maximum was recorded at the Kafolo station and the minimum at Sérébou. Water transparency varied between 8.5 cm (Yabrasso) and 45.5 cm (Adiaho) (Figure 3). The average value is 17.51 cm. Dissolved oxygen levels fluctuate between 4.48 mg/L (at Adiho) and 7.76 mg/L (at Grand-Bassam). With an average of 5.93 mg/L, the level drops slightly downstream (Figure 4). Conductivity varied from 41.51µS/cm to 187.38 µS/cm (Figure 5). The average is 70.69 µS/cm. The maximum value was recorded at the Grand-Bassam station. Nitrate concentrations ranged from 1.6 mg/L to 6.17 mg/L (Figure 6). The average is 4.26 mg/L. With the minimum recorded at Gansé, nitrate levels increase from upstream to downstream. Orthophosphate levels ranged from 0.09 mg/L to 0.75 mg/L, with an average of 0.46 mg/L (Figure 7). The highest value was recorded at the Alépé station and the lowest at Kafolo. Orthophosphate levels increase from upstream to downstream.

The pH values vary between 5.60 (at Kafolo) and 7.63 (at Kokonou). The average of 6.66 indicates that the waters of the Comoé are generally acidic.

Taxonomic composition and occurrence of microalgae taxa: A total of 190 taxa (species, varieties and forms), divided into 79 genera, 39 families, 23 orders, 10 classes and 5 phyla, were inventoried in the waters of the River Comoé. The phyla with the highest number of taxa were Euglenophyta with 59 taxa (31.05%), Chlorophyta with 55 taxa (28.94%) and Heterokontophyta with 51 taxa (26.84%). The class Euglenophyceae with 58 taxa (30.52 %) is the most diverse, followed by Bacillariophyceae with 43 taxa (22.63 %) and Chlorophyceae with 37 taxa (19.47 %). Of the taxa identified, 39 were inventoried at the Kafolo station, 47 at Gansé, 50 at Sérébou, 54 at Yabrasso, 92 at Kokonou, 55 at Anékouadiokro, 53 at Béttié, 52 at Alépé, 65 at Adiaho and 85 taxa at Grand-Bassam.

In terms of frequency of occurrence (Table 2), there were 32 constant taxa (16.84%), 72 accessory taxa (37.89%) and 86 accidental taxa (45.26%). The most important constant taxa were : *Aulacoseira granulata, Aulacoseira granulata f. curvata, Nitzschia intermedia, Nitzschia vermicularis*, for the Heterokontophyta; *Euglena ehrenbergii, lepocinclis acus, Strombomonas fluviatilis, Trachelomonas abrupta,* for the Euglenophyta; *Desmodesmus opoliensis, Scenedesmus obtusus f. disciformis, Ankistrodesmus arcuatus, Cosmarirum reniforme* for the phylum Chlorophyta. No Cyanobacteria or Dinophyta are among the constant taxa.

Spatial and seasonal variations in stand diversity: Variations in the Shannon diversity index (H') and equitability index (E) are studied. The Shannon diversity index varies from 1.32 to 2.96 bits/cell. The highest values of this index were recorded in the dry seasons at most of the stations. The maximum (2.96 bit/cell) is obtained at Kokonou in the dry season and the minimum at Adiaho (1.32 bit/cell) in the rainy season. The equitability index varies between 0.54 (in Adiaho) and 0.98 (in Kafolo). These extreme values are recorded in the dry seasons. The index remains virtually constant throughout the year at the Yabrasso, Béttié, Adiaho and Grand-Bassam stations.

Spatial and seasonal variations in microalgal abundance: Microalgal abundances are given in Tables 3 and 4. The highest absolute abundances in the various parts of the river were obtained respectively at the Gansé (212,000,000 cells/L), Kokonou (883,000,000 cells/L) and Grand-Bassam (1,153,000,000 cells/L) stations, mostly in the dry seasons (Tables 3). Relative abundances are dominated by the phyla Chlorophyta (81.66 %) and Euglenophyta (64.13%) phyla in the headwaters during the rainy and dry seasons, respectively, at the Gansé station. In the middle reaches, the Kokonou station recorded the highest abundance with 883,000,000 cells/L. It is followed by the Yabrasso and Anékouadiokro stations with 503,000,000 cells/L and 495,000,000 cells/L respectively.

