E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2022; 10(1): 130-141

www.fisheriesjournal.com
Received: 22-11-2021
Accepted: 25-12-2021

TK Hain
1. Laboratory of Hydrobiology and Aquaculture (LHA), Faculty of Agricultural Sciences (FAS), University of Abomey-Calavi (UAC), Benin
2. Geology-Biology Department, Sciences and Technics Faculty of the University of Sarh (Tchad) (NUA), Benin

D Adandedjan
Laboratory of Hydrobiology and Aquaculture (LHA), Faculty of Agricultural Sciences (FAS), University of Abomey-Calavi (UAC), Benin

ME Hountogan
Laboratory of Hydrobiology and Aquaculture (LHA), Faculty of Agricultural Sciences (FAS), University of Abomey-Calavi (UAC), Benin

Corresponding Author:
D Adandedjan
Laboratory of Hydrobiology and Aquaculture (LHA), Faculty of Agricultural Sciences (FAS), University of Abomey-Calavi (UAC), Benin

Phytoplankton communauties of the Porto-Novo Lagoon (South-East Bénin)

TK Hain, D Adandedjan and ME Hountogan

DOI: https://doi.org/10.22271/fish.2022.v10.i1b.2633

Abstract
This work aims to reveal the ecological status of the Porto-Novo Lagoon in the South-East of Benin, after some development works by analyzing phytoplankton communities. The phytoplankton sampling was carried out monthly from March to august 2017 using a plankton net (30 µm in diameter) at 6 sites located using a Global Positioning System (GPS). Alpha diversity was assessed using Shannon-Weiner index and Pielou evenness. The occurrence frequency of each taxon was determined for habitat preferences. The distribution profile of the taxa was revealed by a bio typology using the algorithm of ″Self Organizing Maps (SOM)″. In total, 160 taxa (genera and species) of phytoplankton belonging to 8 phytoplankton, 11 classes, 26 orders and 31 families have been identified. Cyanophyta, Eugenophyta, Dinophyta and Pyrrophyta were each represented by one class. It was the Chlorophyta with 4 classes followed by Diatomophyta, 3 classes that were the richest phyla. This observed biodiversity shows significant monthly variations. The highest densities of certain orders such as Cyanophyceae, Chlorophyceae and Euglenophyceae in the environment revealed the eutrophic state of the waters of the lagoon. The large number of accessory species, the different values of the various biodiversity indexes calculated added to the dominance of the various tolerant polluting species indicated the ecological instability of the lagoon despite the fitting up activities made in recent years. It is urgent to redefine the typical works to be done for the sustainability of this ecosystem.

Keywords: Phytoplankton, communauties, Lagoon, Porto-Novo, Benin

1. Introduction

The ecological functioning of aquatic ecosystems is closely dependent on the process of the organic matter degradation [1]. Planktonic organisms play an essential rule in this functioning. They are the basis of the food web and their balance depends on the animals above them, including humans. Although phytoplankton represents only 1% of the biomass of photosynthetic organisms on earth, it provides 45% of the primary production of rivers and lakes [2]. Despite their importance, aquatic ecosystems receive very little benefit from environmental assessments and global monitoring [3, 4]. Thus, the study of phytoplankton communities in aquatic ecosystems is essential in order to better understand the structure of food webs and the functioning of these systems [3]. But, thèse communistes change during periods with the environmental conditions and particularly with the trophic ones. Also, nowadays, there are particularly using as indicators to bio monitor the aquatic ecosystems as there exist a lot of biotic indexes elaborated with phytoplankton of the aquatic ecosystems used to the determination of water quality.

In Benin, several works have been carried out to understand the functioning of aquatic ecosystems among with we can quote the specific regression of fish and other organisms on Nokoué Lake through the study of the Spatial and seasonal distribution of the ichtyofauna of Nokoué Lake, Benin, West Africa done by [5], the benthic organisms' function in the trophic chain of Nokoué Lake [6], the exploitation and the demography of Cichlid fish of the Nokoué and Ahémé Lakes in Benin [7], the determinism of benthic macro invertebrates in the Porto-Novo Lagoon and the Coastal Lagoon in Benin [8]. Despite all studies above mentioned, the knowledge on the phytoplankton diversity of the aquatic ecosystems in Benin and especially in the Porto-Novo Lagoon remains rudimentary and we lack information on these aquatic resources. As there are nowadays widely used as new methods of bio monitoring aquatic resources, it urges to have a list of the different phytoplankton species in order to constitute a data basis of them. This motivated our work titled "Phytoplankton communities of the Porto-

Novo Lagoon in the South-East of Benin.
In general, the aim of this work is to acquire better knowledge of phytoplankton communities to appreciate the ecological functioning of the Porto-Novo Lagoon. More specifically, it is necessary to (i) inventory the phytoplankton species in the Porto-Novo Lagoon and (ii) to characterize the phytoplankton diversity of the environment.

