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Spatio-seasonal dynamics of microalgae from the Nonhon and Gninhin Rivers of the Cavally watershed (Côte d'Ivoire, West Africa)

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Abstract

The Nonhon and Gninhn rivers, in the west of Côte d'Ivoire, are under considerable pressure due to mining and agricultural activities carried out around them. This study therefore aims to know the composition, structure and dynamics of microalgae in said rivers. Thus, the micro-algal flora and the physicochemical parameters of these rivers were sampled every 45 days from 9 a.m. to 2 p.m. from October 2020 to February 2022. In total 103 taxa distributed between 30 genera, 20 families, 15 orders, 4 classes and 4 phyla were collected, of which the Euglenophyta phylum is more diverse. The Gninhin river records 100 taxa and that of Nonhon mentions 97 taxa. Abundance and species diversity are high in the two rivers during the main rainy and dry seasons in the Nonhon and Gninhin rivers respectively. Bacillariophyta dominate the micro-algal population whatever the river. The spatial-seasonal dynamics of microalgae revealed significant variations, with a peak in abundance during the long rainy season and the long dry season respectively in the Nonhon and Gninhin rivers. The spatio-seasonal results of chlorophyll a indicate a proliferation of microalgae during the rainy season compared to the dry season. The dynamics of microalgae from the Nonhon and Gninhin rivers evolve over time and depending on the stations.

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Introduction

Fresh water plays a vital role in development and constitutes an essential resource for life (Konan *et al.,* 2017). This treasure is a response to the primordial needs of man in various areas such as agriculture, fishing, irrigation, the supply of drinking water and also domestic uses (Diab, 2016). In Ivory Coast, according to Gourène *et al.* (1999) the demands of development have generated activities that increasingly pose threats to aquatic ecosystems. These activities certainly constitute an essential link in development through the advantages they offer to populations, but they still do not take place without inconvenience in the aquatic environment. The west of Côte d'Ivoire, specifically the departments of Danané and Zouan-Houmien, is the place of agricultural crops and mining activities. These activities threaten the balance of the ecosystems of several waterways, notably that of the Gninhin and Nonhon rivers. Taking into account the alterations caused by these anthropogenic activities on these ecosystems currently appears to be a major concern on a national scale. Among the aquatic organisms whose distribution and abundance are influenced by mineral and organic elements from the leaching of cultivated soils, by runoff water, microalgae figure prominently (Schlumberger and Bouretz 2002). The latter are known as organisms playing an important role in aquatic environments, through carbon fixation, oxygenation of water bodies, and as an important source of food for fish, zooplankton, etc. (Angelier, 2000). Despite their importance, microalgae in West African rivers are known only through few studies. In Côte d'Ivoire, the work carried out on rivers is that carried out by Iltis (1982a, 1982b and 1982c) on the Marahoué and Bandama rivers, Ouattara (2000) on the Agnéby and Bia rivers, Da (2007) on the Bia river, Niamien-Ébrottié (2010) on the Éhania, Éholié, Noé and Soumié rivers and Lozo *et al.* (2019) on the Bandama. No study on microalgae has been carried out in the Nonhon and Gnihin rivers. The ecological importance of this group and the lack of information on the diversity and dynamics of these microalgae justifies the interest of this work, the main objective of which is to determine the composition, structure and dynamics of microalgae in the Nonhon and Gnihin rivers in relation to environmental variables.

Specifically, this will involve: (1) characterizing the composition and dynamics of microalgae in these rivers, (2) determining the physicochemical parameters that influence microalgae dynamics.

Materials and methods

Description of the study area and sampling sites

The study area is influenced by two very individualized seasons: the dry season and the rainy season. The dry season is quite short (November to February), while the rainy season lasts from March to October with peak rainfall in September. According to Doffou (2019), anthropogenic activities carried out in the study area are dominated by agricultural and mining exploitation. Three sampling points were set on each river based on accessibility, the upstream-downstream gradient and the influence of anthropogenic activities. The characteristics of these sampling stations are recorded in Table 1.

Table 1. Characteristics of the sampling stations on the Nonhon and Gninhin rivers

Rivers	Stations	Geographical coordinates		Canopy (%)	Position
		North Latitude	Longitude west		
Nonhon	NO1	7°26’53,088”	8°18’16,42788”	52,85	Upstream
	NO2	7°26'54,91212"	8°18'21,89988"	53,57	Intermediate
	NO3	6°50'15,87012"	8°18'21,89988"	67,14	Downstream
Gninhin	GN1	6°50'15,87012"	8°6'49,57812"	35,00	Upstream
	GN2	6°50'14,442"	8°6'57,042"	28,89	Intermediate
	GN3	6°50'15,864"	8°6'59,112"	55,56	Downstream

Data collection

The micro-algal flora and the physicochemical parameters of these rivers were sampled every 45 days from 9 a.m. to 2 p.m. from October 2020 to February 2022.