These higher values were recorded during the dry season. In terms of relative abundance, the Chlorophyta phylum is the most abundant at all the stations in this part of the river during the rainy season. On the other hand, other groups such as the Heterokontophyta, Cyanoprokaryota and Euglenophyta predominate in the dry seasons.
In the lower reaches of the river, the Grand-Bassam station recorded the highest abundance with 1,153,000,000 cells/L. Next come the Béttié and Adiaho stations, with 848,000,000 cells/L and 846,000,000 cells/L respectively. This abundance is dominated during the rainy season by Chlorophyta, except at the Alépé station. Chlorophyta are followed by Cyanoprokaryota, Heterokontophyta and Euglenophyta. Cyanoprokaryota predominate at most of these stations during the dry season. The abundance of Heterokontophyta and Euglenophyta varied little during the different sampling seasons. A few Dinophyta taxa were identified at the Béttié, Alépé and Grand-Bassam stations, but were absent from the upper and middle rivers.

Table 1. Coordinates and characteristics of sampling stations

Section of the river	Sampling stations	Station code	Station coordinates	Human activities
Upper section	Kafolo	Kafo	09°58'847 N – 04°30'820 W	- cattle rearing - cotton growing
	Gansé	Gans	08°61'493 N – 03°92'148 W	- Comoé National Park - Rice and cotton cultivation
Medium section	Sérébou	Séré	07°56'247 N – 03°56'257 W	- small-scale fishing - cocoa plantations - laundry
	Yabrasso	Yabr	07°26'525 N – 03°30'317 W	- small-scale fishing - cocoa plantations - transport by motorised canoes
	Kokonou	Koko	07°07'186 N – 03°37'177 W	- small-scale fishing -cocoa, rubber and cassava plantations - laundry
	Anékouadiokro	Anék	06°38'135 N – 03°42'457 W	- small-scale fishing - cocoa plantation - bridge building
Lower section	Béttié	Bétt	06°03'594 N – 03°25'227 W	- small-scale fishing -cocoa, rubber and plantations - washing of equipment (motorbikes, vehicles)
	Alépé	Alép	05°50'260 N – 03°65'683 W	- small-scale fishing - cocoa plantation - sand extraction - laundry -Brick production
	Adiaho	Adia	05°28'544 N – 03°61'570 W	- small-scale fishing - cocoa plantation - pineapple fields - laundry
	Grand-Bassam	GrdB	05°21'544 N – 03°71'611 W	- small-scale fishing - rice fields

