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Phytoplankton communities and trophic state of Lake Nokoué (South-East Benin)

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Abstract

This study was initiated on Lake Nokoué to update the phytoplankton data basis and determine its trophic state. For this, five sampling campaigns were carried out during five months from March to July 2019. Eleven sites were used to collect phytoplankton using a plankton net (diameter: 30 cm). Eight physico-chemical parameters were also measured and five dissolved salt analyzed. The ccommunity structure was performed through the diversity indexes and the Factorial Corrspondancy Analysis (FCA). In sum, a total of 6.472.106 cells/L representing 141 taxa (genera, species and varieties) belonging to 7 phyla, 16 classes, 41 orders and 56 families were collected. The different environmental parameters of the lake indicated a high eutrophication especially in the sites under the influence of the Ouémé River and the Cotonou channel due to nutrient inputs from its tributaries and anthropogenic actions. This physicochemical quality of the lake is related to the predominant phyla such as Diatomophyta, Chlorophyta, Cyanophyta and Euglenophyta, which are mostly pollution indicators. The feable rate of constant species and low diversity observed confirmed the alarming state of this lake that must arouse consciousness for sustainable management actions for its restoration.

Keywords: Communities, Phytoplankton, trophic level, Lake Nokoué.

Introduction

Continental aquatic environments provide a variety of goods and services to humans, which gives them irreplaceable economic value. In fact, these aquatic ecosystems shelter diverse groups of organisms interacting with each other and with their habitats. Each of them, through its ecological niche and regardless of its size, plays a specific role in the functioning and the balance of the ecosystem. But in developing countries, the integrity of the aquatic ecosystems is threatened by the evacuation of the tons of wastes from cities and industries. These anthropogenic actions undoubtedly lead to a degradation of the water quality, a modification of populations and most often, a reduction in biodiversity (Adandédjan et al, 2017). The concrete examples today are the reduction in the size spectra of fish, the reduction of the mass capture, and even the abandonment of the fishing sector by local residents who become taxi drivers such as the motorcycle drivers, Zemidjan man, in Bénin (Adandédjan, 2012).

And the Lake Nokoué, one of the most productive lagoon in West Africa with an annual yield of around one ton per hectare against 290 kg/ha/year for all West African lagoons is unfortunately subjected to all kinds of pollution which are in the origin of its impoverishment (Lalèyè et al., 2003; Adandédjan et al., 2017). The activities that take place around this ecosystem are not without negative influence on the fauna and flora of this body of water. The increasing of the intensification of the fishing activities by local residents that demography is in permanent increase and the alarming acceleration of all the degradation processes of the natural environment pose a major risk of depletion of stocks (Niyonkuru and Lalèyè, 2010). The consequences of the lost of the biodiversity and the species' habitats alteration on the goods and services provided by ecosystems are at the first concerns of researchers, politicians and managers (Hooper et al. 2005). Consequently, their monitoring must be done through the evaluation of reliable and adequate indicators such as biological indicators (Barton et al., 2014). And the phytoplankton, abundant in fresh waters, is very sensitive to variations in the environment conditions (Houssou et al., 2015).

In addition, in continental waters, phytoplankton form the basis of the food chain and is responsible for primary production (Azam and Malfatti, 2007). Phytoplankton represents a remarkable compartment for the role it plays, not only in the aquatic environment, but also in all areas of our life: quality of the environment (oxygen), food (fish and seafood), well- being (health, beauty), industrial resource. Phytoplankton is therefore the basis of the building that constitutes all aquatic organisms (Groga, 2007, Nyamien-Ebratié et al., 2013). It can be considered as a reliable instrument for the monitoring and evaluation of the ecological quality of aquatic environments reflecting the average ecological condition of water and therefore can be used as an indicator of water quality (Dahdouh-Guebas, 2013).

Despite their importance, the massive growth of certain groups of phytoplankton can cause nuisances or present a risk to public health. For example, certain species of algae produce toxic substances which, when they are accumulated by filter-feeding organisms (e.g. fish, shrimp, etc.), are dangerous for humans who will then consume them (Groga, 2007; Ouattara et al. 2000). The role played by primary producers in the transfers, particularly of oxygen, between lakes and the atmosphere, and the consequences of its variations on the functioning of lake ecosystems consider phytoplankton populations as autotrophic producers. Thus, for a better understanding of the ecological functioning of Lake Nokoué, several works have been carried out. Among these, we can cite the works of Gnohossou (2006) on the role of benthic organisms in the trophic chain of Lake Nokoué, Hountogan (2015) on the phytoplankton diversity and ecological quality of Lake Nokoué and Adjahouinou (2012) on the phytoplankton diversity and the level of pollution of the waters of the Dantokpa collector. However, the knowledge on the quantitative evolution of the phytoplankton population and the primary production which is the guarantee of the

maintenance of the life of this lake remains rudimentary despite the research efforts done in this field. It is why this study, far to bring all responses, has focused attention on the determination of phytoplankton communities and the trophic state of Lake Nokoué. This work is a part of the BioSEL project (Biodiversity and Anthropic Pressures on the Living Aquatic Resources of Estuarine and Lagoon Systems in Southern Benin), that objective is to establish a plan for the sustainable management of lagoon and estuarine environments in South-Bénin.

Methodology

2.1. Study environment

Lake Nokoué, considered the largest water body in Bénin, covers an area of 150 km² (Niyonkuru and Lalèyè, 2010). It is limited to the North by the flood plain of the Ouémé and Sô Rivers, to the South by the Cotonou City, to the West by the Abomey-Calavi plateau and then to the East by the Porto-Novo Lagoon. (Figure 1). Located in the south-east of the country, between the parallels 6°20' and 6°30' North and the meridians 2°20' and 2°35' East, this lake extends over the departments of Ouémé, Atlantic and Littoral. This lake, 20 km long in its East-West direction and 11 km wide in its North-South direction, represents the largest lagoon water body in the Republic of Benin and the most important. (Lawani, 2013). The lake is connected in its southern part to the Atlantic Ocean by the Cotonou Channel from which it receives marine intrusion. Connected also to the Porto-Novo Lagoon by the Totchè Channel, this lake is supplied with fresh water by the Ouémé River and the Sô River (Niyonkuru and Lalèyè, 2010; Bossou, 2013). Equally, it receives the influences of wastewater from the rain water collectors of Abomey-Calavi, Cotonou (Mama, 2010). According to Adouvo (2001), the bottom of the lake is mostly muddy on its western side and in the deep areas of the center. Sandbanks are observed in the shallow coastal areas of the South and East, particularly near the Ouémé delta (Adounvo, 2001).