Measurement of physicochemical parameters

At each sampling station, before sampling the microalgae, all the physicochemical parameters are sampled. Parameters such as temperature, pH, conductivity, dissolved oxygen, and transparency were measured in situ. The multiparameter was powered on approximately 5 minutes before the measurements. The probes were then immersed in water, then selecting the desired function (temperature, pH, conductivity and dissolved oxygen) made it possible to obtain the parameter value on the display screen. For transparency, the Secchi disk was immersed in the water column until it disappeared then slowly raised until it was visible. In addition, at each station, one liter of water was taken directly from the first layers of the water column for the determination of nutrients (nitrates, ammoniums and phosphates). Each water sample taken is kept cool, protected from light at 4°C and then transported to the laboratory for subsequent determination of nutrient salts (nitrates, ammoniums and phosphates) and organic matter (COD and DB05).

Sampling, observation, identification and enumeration of microalgae

Sampling was carried out using two methods: qualitative and quantitative according to Standard NF EN 15972 (2011). Qualitative sampling was carried out using a plankton net with a mesh size of 20 µm by filtration of 40 L of water drawn using a 10 L capacity bucket. After filtration, the filtrate collected in the net collector is kept in a pillbox and fixed with lugol then with formalin at the final concentration of 5%. Quantitative sampling was carried out by sedimentation of 10 L of water in a bucket. A water sample from each sample was kept in pill bottles with a capacity of 120 mL, then fixed with Lugol and formalin at the final concentration of 5%. The enumeration of diatomic species was carried out following the method of Utermöhl (1958). The 10 mL sedimentation tanks were filled with the collected samples and allowed to sediment for a period of 12 hours, then observed under an inverted microscope, using a 40x objective. The diametric strip method was used and all cells within a bottom diameter of the sedimentation dish were counted. Moving from one field to another is done without looking through the eyepieces in order to minimize bias in the results (Aktan *et al.*, 2005). In this study, only cells contained in the counting field were taken into account. The cell densities thus obtained were expressed as number of cells per unit volume for each taxon observed. The density (N) was determined according to the following formula:

$$D=N/(a/A) \times V$$

Where,

$a = C40x \times (R40x)^2 \times \pi$

N : Quantity of cells counted for a taxon;

a : surface area observed under the microscope;

C40x : number of fields observed at 40x;

R40x : field radius at 40x (0.25 mm);

A : surface area of the sedimentation dish where the cells accumulate (490.8 mm^2);

V : surface area of the sedimentation dish where the cells accumulate (490.8 mm^2).

Sampling, filtration and determination of chlorophyll biomass

The 250 mL water samples intended to measure chlorophyll *a* were collected in polyethylene bottles then wrapped in aluminum foil and stored in a cooler containing dry ice until the laboratory. Once in the laboratory, the samples taken were then filtered on Whatman GF/F filters with a mesh size of 0.7 µm using a vacuum pump. After each filtration, the filters were immediately immersed in a volume of 15 mL of a 90% acetone solution contained in a dark glass bottle wrapped in aluminum foil. The whole is kept cold and protected from light at a temperature of 4°C for 24 hours for the extraction of chlorophyll pigments. Chlorophyll a was extracted by centrifugation at 2000 rpm-1 for 15 minutes. The supernatant obtained is placed in a tank with an optical path of 1 cm. The

absorption is then measured at different wavelengths (665 and 750 nm) with a spectrophotometer, initially without acidification, then after acidification. Acidification destroys chlorophyll a without destroying other pheopigments. Chlorophyll biomass was obtained from the formula of Lorenzen (1967).

$$Chla = \frac{26{,}7 * (E_1 - E_2) * V}{l * V_g}$$

Where,

Chl*a* expressed in µg / L;

E1: absorbance before acidification (DO665 -DO750);

E2: absorbance after acidification (DO665 -DO750);

V: volume of acetone;

Vg: volume of filtered water;

l: length of the optical way of the curve (cm).

Data analysis

Microalgae community was analysed using: taxonomic composition, Shannon-Weaver index (H') (Quinn and Hickey, 1990), Pielou Evenness index (Piélou, 1966) (E) and population density (cells/L). Shannon-Weaver index was used to assess taxa diversity of phytoplankton. Evenness was used to show the organization of the structure, regardless of species richness. Calculations were performed using the vegan package (Oksanen *et al.*, 2013) for the R 3.0.2 freeware (R Core Team, 2013). FO is the percentage of samples in which each taxon occurred. It was calculated to classify the phytoplankton according to Dajoz (2000). Phytoplankton density was obtained by counting all cells per taxon and expressing the results as numbers of cells per liter. Before performing the comparison test, the normality of data was checked by Shapiro test. Variations in environmental variables and biotic index were determined using the Mann-Whitney Utest. A significance level 0.05 was considered.

ReDondance Analysis (RDA) was used to determine the effect of environmental conditions (abiotic variables) on the abundance of major phytoplankton taxa. Indeed, the RDA made it possible to summarize the different relationships that exist between the abundance of taxa and the main physical and chemical descriptors of the environment (Ter Braak and Smilauer 2002). The relevance of this analysis is first verified using a Monte Carlo permutation test (Manly, 1994) on 199 random permutations (McQuoid and Godhe, 2004). The influence of the environment on phytoplankton in the two rivers was in fact studied through 12 physical and chemical variables. These are nitrates, dissolved reactive phosphate, dissolved reactive silica, water transparency, water temperature, conductivity, pH, dissolved oxygen, salt level dissolved, ammonium, chemical oxygen demand (COD) and biochemical oxygen demand (BOD5) In order to reduce the amplitude of fluctuations and ensure the linearity of the relationships between biotic variables.