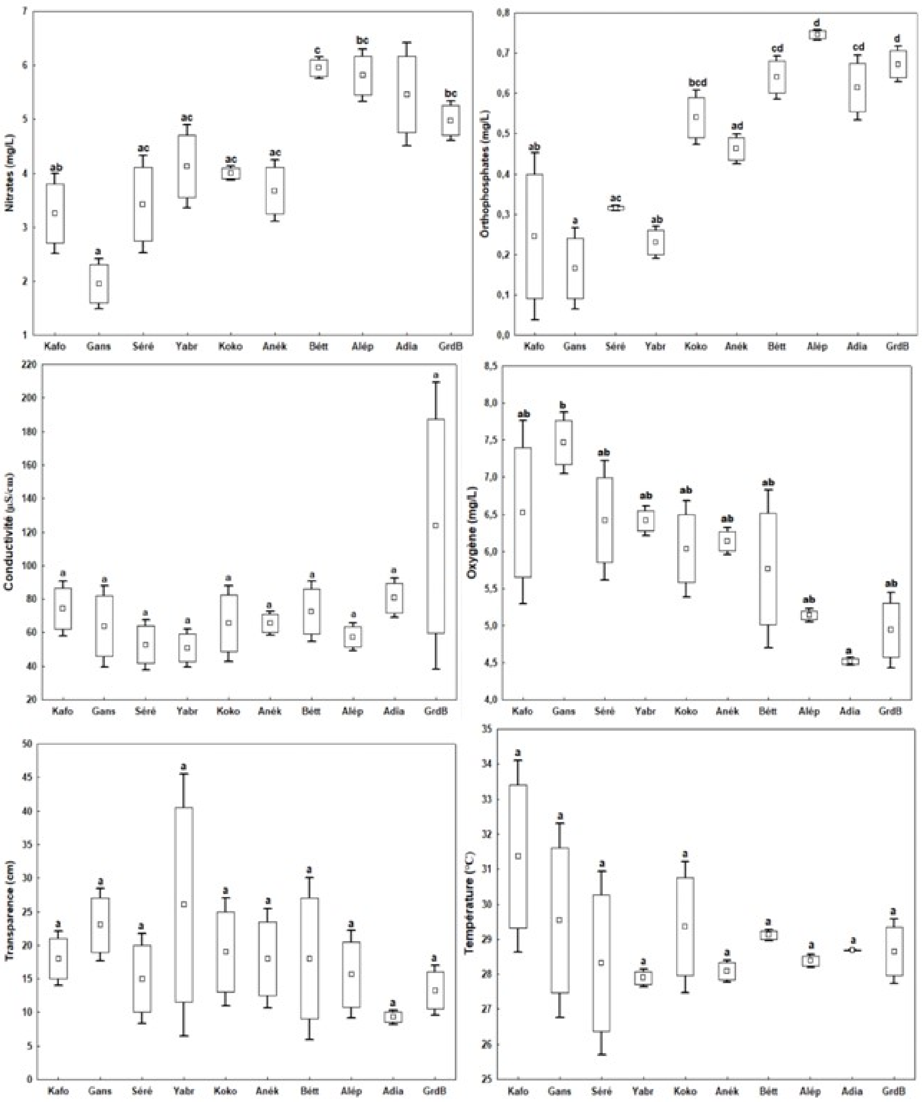

Table 2. Distribution of microalgae taxa in the Comoé River according to occurrence

Branches	Number of constant taxa	Number of accessory taxa	Number of accidental taxa	Total
CHLOROPHYTA Cavalier-Smith	7	22	26	55
CYANOPROKARYOTA Anagnostidis et Komárek	0	11	11	22
DINOPHYTA Auct.	0	1	2	3
EUGLENOPHYTA Pascher	15	18	26	59
HETEROKONTOPHYTA Van Den Hoek *et al.*	10	20	21	51
Total	32	72	86	190

Table 3. Spatial and seasonal variation in the absolute abundance of microalgae in Comoé River
SS : Dry season ; SP : Rainy season

Sections of the river	Sampling stations	Sampling seasons	
		Abundance (10^6 cells/L)	
		SS	**SP**
Upper section	Kafo	34	59
	Gans	92	120
Medium section	Séré	203	100
	Yabr	318	185
	Koko	682	207
	Anék	275	220
	Bétt	460	388
	Alép	456	287
Lower section	Adia	473	373
	GrdB	563	590

Table 4. Spatial and seasonal variation in the relative abundance (%) of microalgae in Comoé River

Sections of the river	Sampling stations	Seasons	Chloro	Cyano	Dino	Eugle	Hetero
Upper section	Kafo	SS	8,82	0	0	55,88	35,29
		SP	42,37	0	0	28,81	28,81
	Gans	SS	10,86	14,13	0	64,13	10,86
		SP	81,66	0	0	10,83	7,5
Medium section	Séré	SS	27,58	29,06	0	19,21	24,13
		SP	68	0	0	12	20
	Yabr	SS	29,55	54,40	0	3,14	12,89
		SP	62,16	0	0	16,21	21,62
	Koko	SS	44,13	34,16	0	8,65	13,04
		SP	73,42	3,86	0	9,66	13,04
	Anék	SS	24	18,90	0	1,81	55,27
		SP	75,90	0	0	5	19,09
Lower section	Bétt	SS	33,04	44,56	0,43	5,21	16,73
		SP	60,56	2,02	0,25	9,53	27,57
	Alép	SS	44,29	27,19	0,87	5,92	21,71
		SP	60,97	17,42	0,34	7,66	13,58
	Adia	SS	41,69	14,36	0	11,54	32,39
		SP	34,41	34,41	0	7,33	23,82
	GrdB	SS	38,89	34,63	0	9,59	17,40
		SP	48,47	21,35	0,16	10,84	19,15