The vegetation around and in the lake can be divided into two groups of plants that depend on the alternation of seasons controlled by a decrease and an increase of the salinity (Lawani, 2013). The species of periodically flooded areas classified into 2 subgroups; firstly, those which tolerate salinity changes such as *Paspalum vaginatum*, *Cyperus articulenius* and *Phragmites australis* and secondarily, those which only develop in fresh water such as *Eichornia crassipes*, *Crotalaria retusa*, *Penisetum polystachion* and *Pista stratiotes*. Among these plants, the case of *Eichhornia crassipes* (water hyacinth) is the most worrying because of its growth rate and its rapid invasion of the lake during floods.

In this lake, Niyonkuru (2001) has inventoried 50 species of fish belonging to 46 genera divided into 33 families and 10 orders. Two years later, Lalèyè et al. (2003) identified 51 species belonging to 47 genera distributed in 34 families and 10 orders. Fishing is a main activity for many communities living around this ecosystem such as the Tofinou, the Wémènou and the Xuéda people who use a wide range of fishing gears and techniques (cast nets and gill nets, etc.). These communities also practice agriculture for subsistence with as principal cultivation, maize, yams, haricot, beans and greens during the fall. Rice cultivation is practiced near the mouth of the Ouémé River and in the “Aguégués” area.

2.2. Samplinsg sites

Eleven (11) sampling sites were chosen on Lake Nokoué for the study (Figure 1) and identified using a Global Positioning System (GPS model GPS MAP 64s). A lot of criteria have lead us in the choice such as the geographical location, the intensity of the fishing activities, the importance of human activities due to human concentration in the proximity villages and the salinity gradient. The sites were separated from each to other to ensure the representativeness of the data (Figure 1). Also, these different sites have already been used in previous studies (PHD thesis and Master's theses) carried out in the laboratory. Among these 11 sites, 8 of them have already been used for

phytoplankton studies in the master's degree study.

Six (06) sampling campaigns were carried out monthly from March to August 2019. In addition, no sampling campaign was carried out this period to avoid distortion in the homogeneity and representativeness of the data (Hountogan, 2015; Hain et al., 2022).

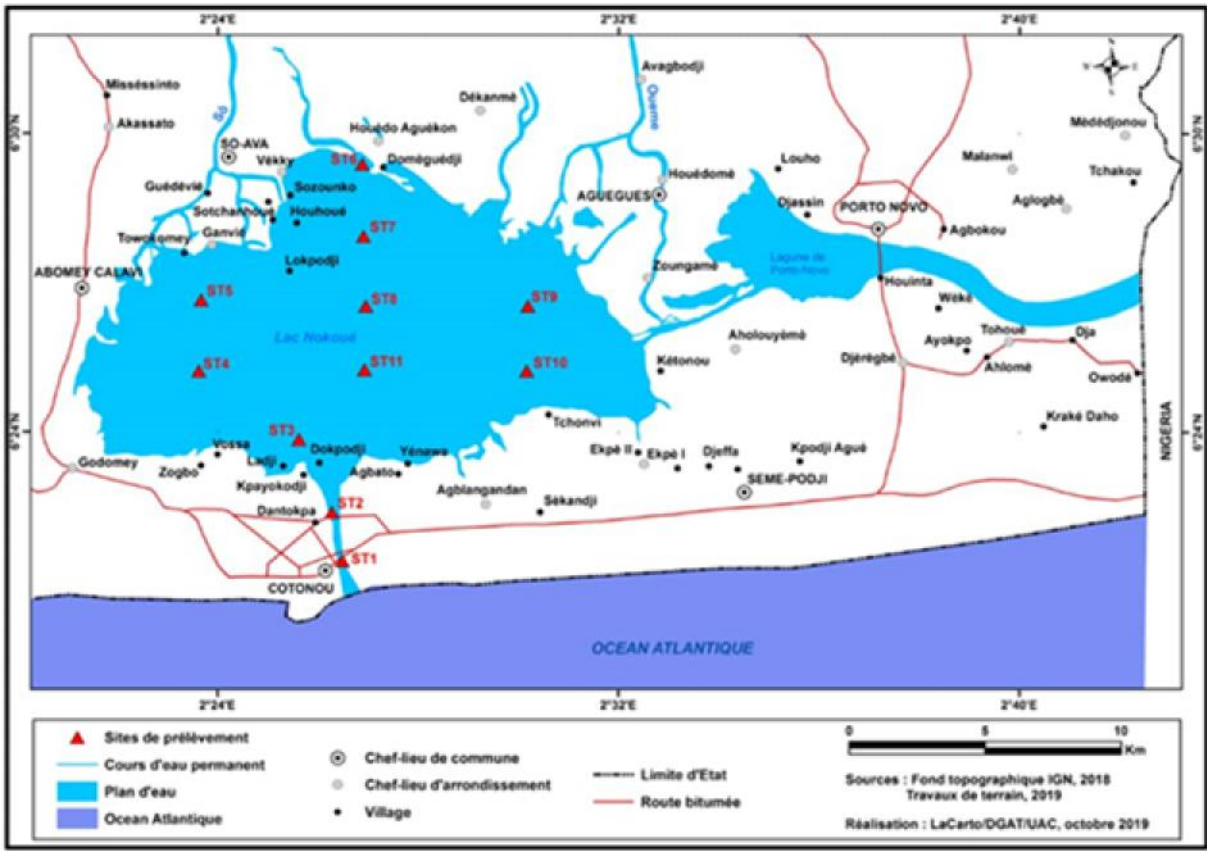

Figure 1: Study environment and sampling sites.

2.3. Sampling

2.3.1- Physico-chemical parameters measurements

Eight (08) physico-chemical parameters of water were measured *in situ* between 7 h and 9 h. There were dissolved oxygen, oxygen saturation rate, water temperature, pH and salinity measured with a multimeter model SX736 pH /mV/ Conductivity/ DO Meter.The water transparency and the depth at each site were measured with a Secchi disc fitted with a graduated rope. The water velocity was determined using a float and a chronometer. The temperature, the dissolved oxygen, the salinity and the pH were measured with the device which, previously calibrated and switched on a few minutes before any manipulation. The probe was then immersed in the water and selection of the appropriate function allowed to display the value of the parameter concerned on the screen. For Water velocity (Vs), we timed the time a float took to cover a distance of 1m measured with a decameter. This exercise was repeated three times and the water velocity the distance done (1 m) divided by the average time (in seconds) (Adandédjan, 2012).

Water samples taken at each site and kept in coolers to avoid any degradation have brought back in the laboratory. These samplings have served to immediately analyze dissolved salts such as total phosphorus Pt, phosphates (PO43-), nitrites (NO2-), nitrates (NO3-) and ammonia (NH4+) at the Applied Hydrology Laboratory (LHA) of the National Water Institute (INE) of the Faculty of Technical Sciences (FAST) at the University of Abomey-Calavi. Two (02) serials of analyses have been done in March and June.