Results

Spatial-seasonal variations of physico-chemical parameters

Table 2 and 3 present the spatial-seasonal variations of physico-chemical parameters in the Nonhon and Gninhin rivers. In the Nonhon River (Table 2), the temperatures recorded are between 23.2°C (station 2; dry season) and 26.2°C (station 3; rainy season). The pH values (Table 2) vary between 2.87 (station 2; rainy season) and 11.12 (station 3; dry season). The minimum (17 µS/cm) and maximum (140 µS/cm) value of conductivity (Table 2) are observed respectively at stations 1, dry season and 2, rainy season. The dissolved oxygen levels in the different stations (Table 2) have a range of variations between 0.69 mg/L (station 1, dry season) and 5.58 mg/L (station 2, rainy season). The maximum (77.1 cm) and minimum (2.6 cm) values of transparency (77.1 cm) are observed during the rainy season at station 3 (Table 2). The high nitrate content (15.1 mg/L) and the low content of this parameter (4.9 mg/L) are observed during the rainy season at station 1 (Table 2). Ammonium concentrations (Table 2) vary from 0.21 mg/L to 0.8 mg/L (station 3; rainy season). The silica contents (Table 2) vary between 4 mg/L (station 1; rainy season; dry season and station 2; rainy season) and 16 mg/L (station 3; rainy season). The maximum content (0.18 mg/L) of phosphate (Table 2) was obtained during the rainy season (station 3).

Table 2. Spatial-seasonal variations of physico-chemical parameters in the Nonhon river in western Côte d'Ivoire (NO=Nonhon River; S=dry season; P=rainy season; 1, 2, 3 = Station number)

Stations	Nonhon river											
	NO1P		NO1S		NO2P		NO2S		NO3P		NO3S	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Temperature (°C)	24.7	26.07	23.7	25.14	24.5	25.87	23.2	25.35	24.6	26.2	23.4	24.49
pH	5.76	8.75	6.2	10.75	2.87	8.56	6.6	10.29	6.57	8	7.08	11.12
Conductivity (µS/cm)	36	84	17	95.2	18	140	18	91.7	20	38	20	93.7
Dissolved oxygen (mg/L)	1.2	4.2	0.69	3.54	2.8	5.58	1.52	3.44	1.2	5.85	2.21	3.68
transparency (cm)	3.1	73.5	8.1	46.2	12.6	67.6	17.2	44.7	2.6	77.1	26.4	47.1
Nitrates (mg/L)	4.9	15.1	4.8	11.6	5.3	13.7	5.1	9.2	6.1	14.1	5.7	10.4
Ammonium (mg/L)	0.36	0.7	0.26	0.33	0.29	0.78	0.29	0.41	0.21	0.8	0.3	0.52
Silice (mg/L)	4	13	4	11	4	12	7	14	5	16	5	14
Phosphates	0.04	0.1	0.05	0.05	0.05	0.14	0.04	0.1	0.04	0.18	0.06	0.08
DCO (mg/L)	17.3	38.9	13.6	16.2	19.2	40.8	14.1	20.8	15.5	40.6	14.6	16.9
DBO5 (mg/L)	7	14	5.5	9.5	6	19.5	6	12.5	6.5	17	5	10.7

Table 3. Spatial-seasonal variations of physico-chemical parameters in the Gninhin river in western Côte d'Ivoire (GN=Gninhin River; S=dry season; P=rainy season; 1. 2. 3 = Station number)

Stations	Gninhin river											
	GN1P		GN1S		GN2P		GN2S		GN3P		GN3S	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Temperature (°C)	26	29.6	25.96	29.53	26.5	31.7	29.61	30.04	25.9	31.52	30.04	34.9
pH	5.4	10.24	7.51	7.9	6.7	8.28	7.86	7.96	5.49	7.29	7.66	7.84
Conductivity (µS/cm)	51	261	31	134	59	111	26	74	11.3	172	36	85
Dissolved oxygen (mg/L)	0.4	4.36	3.56	3.77	0.7	2.81	3.14	5.95	2.2	4.7	2.66	5.5
transparency (cm)	0.02	54	0.01	66.2	0.03	44	45.2	136.3	0.02	31	1.4	37.8
Nitrates (mg/L)	6.3	15.1	8.2	9.1	5.2	13.1	14.3	17.6	6.7	20.4	21.2	24.2
Ammonium (mg/L)	0.08	0.68	0.38	0.38	0.21	0.41	0.44	0.55	0.26	18	0.47	0.71
Silice (mg/L)	4	12	9	16	4	13	9	12	3	13	10	18
Phosphates (mg/L)	0.11	0.14	0.06	0.12	0.05	0.18	0.12	0.21	0.06	0.26	0.09	0.23
DCO (mg/L)	14.8	31.4	18	20.3	14.6	27.8	18.1	20.3	17.3	31	23.8	26.5
DBO5 (mg/L)	4	10	9.5	12.9	6.5	12.5	11.7	17.3	4	14.5	14.5	19.1