DISCUSSION

Physico-chemical parameters of the water: The variation in physico-chemical parameters along the river was studied. The water is moderately well oxygenated (5.93 mg/L). This would appear to be due to the lotic nature of the water. According to Villeneuve *et al* (2006), the flow of water favours the supply of oxygen through the air-water interface. Our values are consistent with those obtained in the Soumié (3.6 to 6 mg/L), Éholié (5 to 9.2 mg/L), Éhania (4.1 to 9.8 mg/L) and Noé (6.3 to 9.8 mg/L) rivers in southern Côte d'Ivoire (Niamien-Ébrottié, 2010). They are slightly higher than those obtained by Kouadio (2022) on the Bandama (3.62 mg/L on average) and by Taffouo *et al.* (2017) in the Nkam river (3.54 to 4.22 mg/L) in Cameroon. With regard to nutrient salts (nitrates and orthophosphates), the average values (4.26 mg/L and 0.46 mg/L respectively) are higher than the thresholds set at 0.45 mg/l for nitrates and 0.03 mg/l for orthophosphates (Hade, 2002). These high concentrations expose the waters of the River Comoé to the risk of eutrophication by nitrates and orthophosphates. In addition, concentrations of these salts increase downstream. This upstream-downstream gradient in mineralisation is attributable to the fact that, under the action of run-off water, these nutrient salts are transported in the river bed, then drained by the current downstream. Rainfall from human activities in the catchment is thought to be the cause of the enrichment of the water with these salts (Seu-Anoï, 2012). This phenomenon could explain the massive presence of macrophytes observed in the Grand-Bassam and Adiaho stations. The highest conductivity values are recorded in the southern part of the river during the dry season. The estuarine zone of the river is currently a sort of receptacle, receiving domestic waste and organic matter from the leaching of cultivated land (Salla, 2015 ; Keumean *et al.,* 2013). This is thought to be linked to the closure of the river mouth (Adopo *et al.,* 2008), which breaks the contact between the river and the sea. The dissolution of these products in the environment leads to an increase in conductivity. This is more marked in the dry seasons, when the water is less diluted. The waters of the River Comoé are not very transparent (17.5 cm on average). The lowest values for this parameter are measured during the rainy season, and are more marked at stations in the southern part of the river. The accumulation of particles (sand, rubbish, etc.) from upstream areas, the activities carried out on the banks and the collapse of the banks by run-off water during flood periods (Affian *et al.,* 2008) are thought to be the cause of this low water transparency. This result corroborates those of Iltis and Lévêque (1982) on the coastal rivers of Côte d'Ivoire, Niamien-Ébrottié (2010) on the Soumié, Eholié, Ehania and Noé rivers and those of Salla (2015) on the Mé and Boubo rivers.