2.3.2 –Algae sampling and identification

Phytoplankton samples were collected at the various sampling sites during the study period in the euphotic zone using a plankton net (30 µm mesh, 13 cm radius). First, at each site, samplings were carried on a vertical line and on a horizontal line, in order to have enough materials for taxonomic identifications. Finally, the sample of 10 L of water was taken using a Vandorn bottle and filtered; the concentrate was placed in a pillbox of 100 mL and fixed in formalin, 5%. This last sampling was done for the density calculation.

Identification phase was processed. For this, two drops of water containing the phytoplankton species are taken using a Pasteur pipette after homogenization. The drops of water from the concentrate are placed between slide and coverslide and observed under a microscope at magnifications 10 and 40. This identification was made at the Laboratory of Hydrobiology and Aquaculture (LHA) of the University of Abomey-Calavi using the following identification keys:Bourrelly (1966, 1968, 1970), Iltis (1980), Ouattara (2000)and Alexis *et al*. (2013 and 2015).

2.3.3. Quantitative analysis of phytoplankton

The technique consists in counting the different species present on a simple or inverted light microscope after sedimentation or not of the sample. For this, from the water samples fixed with formalin (5%) and readjusted to an identical volume of 15 mL, a 1 mL subsample was taken after agitation and homogenization; this subsample was placed on a counting cell of Neubauer type. This cell is mounted on a microscope. Finally, the species present were counted field by field: if the species were abundant, i.e. present in all the counting fields, the individuals were counted in a representative number of fields of the counting cell. The operation was repeated three times. But for species that were rare, the entire counting cell was scanned. This numeration was used to calculate the density.

2.4. Data analysis

2.4.1.- Environmental variables

The summary of the values of the physico-chemical parameters of the water obtained by sites was presented in a table 1. The averages, minimum (Min) and maximum (Max) values of each parameter were presented.

2.4.2. Estimation of the diversity

- Taxonomic richness S and variations: The taxonomic richness S is the number of species/genera/families of phytoplankton collected during the study. Its variations by site/month were presented in the form of boxplots.

- Frequency of taxa

The percentage of occurrence or frequency of taxa (F) was calculated for each species in order to underline their habitat preferences. It is determined by the relationship: $F = (Pa / P) \times 100$ with Pa = total number of samples containing the species taken into consideration and P the total number of samples taken. Depending on the F value, three groups of species were distinguished: constant species ($F \geq 50\%$); accessory species ($25\% \leq F \leq 50\%$); accidental and/or rare species ($F \geq 25\%$) (Dajoz, 2000).

- Density and variations of the main floristic families and species

Calculation of density and relative density Dr:

Phytoplankton density is calculated using the following formula:$D = (N/V) \div (1/Fc)$; with D = density or number of individuals per liter; N =

average number of individuals of the species counted; V = volume of the counting cells converted into liters; Fc = Concentration factor.Fc = V/v with V = volume of filtered water in liters and v= volume of filtrate converted into liters. The relative density (Dr in %) is the ratio between the density of the organisms in a sample or at a site and the density obtained at all the sampling sites.

Main plant families/species and variations

The main families and the main floristic species at each site/ month was determined by the family or the species having at least 5% of the relative density in a site/month.

- Biodiversity study

Two (02) diversity indexes were calculated to characterize the composition and evolution of phytoplankton. These ones were the Shannon and Weaver H' index and Piélou' Equitavility E.

The Shannon-Weiner index, H' was calculated per site and per month for taking account the organization of species and individuals within the plant community. If H' is close to 0, the community is not very diverse and if H' is between 3 and 4.5 bits, the community is relatively diverse. Its expression is: $H' = -\Sigma((ni/N) \times \log_2 (ni/N))$, where, ni = the number of the ith species and N is the total number of individuals in the sample.

- Pielou's Evenness E

The Equitability or Evenness of Pielou translates the degree of diversity reached by an environment. It corresponds to the ratio between the effective diversity (H') and the theoretical maximum diversity (H'max). It varies from 0 to 1 and we have:$0 \leq E \leq 0.6$: Weak equitability, strong dominance in the habitat; $0.7 \leq E \leq 0.8$: Mean evenness and if $0.9 \leq E \leq 1$: Strong equitability, No dominance in the habitat. $E=H/\log_2 S$

2.4.3. Determination of the primary production and the trophic state of the lake

- Determination of primary production

The determination of primary production amounts to calculating the concentration of chlorophyll a. Indeed, in the aquatic environment, chlorophyll is considered to be an indicator of algal biomass and productivity. Therefore, phytoplankton can be quantified by chlorophyll extraction (Hallegraeff, 1977), which is a fast, satisfactory and accurate method (Butterwick et al., 1982). In our study, the dosage of chlorophyll is carried out according to the monochromatic method at the Laboratory of Applied Hydrology.

- Determination of the trophic state

To characterize the trophic state of the lake, the system developed by the O.C.D.E, (1982) used by Groga (2012) (Table 2) and widely used at the international level, was chosen. This system combines the information concerning the nutrients state and the algal biomass. This system takes into account the following parameters (Yeutsch and Menzel, 1963).

- Total phosphorus (TP), a nutrient that limited concentration usually promotes the growth of algae and aquatic plants in continental environments. There is a link between the concentration of phosphorus, the productivity of the lake and its trophic level. Eutrophic lakes have a high concentration of phosphorus. It can be present in water either in particulate form or in dissolved form. As part of this study, only dissolved phosphorus was measured.

- chlorophyll a (Chl a) is an indicator of the biomass of microscopic algae present in the lake. The concentration of chl a increases with the concentration of nutrients. Eutrophic lakes often have an important production of algae integrated on the euphotic zone.

- water transparency or Secchi depth (measured with a Secchi disk) decreases with the increase in the amount of algae in the lake. Eutrophic lakes are characterized by low water transparency.

2.4.4.Statistical processing

2.4.4.1. Classification of stations according to floristic similarities

Factorial Correspondence Analysis (FCA) was applied using the presence-absence matrix of taxa with at least 5% occurrence at a site, in order to group the sampling sites according to their floristic similarities. The analysis was performed with Statistica version 6 software.

A hierarchical classification (ACH) was applied to gather samples that have a sufficient degree of similarity together in the same cluster. For quantitative variables representing descriptors of the environment, the Euclidean distance was retained (Dufrêne, 1992 in Adandédjan, 2012). The Ward method was used as an aggregation criterion. The result of this analysis is presented in the form of a dendrogram. Statistica version 6 software was used for this purpose. Acronyms used for taxa are recorded in Table 1.

Table 1: Acronyms of taxa used for CFA.