The minimum content (0.04 mg/L) of this parameter was recorded at stations 1 and 3 (rainy season) and at station 2 (dry season). The high value of COD (Table 2) was recorded during the rainy season at station 2 and the low value was obtained at station 1 in the dry season. Biochemical oxygen demand (BOD5) concentrations (Table 2) range between 5 mg/L (station 3; dry season) and 19.5 mg/L (station 2; rainy season). Regarding the Gninhin River, the temperature values (Table 3) fluctuate between 25.9°C (station 3; rainy season) and 34.9°C (station 3; dry season). The pH values (Table 3) oscillate between 5.4 and 10.24 (station 1; rainy season). The recorded conductivity values (Table 3) are between 11.3 µS/cm (station 3) and 261 µS/cm (station 1) during the rainy season. Dissolved oxygen levels (Table 3) vary between 0.4 mg/L (station 1; rainy season) and 5.95 mg/L (station 2; dry season). The transparency values (Table 3) fluctuate between 0.01 cm (station 1) and 136.3 cm (station 2) in the dry season. The highest nitrate concentration (24.2 mg/L) was recorded at station 3 (dry season) and the lowest (5.2 mg/L) was obtained at station 2 (rainy season). Ammonium concentrations (Table 3) are between 0.08 mg/L (station 1; rainy season) and 0.71 mg/L (station 3; dry season). The silica concentrations (Table 3) present a range of variation oscillating between 3 mg/L (rainy season) and 18 mg/L (dry season) at station 3. The phosphate values (Table 3) vary between 0, 05 mg/L (station 2; rainy season) and 0.26 mg/L (station 3; rainy season). The highest COD value (Table 3) (27.8 mg/L) and the lowest value (14.6 mg/L) were recorded at station 2 in the rainy season. The BOD5 concentrations (Table 3) vary between 4 mg/L (station 1 and 3; rainy season) and 19.1 mg/L (station 3; dry season). The values of the physicochemical parameters do not vary significantly at the spatio-seasonal level (Kruskall-Wallis test, $P > 0.05$).

Table 4. List of microalgae taxa listed in the Nonhon and Gninhin rivers (NO= Nonhon river; GN= Gninhin river; Acro = Acronyms; 1, 2, 3= Number of stations; Presence = *)

Taxa		Nonhon			Gninhin		
	Acro	NO1	NO2	NO3	GN1	GN2	GN3
Cyanoprocaryota							
Cyanophyceae							
Chroococales							
Chroococcaceae							
Chrococcus limenticus Lemmermann	Chli			*	*	*	
Chrococcus sp.	Chsp	*		*			
Nostocale							
Nostocaceae							
Aphanizoenon issatschenkoi (Bocher)	Apiss					*	
Pseudanabaenales							
Pseudanabeanaceae							
Pseudanabaena galaeta Böcher	Psga		*				
Pseudanabaena limnetica (Lemmermann) Komârek	Psli				*		
Chlorophyta							
Zygnematophycidae							
Desmidiale							
Closteriaceae							
Closterium cf. *dianae* Ralfs	Cldi						*
Closterium cf. *gracile* Brébisson ex Ralfs	Clgr	*					
Closterium cf. *macilentum* Brébisson	Clma			*			
Closterium cf. *parvulum* Nageli	Clpa				*	*	
Closterium directum Archer	Cldi	*				*	
Closterium sp.1	Cls1				*	*	
Closterium sp.2	Cls2		*			*	
Closterium sp.3	Cls3			*			*
Closterium sp.4	Cls4						
Closterieum sp.5	Cls5			*		*	
Euglonophyta							
Euglenophycea							
Euglenales							
Euglenaceae							
Euglena polymorpha Dangeard	Eupo						*
Euglena proxima Dangeard	Eupr	*		*	*	*	*
Euglena sp.1	Eusp					*	
Euglena sp.2					*		
Euglena sp.3						*	*
Tranchelomonas cf. *angustispina* Elegans Bourrelly	Tran				*	*	*
Tranchelomonas cf. *horrida* Moenacanthum skvortzov	Trho				*	*	
Trachelomonas cf. *kellogii* H.Brand	Trcke				*		
Trachelomonas oblonga Lemmermann	Trob				*	*	*
Trachelomonas pisciformis var.bicoronata Couté & Iltis	Trpis					*	
Trachelomonas similis Stokes	Trsi						*
Trachelomonas sp.1		*			*		
Trachelomonas sp.2						*	
Tranchelomonas sp3				*			*
Trachelomonas superba Swirenko	Trsu				*		
Trachelomonas volvocina Ehrenberg	Trvo				*		
Strombomonas pigarroi Y. Zalacar Domitrovic	Stolo				*		
Strombomonas verrucosa var. zmiewika (Svirenko) Deflandre	Stve					*	
Phacaceae							
Lepocinclis acus (Otto. Friedrich. Müller) Ehrenberg	Leac				*	*	*
Lepocinclis cf. *caudata* (A. M. Cunha) Pascher	Leca			*	*	*	
Lepocinclis cf. *texta* (Dujardin) Lemmermann	Lete			*	*	*	*
Lepocinclis ovum (Ehrenberg) Lemmermann	Leov			*	*	*	*
Lepocinclis sp.1	Les1				*	*	
Lepocinclis sp.2	Les2					*	
Lepocinlis sp .3	Les3						*
Lepocinclis sp.4	Les4	*					
Lepocinclis sp.5	Les5				*		
Lepocinclis sp.6	Les6						*
Lepocinclis sp.7	Les7	*					
Lepocinclis sp.8	Les8			*			