Taxonomic composition, occurrence and abundance of micro-algae: According to the micro-algal composition, the Comoé river can be considered as being rich in taxa. This taxonomic richness is linked to the enrichment of the water in nutrients, which is favourable to the development of several species of algae. Indeed, the number of taxa (190) inventoried in the Comoé is greater than those obtained by Ouattara (2000) in the Agnéby river (148 taxa), Da (2007) in the rivers of south-eastern Côte d'Ivoire (108 taxa) and Kouadio (2022) in the Bandama river (171 taxa). In addition, the stations in the central and southern zones are richer and more diverse. This would be justified by the structure (longitudinal gradient of physical conditions) of the river. The low richness of the upper reaches could be explained by the permanent renewal of the water, which does not favour the reproduction and development of algae. Downstream, the taxonomic richness is greater. The same observations have been made by Ouattara (2000), Niamien- Ébrottié (2010) and Dibong and Ndjouondo (2014) in other rivers. Furthermore, the microalgae community is dominated by Euglenophyta (31.05%), followed by Chlorophyta (28.94%), Heterokontophyta (26.84%), Cyanoprokaryota (11.57%) and Dinophyta (1.57%). This predominance of Euglenophyta, Chlorophyta and Heterokontophyta is thought to be linked to the favourable physico-chemical conditions (nutrient salts, temperature and transparency) of the environment at the time of sampling. According to the ecology described by Elif and Arif (2003), Euglenophyta proliferate in environments rich in organic matter. As for the Chlorophyta, which are typically thermophilic and photophilic (Sheath and Wehr, 2003), they would have been favoured by the temperature and illumination of the water.

According to Ebang *et al* (2012), diatoms tolerate low transparency, high mineralisation and high organic loads.Determination of the occurrence of the various taxa revealed 32 constant taxa, 72 accessory taxa and 86 accidental taxa. The high number of accidental taxa is due to the fact that most of the taxa collected are periphytic. They would have been accidentally torn from their supports by the water current at some point in their lives. As for the constant taxa, their low numbers reflect the dynamics of micro-algae in the river. These minority taxa would have had the capacity to adapt to the various climatic, hydrological and physico-chemical changes in the environment. Similar results were obtained by Kouadio (2022) on the Bandama, Salla (2015) on the Boubo and Mé rivers. A study of the abundance of micro-algae revealed a fairly abundant microflora. This abundance is greater in the lower and middle reaches. The high abundance is thought to be due to the fertilisation of the water in these areas. The river basin in the central and southern zones is home to vast village and industrial fields and plantations. Fertiliser residues and organic matter from these cultivated areas are thought to be responsible for enriching the water with nutrient salts that favour algal blooms. What's more, these high abundances occur during the dry seasons. This situation is linked to the low flow and relative stability of the water during these seasons, which favours algal development (Lavoie *et al.*, 2003). Also, according to Angelier (2000), phytoplankton communities become abundant and diversified in the pondweed where conditions favourable to their proliferation are present. Our results are similar to those of Niamien-Ébrottié (2010) during the short dry season in the Éholié, Éhania and Soumié rivers.

In addition, Cyanoprokaryota, which are rarely found in the upper reaches of the river, are relatively abundant in the central and estuarine zones of the river during the dry seasons. This high abundance can be explained by the fact that Cyanobacteria are characterised by very high ecological plasticity (Lévi *et al.,* 2006). Thanks to their great adaptability, Cyanoprokaryota colonise most freshwater aquatic ecosystems (Lavoie *et al.,* 2003). Our results corroborate those of Ouattara (2000) in the Agnéby river and Dibong and Ndjouondo (2014) in the Kambo and Longmayagui rivers in Cameroon. The Comoé river is home to a wide variety of algae. Diversity and taxonomic richness increase from upstream to downstream. The high abundances of algal populations were obtained during the dry seasons.

CONCLUSION

This study provided information on the floristic composition and spatio-seasonal dynamics of micro-algae in the Comoé River. A total of 190 taxa in 79 genera, 39 families, 23 orders, 10 classes and 5 phyla were inventoried. The most diverse phyla, in order of importance, were Euglenophyta with 59 taxa, Chlorophyta with 55 taxa and Heterokontophyta with 51 taxa. According to their frequency of occurrence, 32 constant taxa, 72 accessory taxa and 86 accidental taxa were counted. The high abundances of algal communities were obtained in the dry seasons at most of the stations. The lower river recorded the highest abundance thanks to the Chlorophyta, Cyanoprokaryota and Heterokontophyta. The lowest abundances were observed at the Kafolo station and the highest at Kokonou and Grand-Bassam. Over the entire watercourse area studied, maximum abundance was recorded in the dry seasons.

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