Taxons	Codes	Taxons	Codes	Taxons	Codes
Klebsormidium	klbsor	*Lyngbya*	lynori	*Stenopterobia* sp.	stenop
Monostroma sp.	monost	*Spirulina*	spirul	*Urosolenia* sp	uroson
Ulothrix sp.	ulotsp	*Rhizoclonium* sp.	rhizoc	*Lauderia annulata*	lauder
Ulothrix zonata	ulozon	*Ditylum* sp	ditylu	*Cyclotella*	cyclku
Closterium sp.	clossp	*Melosira*	melomo	*Cyclotella*	cyclme
Pediastrum duplex	pedidu	*Hyalodiscus*	hyalae	*Cyclotella* sp.	cyclsp
Tetraedron sp.	tetras	*Hyalodiscus*	hyarad	*Stephanodiscus*	stepha
Monoraphidium sp.	monora	*Chaetoceros* sp.	chaeto	*Stephanodiscus* sp.	stepsp
Oocystis sp.	oocyst	*Cocconeis*	coccon	*Ceratium*	ceratr
Pandorina sp.	pandor	*Biddulphia*	biddul	*Euglena gracilis*	euggra
Haematococcus	haemat	*Fragilariopsis*	fragsi	*Peridinium*	perium
Coelastrum	coelas	*Asterionella* sp.	astesp	*Peridinium* sp.	perisp
Actinastrum sp.	actina	*Gyrosigma* sp.	gyrosp	*Trachelomonas*	tracsu
Pediastrum sp.	pedisp	*Gyrosigma*	gyrosp	*Trachelomonas* sp.	tracsp
Chlorella vulgaris	chlore	*Petrodictyon*	petrod	*Trachelomonas*	tracst
Asterococcus sp.	astero	*Peroniopsis* sp.	peroni	*Phacus* sp.	phacus
Goniochloris gigas	gonioc	*Gomphonema*	gompho	*Hildenbrandia*	hilden
Vaucheria sp.	vauche	*Entomoneis* sp.	entome	*Rhizosolenia* sp.	rhizsp
Microcystis incerta	microc	*Amphora* sp.	amphor	*Rhizosolenia*	rhizos
Oscillatoria sp.	oscisp	*Diploneis* sp.	diplon	*Heribaudiella*	heriba
Oscillatoria limosa	osclim	*Nitzschia*	nitzve	*Ceratium* sp.	cerasp
Phormidium sp.	phormi	*Nitzschia*	nitsig	*Ceratium tripos*	certrp
Actinoptychus sp.	actino	*Nitzschia sigma*	nitzsi	*Ceratium longipes*	ceralo
Actinoptychus	actnsp	*Nitzschia* sp.	nitzsp	*Pinnularia viridis*	pinnul
Coscinodiscus	coscon	*Nitzschia*	nitzin	*Surirella robusta*	suriro
Coscinodiscus	cosrud	*Navicula*	navicr	*Thalassiosira* sp.	thalas

2.4.4.2. Determination of discriminant environmental variables of the communities

A Principal Component Analysis (PCA) was performed on the matrix of environmental variables to help determine the variables that explain the observed station distribution. The result is a correlation circle showing the projection of the variables in the design. Finally, a discriminant factor analysis (DFA) was applied to better identify the discriminant parameters of the different communities identified by the FCA. The matrix used was made of 13 variables (13 columns) * 11 rows (11 stations). Statistica version 6 software was used.

2.4.4.3. Comparison tests

During this analysis, the Ryan Joiner test was applied to test the normality of the distribution of the physico-chemical parameters measured on Lac Nokoué during the study period in order to guide the comparison tests. When the distribution is normal, the ANOVA test was used. Otherwise, the Kruskal-Wallis non-parametric test was used. These tests were applied to test the variability of parameters between sites and months. Statistica versus 6 software was used for these different analyses.

3. Results

3.1. Environmental parameters

The average and extreme values of the physical and chemical parameters of the Lake Nokoué have been determined and presented in Table 2. The Ryan Joiner test carried out on the environmental variables data showed a normal distribution ($p>0.05$) for all parameters with the exception of temperature, salinity, pH and depth which have a normal distribution ($p< 0.05$).

Table 2: Average and extreme values of the physico-chemical parameters of Lake Nokoué

Legend: Anova Test for all parameters and Kruskal-Wallis Test for depth, salinity and temperature. ST1, ST2, ST3, ST4, ST5, ST6, ST7, ST8, ST 9, ST10 and ST 11 are the codes of the sites. The units of the parameters are: temperature (°C), profounder (m), transparency (cm), salinity (g/L), dissolved oxygen (mg/L), Saturation in oxygen (%) and NO3-, NO2-, NH4+, PO43- and Pt in (mg/L).
NS=non-significative:*=p<0.05;**=p<0.01;***=p <0.001.

Parameters	Means	Minimum			Maximum			Variations	
		Values	Sites	Months	Values	Sites	Months	Sites	Months
Water Temperature	28.8	25.1	ST5	Juillet	32.9	ST7	Avril	NS	***
Profounder	1.88	0.88	ST3	Juillet	5,90	ST2	Mars,	***	NS
Transparency	72.84	7	ST10	Juin	167	ST11	Mars	NS	***
pH	7.52	6.35	ST3	Juin	8,70	ST11	Mai	NS	***
Salinity	11.3	0	ST6,	Juillet	36	ST1	Juillet	***	*
dissolved Oxygen	7.27	3.61	ST9	Mai	9,53	ST6	Avril	NS	***
saturation in	88.80	40	ST2	Juillet	94,4	ST6	Avril	NS	***
Nitrates NO_3-	6.36	1.70	ST9	mars	17,7	ST3	Juin	NS	**
Nitrites NO_2-	0.40	0.01	ST10	Mars	1,99	ST9	Juin	NS	**
Ammonium NH_4+	0.39	0.01	ST10	Mars	1,29	ST10	Juin	NS	*
Phosphates $PO_4$3-	0.31	0.07	ST4	Mars	1,29	ST10	Juin	NS	*
Phosphore total Pt	3.02	0.13	ST6	Mars	8,70	ST4	Mars	NS	**

3.2. Taxonomic composition of phytoplankton

The inventory of Lake Nokoué phytoplankton taxa during the study is presented in Table placed in annex. In total, 141 taxa (genera and varieties) were identified which belong to 7 branches, 16 classes, 41 orders and 56 families. The branches identified were Diatomophyta, Chlorophyta, Cyanophyta, Euglenophyta, Chrysophyta, Pyrrophyta, and Rhodophyta.

The Diatomophyta were represented by four classes namely: Coscinodiscophyceae Diatomophyceae Mediophyceae and Phaeophyceae. The Chlorophyta were represented by 5 classes then the Pyrrhophyta and the Rhodophyta by two classes each (Table 3).