Lepocinclis sp.9	Les9	*					
Lepocinclis sp.10	Les10	*				*	
Lepocinclis sp.11	Les11			*			*
Lepocinclis sp.12	Les12			*			*
Lepocinclis sp.13	Les13			*			
lepocinclis sp.14	Les14	*		*			
Lepocinclis sp.15	Les15				*	*	*
Lepocinclis sp.16	Les16			*			
Lepocinclis sp.17	Les17	*	*			*	
Lepocinclis sp.18	Les18			*			
Lepocinclis sp.19	Les19						*
Lepocinclis sp.20	Les20	*	*		*		*
Lepocinclis sp.21	Les21						*
Phacus c.f *ranula* Dujardin	Phra				*		*
Phacus longicauda Lemmermann	Phlo					*	*
Phacus sp.1	Phs1				*		
Phacus sp.2	Phs2						*
Phacus sp.3	Phs3						*
Phacus tortus (Lemmermann) Skvortzov	Phto						*
Bacillariophyta							
Bacillariophyceae							
Licmophorales							
Ulnariaceae							
Ulnaria ulnaria (Kützing) Aboal	Ulul						
Fragilariales							
Fragilariaceae							
Fragilaria crotonensis Kitton	Frcr						
Stephanodiscales							
Stephanodiscaceae							
Cyclotella meneghiniana Kutzing	Cyme	*					*
Stephanodiscus astraea (Kutzing) Grunow	Stas	*				*	
Naviculales							
Stauroneidaceae		*	*				*
Craticula cuspidata (Kützing) Mann	Crcu				*	*	*
Stauroneis anceps Obtusa. Grunow	Stan		*				
Sellaphoraceae							
Sellaphora pupula (Kützing) Mereschkovsky	Sepu						
Pinnulariaceae		*	*	*	*	*	
Pinnularia brauniana (Grunow) Studnicka	Pibr		*	*			
Pinularia nodosa Ehrenberg	Pino	*					*
Pinnularia sp.1	Pisp		*			*	
Pinnularia sp. 2	Pisp					*	
Pinnularia sp. 3	Pisp				*		
Pinnularia sp. 4	Pisp	*	*				
Pinnularia sp .5	Pisp				*		
Pinnularia viridis (Nitzsch) Ehrenberg	Pivi				*		
Naviculineae							
Gyrosigma acuminatum (Kützing) Rabenhorst	Gyac	*		*	*	*	*
Gyrosigma sp.1	Gysp	*	*	*	*	*	*
Gyrosigma sp.2	Gysp	*	*	*	*	*	*
Navicula placentula (Ehrenberg) kutzing	Napl	*	*	*	*	*	*
Sellaphora pupula var. bacillarioides Grunow	Sepu						*
Stauroneis legument (Ehrenberg) Kutzing	Stle	*	*	*	*	*	*
Achnanthale							
Achnanthaceae							
Achnanthales tropica Hustedt	Actr		*			*	*
Sphaeropleale							
Scenedesmaceae		*	*	*	*	*	*
Cymbellale							
Gomphonemataceae					*	*	*
Encyonema silesiacum (Bleisch) Michael Dominic.Mann	Ensi						
Surirellale							
Surirellaceae							
Stenopterobia intermedia Heurck	Stin	*	*	*	*		*
Surirella capronii Brebisson & Kitton	Suca			*	*	*	*
Surirella tenera Gregory	Sute		*	*	*		*
Surirella sp.2	Susp	*	*	*	*	*	*

Surirella sp.3	Susp	*	*				
Cymbellale							
Cymbellaceae							
Placoneis elginensis (Krasske) Patrick	Plel					*	*
Total	103	25	17	26	37	40	41

Qualitative study of the micro-algal population

The micro-algal flora (Table 4) of the rivers explored is composed of 103 taxa divided into 30 genera, 20 families, 15 orders, 4 classes and 4 phyla. These phyla are made up of Euglenophyta, Bacillariophyta, Chlorophyta and Cyanobacteria. The phylum Euglenophyta with 53 taxa (51.45%) presents the greatest number of taxa. It alone represents more than half of the taxa listed during this study. The phylum Bacillariophyta and Chlorophyta present respectively 31 taxa or 30.09% and 14 taxa or 13.59%. Then come the Cyanobacteria, the least diverse phylum with 5 taxa or 4.85%. The genus *Trachelomonas* (11 taxa) is the most representative of the phylum Euglenophyta. The genus best represented among Chlorophyta is *Closterium* with 14 taxa. The *pinnularia* genus (8 taxa) is best represented among Bacillariophyta. Table 4 shows the distribution of microalgae classes in the different rivers explored. In all rivers, Euglenophyceae constitutes the most important class with 51.55%. This class is followed by diatoms with 30.9%. At the Nonhon river, the most diverse class is made up of diatoms, followed by Euglenophyceae with 51.55% and 37.11% respectively. Regarding the Gninhin river, the class Euglenophyceae predominates the composition of microalgae with 62%. It is followed by diatoms with 27%. Regarding the number of taxa per station, we note in the Nonhon river (Table 4), values which oscillate between 17 taxa (station 2) and 26 taxa (station 3). At the Gnihin river, the values are between 37 (station 1) and 41 taxa (station 3). Eight taxa are present in all samples collected in the Nonhon river (occurrence percentage of 100%) compared to 10 taxa in the Gnihin river. The floristic inventory reveals that the Gninhin river is the richest with 100 taxa compared to the Nonhon river with 97 taxa.