Three (03) branches presented a significant taxonomic richness (Figure 2) during the study. These are Diatomophyta (48.94%), Chlorophyta (22.70%) and Cyanophyta (11.35%).

Six (06) taxa (species, genera and varieties) were common to all stations. These are Heliopeltaceae, Melosiraceae, Achnanthaceae, Naviculaceae, Nitzchiaceae, Stephanodiscaceae all belonging to the Diatomophyta class (See Table in annex).

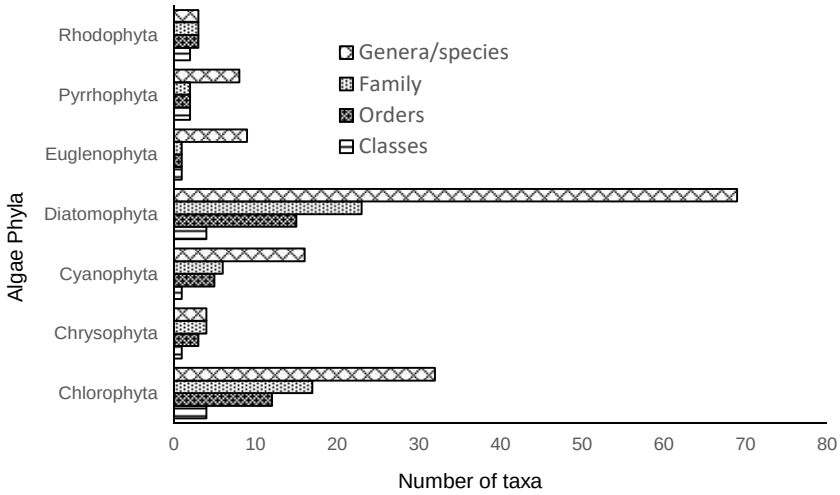

Figure 2: Richness of the different phyla of phytoplankton in the Nokoué Lake.

3.3. Taxa frequency

Only 8 families were constant, 11 secondary families and 37 families accidental or rare. Three (03) species were constant namely *Oscillatoria limosa*. *Coscinodiscus rudolfii* and *Cyclotella kuetzingiana*. Then, 8 species were secondary and 130 accidental species. Only constant, secondary and accidental species that had at least 5% of frequencywerelisted in Table 4 below.

Table 4: Occurrence algae species collected in the lake..

Espèces constantes	Espèces accessoires	Quelques espèces rares
Cyclotella kuetzingiana (67.27%)	*Cocconeis placentula* (43.54%)	*Stephanodiscus astraea* (23.64%)
Oscillatoria limosa (65.45%)	*Gyrosigma* sp. (36.36%)	*Haematococcus pluvialis* (23.64%)
Coscinodiscus rudolfii (56.36%)	*Oscillatoria* sp. (32.73%)	*Schizomeris* sp. (23.64%)
	Melosira moniliformis (30.91%)	*Eunotia bilunaris* (23.64%)
	Synedra fulgens (29.09%)	*Vaucheria* sp. (21.82%)
	Synedra ulna (27.27%)	*Cyclotella* sp. (21.82%)
	Pseudanabaena sp. (25.45%)	*Pediastrum duplex* (20%)
	Coscinodiscus concinnus (25.45%)	*Coscinodiscus radiatus* (18.18%)
		Zygnema sp. (18.18%)

3.4. Density and main taxinomic groups collected

A total of 6.472.106 cells/L were collected during the study. It is always the Diatomophyta which presented the highest densities (4 3361.106 cells/L). Then. Chlorophyta and Cyanophyta with respectively 804.106 cells/L and 764.106 cells/L were also important groups of the ecosystem. The less important such as Euglenophyta. Pyrrhophyta. Chrysophyta and Rhodophyta totalized respectively 22.107 cells/L; 16.107 cells/L; 144.106 cells and 44.106 cells/L.

Six classes were preponderant. These were Diatomophyceae (38.50%), Coscinodiscophyceae (15.76%), Mediophyceae (12.60%), Cyanophyceae (11.80%), Chorophyceae (6.36%) and Euglenophyceae (3.39%).Also, the Naviculales (18.54%), the Coscinodiscales (13.59%), the Thalassiosirales (12.60%), the Oscillatoriales (8.22%) and the Achnantales (6.36%) were the densest orders of the ecosystem.

Five families of phytoplankton were main (Nr ≥ 5%) during the study. These are the families of Stephanodiscaceae, Nitzschiaceae, Oscillatoriaceae, Naviculaceae and the Achnanthaceae family Also 2 other families were abundant, namely Rhizosoleniaceae (Nr=4.16) and Euglenaceae (Nr=4.02%). Finally, 29 families have less than 1% of relative abundance.

On the specific level, only 3 species were preponderant and 4 others have at least 2% relative abundance. Mention may be made of *Oscillatoria limosa* (Nr=4.97%); *Nitzschia sigmoidea* (Nr=3.29%); *Stephanodiscus astraea* (Nr=2.98%) and *Rhizosolenia imbricatum* (Nr=2.61%). In addition, 116 species (82.27%) of the taxonomic richness have less than 1% relative abundance.

3.5. Spatial and monthly variations in taxonomic richness and relative density of algae

The global taxonomic richness has been presented in table 1 of the inventory. Site ST1 totaled the highest richness, 60 taxa (species / genera and varieties) while site ST2, the lowest, 27 taxa (species / genera and varieties). Figure 4 presents the spatial variations of the lake's phytoplankton taxonomic richness (A) and relative density (B). During the study, this richness varied from 1 taxon at sites ST8 (in June) and ST9 (in April) to 11 taxa at site ST2 (May) without significant difference (Kruskal-Wallis test: p>0 .05) (Figure 3A).

But the monthly variations in richness were significant (Kruskal-Wallis test: p < 0.05%) (Figure 4A) and it was during the month of July that the most algal cells were collected, 96 taxa and the lowest richness in April, 70 taxa.

As for the relative density, it is the site ST1 which gathered the most cells. i.e. 628108 cells or 15.13% of the total abundance. The minimum density was obtained at site ST10 i.e. 4.82%. For all observations, the relative density evolved from 0.19% at site ST10 in June to 7.71% at siteST1 in July (Figures 4B). Neither the spatial variations nor the monthly variations of the relative density are significant (Kruskal-Wallis test: p>0.05)(Figures 3 and 4B).