Quantitative study of the micro-algal population

Fig. 1 presents the results of the absolute abundance of microalgae in the two rivers explored. Regarding the Nonhon river, the highest abundance (9 x 106 cells/L) is noted at station 1 during the rainy season. On the other hand, the lowest value (3.6 x 106) is recorded at station 2 during the dry season. At the Gninhin river, the values oscillate between 0.25.106 and 3.2.106 cells/L respectively at stations 1 and 3 in the dry season. In the two watercourses explored, we note a clear domination of Bacillariophyta. This dominance is due to taxa such as *Gyrosigma acuminatum* (Kützing) Rabenhorst (Gyac), (Chli), *Pinnularia* sp1 (Pisp1) and *Stenopterobia intermedia* Heurck (Stin) (Nonhon river) and *Surerula* sp1. (Susp1), *Craticula cuspidata* (Kützing) Mann (Crcu), *Stauroneis legumen* (Ehrenberg) Kutzing (Stle) (Gnihin river).

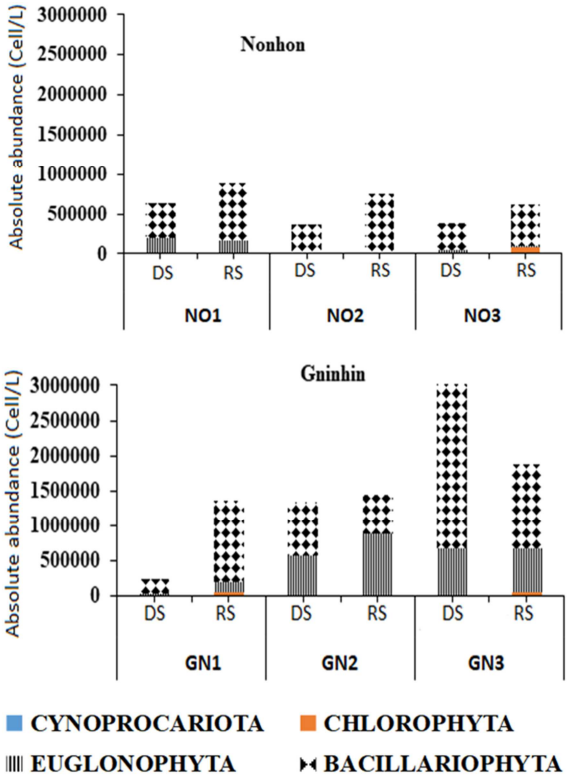

Fig. 1. Absolute abundance of phytoplankton branches in the Nonhon and Gninhin rivers (NO=Nonhon River; GN=Gninhin River; DS= dry season; RS= rainy season; 1, 2, 3 = Station number)

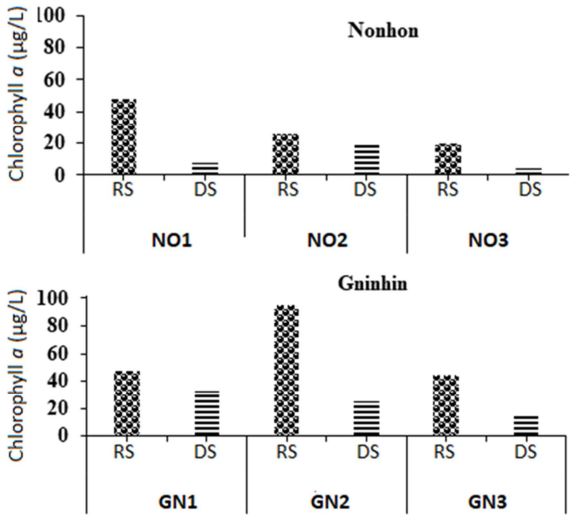

Fig. 2. Spatial-seasonal variations of chlorophyll a content in the Nonhon and Gninhin rivers (NO=Nonhon river; GN= Gninhin river; DS= dry season; RS= rainy season; 1, 2, 3 = Station number)

Fig. 2 illustrates the spatio-seasonal evolution of the chlorophyll a content within the two rivers studied. In the Nonhon river, the low (4 µg/L) and high (47.72 µg/L) values are obtained at stations 3 and 1 respectively during the dry and rainy seasons. Concerning the Gninhin river, the minimum (16.48 µg/L) and maximum (95.31 µg/L) values of the chlorophyll a content are noted respectively at stations 3 (during the dry season) and 2 (during the rainy season).

Diversity of microalgae

Fig. 3 presents the spatio-seasonal variations of the Shannon-Weaver index (H') and Evenness (E) in the Nonhon and Gnihin rivers. In the Nonhon river, the high value of the Shannon-Weaver index (H'= 2.15 bit/Cell) was recorded at station 1 during the rainy season and the low value (1.76 bit/Cell) was obtained at station 2 in the dry season. In terms of Evenness in this river, the values oscillate between 0.73 bit/Cell (station 3, dry season) and 0.82 bit/Cell (station 1, dry season and station 3, rainy season). Concerning the Gninhin river, the high values of the Shannon-Weaver index (H'= 2.7 bit/Cell) and Evenness (E = 0.81 bit/Cell) are recorded at station 2 during the dry season. On the other hand, the low values of Shannon-Weaver index (H'= 0.55 bit/Cell.) and Evenness (E= 0.46 bit/Cell.) are recorded at station 1 during the rainy season.

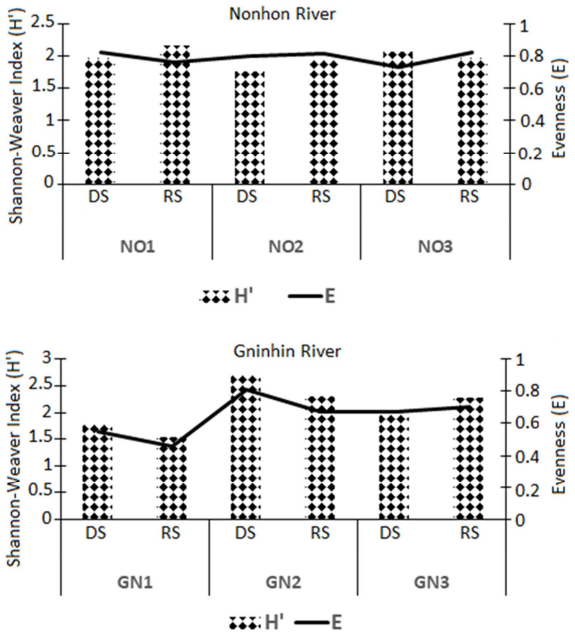

Fig. 3. Spatial-seasonal variations of the Shannon-Weaver index (H') and Evenness (E) in the Nonhon and Gninhin rivers (NO=Nonhon river; GN= Gninhin river; DS= dry season; RS= rainy season; 1, 2, 3 = Number of the station).

Influence of environmental parameters on microalgae abundances

The first axis of the RDA, Nonhon River, (Fig. 4) accounts for 68.77% of the total inertia. It is strongly positively correlated with transparency and conductivity. It contrasts stations where transparency and conductivity are high with stations with low transparency and conductivity. Axis 2 explains 0.62% of the variability. It is positively correlated with dissolved reactive phosphorus (DRP), BOD5, COD and NH4 while it is negatively correlated with TDS, pH and Silica (Si). Thus, it contrasts stations whose concentrations of dissolved reactive phosphorus (PRD), NH4, BOD5, COD are high with stations which have low concentrations of dissolved reactive phosphorus (PRD), NH4, BOD5 and COD. On this axis 2, the strong contributions are due to taxa such as Susp, Cls2, Gysp, Eusp, Actr and Stin. In addition, seasonal heterogeneity is more or less highlighted by the dispersion of the points.

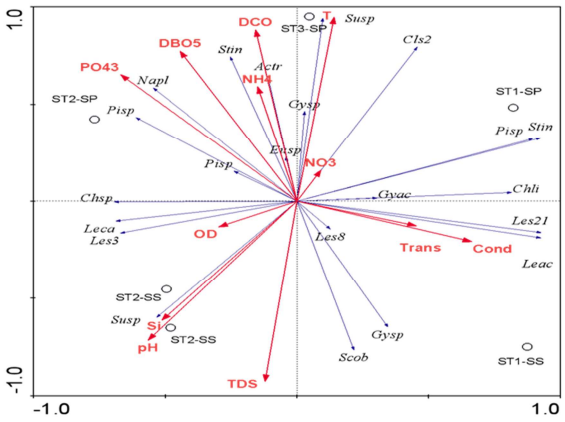

Fig. 4. Redundancy analysis carried out on 22 micro-algal taxa and 12 environmental variables from the Nonhon river (taxa acronyms identical to those defined in Table 4; Phosphat: Phosphate; TDS: Total dissolved solids; St: stations; 1 to 3: station number; SS: dry season; SP: rainy season)

Thus, in general, the rainy season samples are generally positively correlated with the second axis. On the other hand, the samples from the dry season are negatively correlated with this axis 2. On axis 1, the strongest contributions are due to the following species: Gyac, Chli, Pisp and Stin which reach their high abundances in the rainy season.