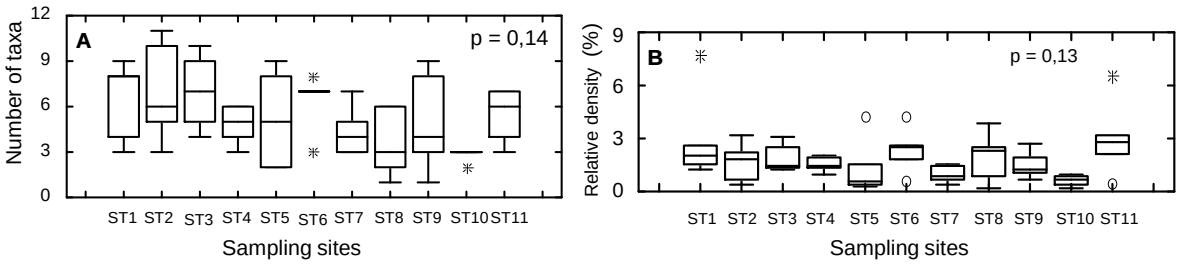

Figure 3: spatial Variations of thetaxonomic richness (A) and the relative density (B) of the algae.

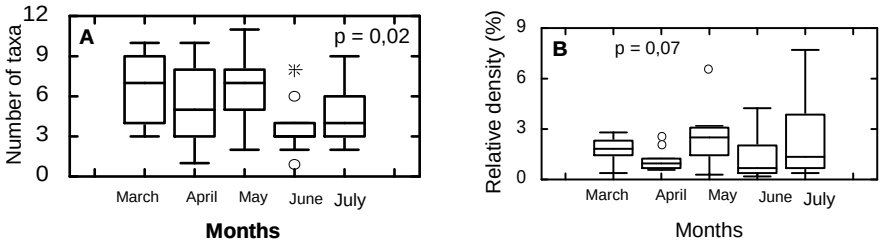

Figure 4 : Monthly variations of the taxonomic richness (A) and the relative density (B).

3.6. Spatial and monthly variations of the Shannon index and Piélou evenness

Figure 5 illustrated the spatial variations of the Shannon index, H' (A) and Piélou evenness, E (B). Also, the figure 6 A and B illustrates with respect, the monthly variations of the two indexes. The lowest H' (0 bits) was obtained at site ST8 in July and the highest (3.46 bits) was noticed at site ST9 in April without significant variation (Kruskal-Wallis test: p>0.05).

As for the Pielou's index E, it evolved from zero value at the ST8 site in April to 0.7 at the ST6 site in June (Figure 6.B) without significant variation (Kruskal-Wallis test: p>0. 05).

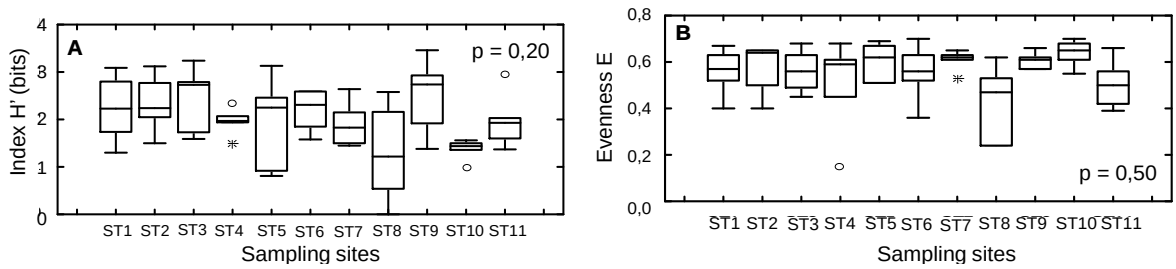

Figure 5: Spatial variations of Shannon index (H') and Piélou's evenness (E).

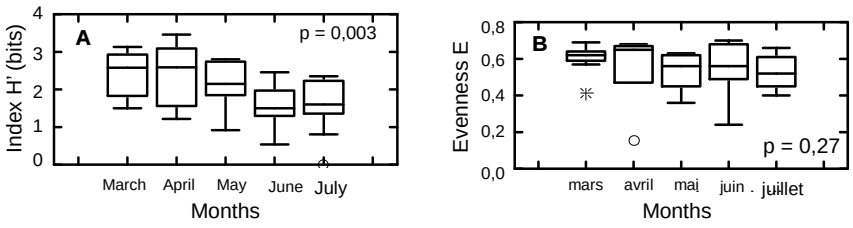

Figure : 6: Monthly variations of Shannon index (H') and Piélou's evenness (E).

3.7. Community structure

In total, a matrix of 94 columns (taxa) ×11 rows (sites) was used to project the variables into the factorial plane (F1, F2). Figure 7 presenting the result of the factorial analysis of correspondences based on the presence-absence matrix indicated that the first two factorial axes express respectively 32.10 and 20.03% of the total variability (Figure 7A). The AFC revealed that the different sites have a large part of their flora in common but are differentiated by a limited number of taxa which are characteristic of them (Figure 7B). However, the hierarchical classification (ACH) of the sites carried out on the first two axes of this AFC indicated an association of the sites into three groups (I. II and III) (Figure 7C). Group I brought together the stations close to the channel ST1. ST2 and ST3. The second group is composed of sites ST5. ST6 and ST9. As for the third, it is made up of sites ST4. ST7. ST8. ST10 and ST11. Overall, taxonomic richness varied significantly between groups (Kruskal-Wallis test. $p < 0.05$). Group I showed higher taxonomic richness (Mann-Whitney test. $p < 0.05$) than the other two assemblages (Figure 8A). But the abundance of algal cells did not change significantly from one group to another (Kruskal-Wallis test. $p > 0.05$). Figure 9 showed the correlation circle of the environmental variables governing the structure of the observed algal flora and Table 4, the result of the discriminant factor analysis. The F1 axis which explains 45.40% of the information (Figure 9A) is strongly correlated positively with water temperature and negatively with dissolved oxygen, oxygen saturation rate and dissolved salts. The F2 axis (34.29%) (Figure 9A) is strongly and positively correlated with parameters such as depth, transparency, current velocity and water pH. Five (05) water parameters best discriminated the observed distribution. These are salinity, dissolved oxygen, water depth, current velocity and nitrates (Table 5).