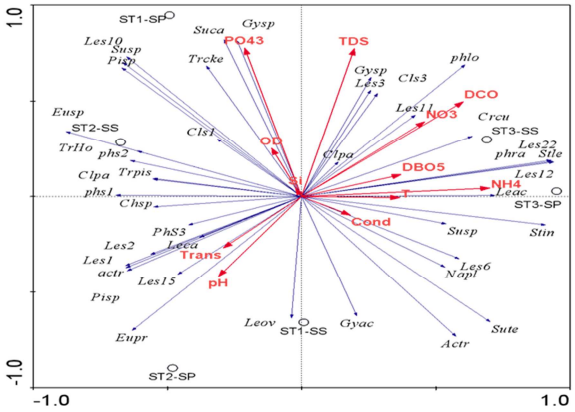

Fig. 5. Redundancy analysis carried out on 42 micro-algal taxa and 12 environmental variables from the Gninhin river (taxa acronyms identical to those defined in Table 4; Phosphat: Phosphate; TDS: Dissolved solid rate; St: stations; 1 to 3: station number; SS: dry season; SP: rainy season)

Regarding the Gninhin river (Fig. 5), the redundancy analysis showed that axes 1 and 2 provide 43.8% and 24.7% respectively. The distribution of seasonal observations is less clear. No season stands out clearly. Axis 1 is positively correlated with NH_4, Cond, BOD_5, COD and NO_3 and negatively with transparency and pH. It contrasts stations where BOD_5, COD and ammonium concentration (NH_4) are high with stations where BOD_5, COD and ammonium concentration (NH_4) are low. The dominant taxa at the positive part of the axis are: *Surirella* sp.2 (Susp), *Stenopterobia intermedia* (Stin), *Lepocinclis acus* (Leac), *Craticula cuspidata* Crcu, *Lepocinclis* sp.12 (Les12), *Stauroneis legument* (Stle) *Lepocinclis* sp.2 (Les2), *Phacus* cf. *ranula* (Phra). Two environmental parameters clearly appear in the definition of axis 2: these are dissolved reactive phosphorus and TDS, the highest values of which are found in the rainy season. On this axis, the strong contributions are due to taxa such as *Trachelomonas* cf. *kellogii* (Trcke), *Lepocinlis* sp.3 (Les3), *Gyrosigma* sp.1 (Gysp), *Lepocinclis* sp.1 (Les1).

Discussion

The qualitative analysis of phytoplankton populations shows that the Gninhin and Nonhon rivers can be considered rich in taxa. In fact, 103 taxa were inventoried in these two hydrosystems. The Gninhin River community presents a taxonomy dominated by Euglenophyta. This situation could be explained by the way the watershed is occupied.

Indeed, the presence of vegetation and the discharges generated by ore washing stations are likely to be loaded with organic matter, which would explain the predominance of Euglenophyta (Munawar, 1972; Dia and Reynaud, 1982; Kim and Boo, 1998). That of the Nonhon river also presents a taxonomy dominated by Bacillariophyta. Bacillariophyta are the most diverse autotrophic organisms in rivers since they have the possibility of colonizing all available surfaces. This ease of colonization could justify their predominance in the taxonomic composition of this watercourse. This dominance of Bacillariophyta was also noted by Cazaubon (1990) in the Agnéby River and in the fluvial zones of the Bia river, by Ouattara *et al.* (2000). As for phytoplankton densities, the highest

values are recorded during the rainy season. We note a dominance of Bacillariophyta whatever the seasons. This increase in density can be correlated with the physico-chemistry of the water and the chemicals used by gold miners. Indeed, station 1 presents, during periods of high density in the rainy season, the high temperature value which would favor the development of Bacillariophyta. This result corroborates the observations of Angelier (2000) according to which the development of phytoplankton is linked to the change in the conditions of their environment and to the speed of the current in temperate regions. In addition, the density observed during the rainy season could be explained by the existence of plantations whose maintenance requires fertilizers and pesticides near the Nonhon River. During periods of heavy rain, part of the water from this site flows into the river through overflow, inducing an enrichment of the phytoplankton in this water. This constitutes environments conducive to the proliferation of phytoplankton (Ouattara, 2000). These results are similar to those of Niamien Ebrottie *et al.* (2008) who observed a high density of phytoplankton during the rainy season in coastal rivers in the south-east of the Ivory Coast. The Shannon diversity and Equitability indices indicate that the phytoplankton population is quite diverse and regularly distributed in most of the surveyed stations. Such an observation shows that rivers host algal flora with varied ecological requirements (Wetzel, 1983). In addition, the physicochemical conditions of the environments which are quite diverse for the two rivers would contribute to the distribution of the taxa. The spatial-seasonal variations of phytoplankton biomass estimated by chlorophyll a showed that the highest values were obtained in the rainy season within the two rivers. Indeed, the high values recorded during the rainy period are due to increased nutrient inputs into the environment through soil leaching, which leads to high productivity.

These results are consistent with those of Pagès *et al.* (1979) and Mercado (2003), for whom the maximum chlorophyll a values were recorded during the rainy season.

Conclusion

At the end of this study, the microalgae population of the two rivers includes 103 taxa which are distributed between 4 phyla dominated by the phylum Euglenophyta (53 taxa). In the Nonhon river, the microalgae population is dominated by Diatoms with 51.55% followed by Euglenophyta (37.11%). the Gninhin river, on the other hand, records a population of microalgae dominated by Euglenophyta (62%) followed by Diatoms (27%). Concerning abundance, Bacillariophyta are the most abundant whatever the river and the season.

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