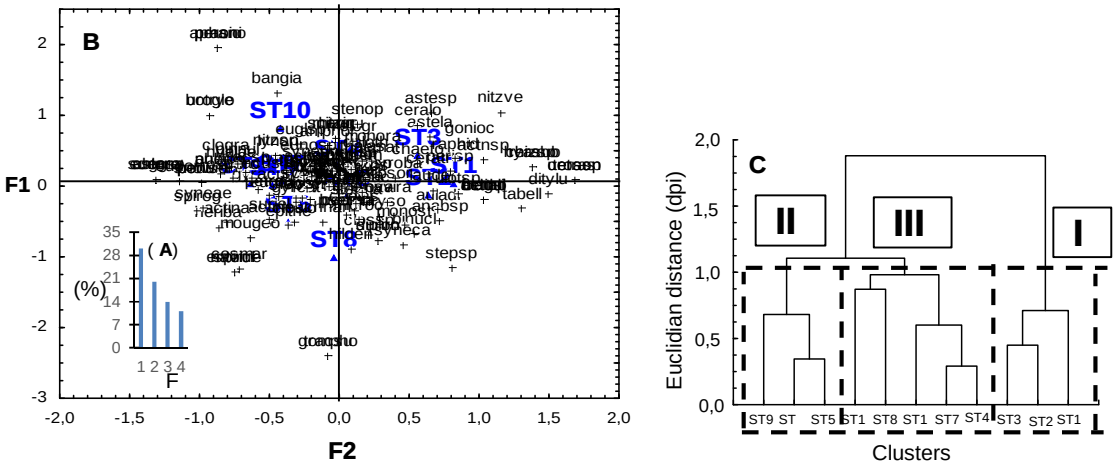

Figure 7: Factorial Correspondancy Analysis based on the presence-absence of taxa

A) histogram of main values of axis. B) distribution of sites and taxain the factorial plan F1 x F2 and C) Dendrogramme summarizing the faunal similarities between sampling sites. The taxa acronyms used are in the table 1.

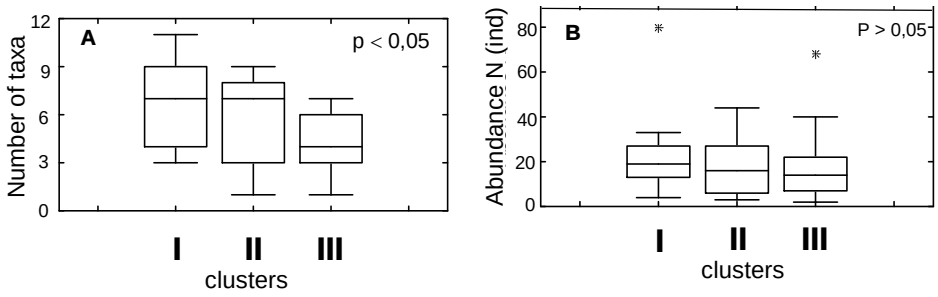

Figure 8 : Variations of the richness (A) and the abundance (B) of taxa into the clusters

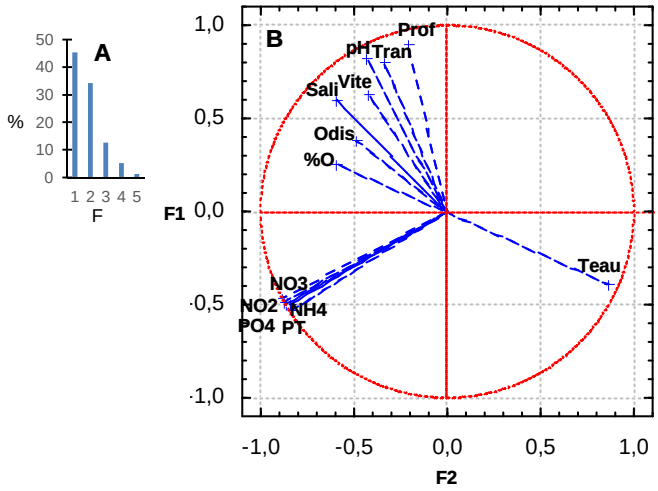

Figure 9: Corrélation circle of the environmental parameters.

Table5: Dicriminant variables of the classification of sites.

Effet	Tests Multivariés de Significativité (variances finale) Paramétrisation sigma-restreint Décomposition efficace de l'hypothèse					
	Test	Valeur	F	Effet dl	Erreur dl	p
Ord.Orig.	Wilk	0,107313	16,6371	2	4	0,011516
T°C surf	Wilk	1,000000		0		
pH surf	Wilk	1,000000		0		
Sali surf	Wilk	0,027055	71,9236	2	4	0,000732
O2 diss surf	Wilk	1,000000		0		
O2 % surf	Wilk	0,201442	7,9284	2	4	0,040579
Transp	Wilk	1,000000		0		
Prof	Wilk	0,005179	384,1730	2	4	0,000027
Vites	Wilk	0,206666	7,6775	2	4	0,042711
NO3-	Wilk	0,006496	305,8714	2	4	0,000042
NO2-	Wilk	1,000000		0		
NH4+	Wilk	1,000000		0		
PO43-	Wilk	1,000000		0		
PT	Wilk	1,000000		0		

3.8. Phytoplankton biomass (chlorophyll a) and trophic state of the Nokoué Lake

3.8.1. Phytoplankton biomass (chlorophyll a)

The minimum chlorophyll biomass (0.41 µg/L) was obtained in the three sites, ST2, ST3 and ST4. Also, the highest biomass value (28.22 µg/L) was noticed at ST8that corresponded to the lowest chlorophyll concentration observed at thissite (Figure 10).

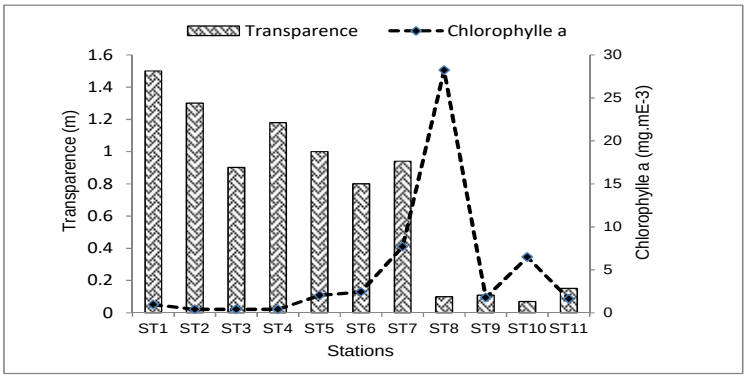

Figure 10: Spatial variation ofthe chlorophyllbiomass.

3.8.2. Determination of the trophic state of Lake Nokoué

During the study, various indicators were used to assess the trophic level of the lake waters such as total phosphorus, transparency and chlorophyll a concentration. Thus, on the basis of the Organization for Economic Cooperation and Development (0.C.D.E.) criteria, the sites ST1. ST2, ST3, ST4, ST5, ST6 and ST7 were eutrophic while the following sites, ST8, ST9, ST10 and ST11 were hypereutrophic (Table 6).

Table 6: Trophic state of Lake Nokoué during the study according to the criteria of the O.C.D.E. (1982)

Indicators	Sampling sites										
	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	ST11
Secchi (m)	1.50	1.30	0.90	1.18	1	0.80	0.94	0.1O	0.11	0.07	0.15
PT ($mg.m^{-3}$)	0.18	0.37	0.20	0.16	0.27	0.13	0.24	0.61	0.90	1.62	0.53
Chla ($mg.m^{-3}$)	0.95	0.41	0.41	0.41	2.03	2.43	7.7	28.22	1.76	6.48	1.62
Trophic state	Eut	Eut	Eut	Eut	Eut	Eut	Eut	Hyp	Hyp	Hyp	Hyp

Legend : Eut = Eutrophic. Hyp = Hypereutrophic. PT = Total Phosphora. Cha = Chlorophylle *a*.Secchi (m) = Water Ttansparency.

4. Discussion

4.1. Phytoplankton communities

This study on the phytoplankton community of the Nokoué Lake showed 141 taxa divided into 7 phyla, 16 classes, 41 orders and 56 families. This algae composition obtained is ahead of the results of Adjahouinou (2010), Goussanou et al. (2012) and Hountogan (2015) who had collected in the same lake, respectively; 39 , 47 and 52 species These differences could be explained by the different period of collecting data and the number of the sampling sites.

In fact, Hountogan (2015) had collected 10 sites in the lake during 4 months (from June to September). Our results are very similar to those of Hainet al. (2022) who has identified 160 species in the Porto-Novo Lagoon during 8 monthsof sampling (February to September). Similar work carried out by Nyamien-Ebrotiéet al. (2013) in the coastal river in the South-East of Côte d'Ivoire showed 196 species corresponding to the period from July to March. Our results suggest that the existing favorable periods of plankton proliferation in the environment that have been covered by these latest studies.

This identified phytoplankton community consists mainly of Diatomophyta (66.99%), Chlorophyta (12.42%) and Cyanophyta (11.80). Therefore, Diatoms constituted the esseential of the species constantly encountered in the samples. These results were found by Hountogan (2015) in this lake and alsoby Hainet al. (2022) in the Porto-Novo Lagoon. This dominance of diatoms in the algae composition has also been observed by other authors such as Ouattara et al. (2000) in the Agnéby River and in the fluvial areas of the Bia River in Côte d'Ivoire. Diatoms are the most diverse autotrophic organisms in watercourses and bodies since they have the ability to colonize all available surfaces (Namien-Ebrotié et al., 2013). In addition, diatoms can also detach themselves from supports and could be found drifting in the water column;this explain their significant diversity both in the periphyton and in the open-water population. However, the development of pelagic algae depends closely on the stability of the water column. This stability, generally observed in lentic hydrosystems. favors biological processes such as the complete cycles of reproduction and development of algae (Ouattara et al., 2000)

Moreover, the majority of phytoplankton species harvested were accidental and/or rare (130 species). These results corroborate those of Hountogan (2015) in the same lake and even those of Hain et al. (2022). In addition, neither the specific richness nor the density did not show significant spatial and monthly variations. Only the Shannon H' index varied significantly between months. These results are on the contrary of those obtained by Groga (2012) for phytoplankton communities in dams in Côte d'Ivoire and by Hountogan (2015) in Lake Nokoué in Benin. These observations could be justified by their studies' periods (4 months) corresponding to the great rainy season. But, Ouattara et al. (2000) studies have shown that the highest densities of algae is in the dry season and a considerable collapse in the rainy season. The increasing evolution over time of the algal richness obtained in our work must be given by the recruitment of the waters of the Ouémé and the Sô Rivers that are situated in the northern part of the lake. These results justify the absence of constant taxa in the population and the low diversities noted (Hain et al., 2022). Only the month of March which marks the end of the great dry season was favorable to the proliferation of algae because of the existence of light energy. It is an environment weakened by the many anthropogenic activities (spills, navigation, markets, quarries, and fishing activities, etc.) coupled by the movements of the tides in the environment.

The Factorial Correspondence Analysis (FCA) carried out in the basis of the presence-absence matrix indicated that the two factorial axes expressed 79.69% of the total variability. The substantial part of the taxa is concentrated around the origin of the axes. This observation could be explained by the fact that the same species were found practically in the different sites. The similar result was found by Niamien-Ebrotié et al. (2013) in the coastal rivers in the South-East of Côte d'Ivoire. Species were scatted into the water column and the discriminating parameters -water velocity, salinity, low concentrations of dissolved oxygen, nitrates and oxygen saturation rate- of the different communities clearly explain the fragile and asphyxiating state of the waters of Lake Nokoué.

4.2. Chlorophyll biomass and Trophic state of the lake

In the aquatic environment, chlorophyll a is considered as an indicator of algal biomass and productivity. Therefore, phytoplankton can be

quantified by chlorophyll extraction (Hallegraeff, 1977) which is a fast, satisfactory and accurate method (Butterwick et al., 1982). In our study, the dosage of chlorophyll carried out showed a maximum biomass (28.22 µg/L) in June in Lake Nokoué. The first assessment of primary productivity in Bénin was carried out on Lake Nokoué and the Porto-Novo Lagoon in Benin by Girault and de Kimpe (1967). Their results showed an average values of 2220 mg C/m2/d for Lake Nokoué and 850 mg C/m2/d for the Porto Novo Lagoon ; values that vary greatly between the seasons. The maximum values were obtained between May and June and the minimum values from July to October (Gnohossou, 2006). The average primary productivity obtained by Adounvo (2001) using the dark and light bottle methods was 2500 mgC/m3/d. It should be noticed that the methods used to estimate primary productivity differ from one author to another.

As for the trophic level of Lake Nokoué, our study showed that the sites from ST1 to ST7 are eutrophic and those from ST8 to ST11 are hypereutrophic. A comparison of our work with that of Mama (2010) reveals similarities. Indeed, the values of 20 to 60µg Chla/L observed show a significant production of algal biomass at different points in the lake and highlight the eutrophic nature of the system (eutrophic system if Chla content greater than 10µg/L according to OCDE classification). This spatial variation of the chlorophyll a is very significant. This parameter is maximum near the lakeside villageswhich were very anthropized (Mama. 2010).The high level of pollution noticed is well justified by the enormous quantity of organic matters imputs coupled with other activities done directly in this lake. All of these ones contribute to the accelerating of the lake fitting up.

Conclusion

In summary, this lake sheltered 141 taxa divided into 56 families of algae. And the phytoplankton community observed is poorly diversified and dominated by a few species. The typology of the sites and the various discriminating physico-chemical parameters of the lake indicate a high eutrophication especially in the sites near the Ouémé and Sô Rivers and the Cotonou Channel. The concentrations of chlorophyll a and the low transparencies obtained have showed that the Lake Nokoué is in hyper-eutrophicstate due to the supply of nutrients from its tributaries and extreme anthropogenic actions. The main phyla as in taxonomic richness as in density sampled were Diatomophyta. Chlorophyta. Cyanophyta and Euglenophyta, mostly indicators of pollution. It would be interesting to carry out the specific identification of phytoplankton over several years and to make adequate managements to limit the eutrophication of the ecosystem for its sustainability.

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