2. Methodology

2.1. Study area and sampling sites

The Porto-Novo lagoon is located in south-eastern Benin, between parallels 6 ° 25 and 6 ° 30 North and meridians 2 ° 30 East, in the Ouémé Department (Figure 1). It is limited to the north by the municipality of Porto-Novo, in the south by the Djrègbé and Tohouè villages, to the east by the Lagos Lagoon (Nigeria) and to the west by Nokoué Lake through the Totchè Channel, 5 km long and 200 m to 300 m wide. Its east-west length is 6 km and its width varies from 2 to 4 km, hence its rough triangular shape. Its area is around 30 km^2 during high water and 20 km^2 during low water [9]. This lagoon is situated in a subequatorial climate zone characterized by two rainy seasons of unequal importance alternated by two dry seasons. The monthly variations in temperature and rainfall show that the hottest period from November to March (28 to 34 °C), corresponding to the great dry season (GDS), the water levels are low. From July to September, the water levels in the ecosystems are higher with a peak in July, it is the great rainy season (GRS) and the temperatures are the lowest (25 to 27 °C). In fact, the analysis of rainfall data in Porto-Novo shows that the highest monthly average rainfall, 244 mm in Porto-Novo, is observed in June (ASECNA, 2005 -2015); in August, approximately 44 mm during the short dry season (SDS), followed by a secondary rainfall maximum (143.90 mm in Porto-Novo) in September and October respectively during the short rainy season (SRS).
According to [8, 10], the water inflow into the lagoon concerns the fresh water input and the runoff. The fresh water input comes mainly from the Ouémé River and others like the Sô, Blon, Avien, Kpoguididonou Rivers. The runoff is concerned by the marine water from the Atlantic Ocean which passes through Nokoué Lake via the Cotonou Channel to enter the lagoon by the Totchè Channel. This salted water could also enter the lagoon via the Lagos Channel [11] situated approximatively at 100 km in the eastern part of the lagoon.

This lagoon is extremely rich and diversified in aquatic fauna, including 53 species of fish belonging to 45 genera and 29 families, mostly freshwater, estuarine and marine ones. The permanent fish species living this lagoon are composed mainly of Cichlidae (*Hemichromis fasciatus*, *Sarotherodon melanotheron*, *Coptodon guineensis*), Claroteidae, Cyprinodontidae, Eleotridae, Elopidae, Gobiidae, Mugilidae The marine species which periodically introduce into the lagoon when the water salinity is very high are mainly the Carangidae, Haemulidae, Lutjanidae, Elopidae and Gerridae.
The aquatic vegetation linked to freshwater or mixohaline inputs during the low water are *Eichhornia crassipes*, *Crotalaria retusa*, *Paspalum vaginatum*, *Penisetum polystachion*, *Pistia stratiotes*. In non-flooded areas, the natural forest of mangroves' trees is almost disappeared. There are remaining few degraded mangroves forests along the Totchè Channel with some *Elaeïs guineensis* plants.
Around the lagoon, agriculture is very diversified, employing nearly 80% of the working population. Fishing is practiced by the real professionals who exploit individually or collectively with a varied range of fishing gears and techniques. The exploitation of the lagoon sand has become one of the main activities practiced by all the population and especially, the young men living around the lagoon. Other activities such as trading and the industrial sector are also very developed there. The extraneous anthropogenic activities by the populations on the environment have induced various pollutions in the lagoon. Despite all the sustainable management efforts done and sensitizations, expensive fishing techniques and practices such as the acadjas systems and prohibited nets continue to be used in this ecosystem.
For the present study, six sites were chosen (Fig. 1) considering the ecosystem area and the importance of human activities in each of them. Note that all these selected sites have already served for the analysis of ecological data in the ichthyological and/or in the macro invertebrate fields. Six (06) sampling campaigns were carried out on a monthly basis No sampling campaign is carried out of this period to avoid distortion of the homogeneity and representativeness of the data collected during the six campaigns. Also, this period (from March to August) corresponds to the three hydrological seasons, namely the great dry season (GDS: from March to mid-April), the great rainy season (GRS: mid-April-mid-July) and the short dry season (SDS: mid-July-August).

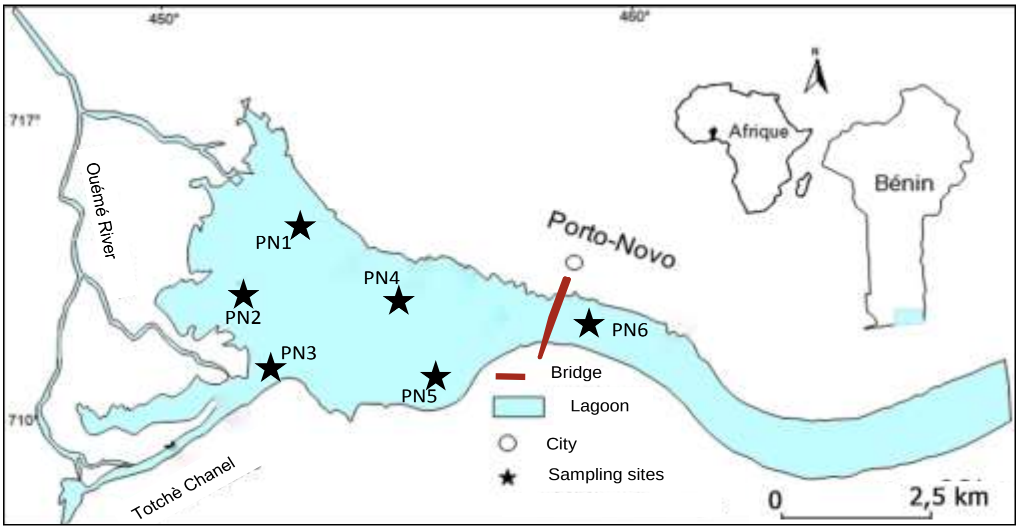

Fig 1: Study area and sampling sites.

2.2. Methods

2.2.1. Phytoplankton collection

The phytoplankton was collected using plankton net (30 µm mesh, opening diameter: 30 cm). For the qualitative study, the sample was taken firstly directly with the plankton net on a vertical line up to one meter above the seabed and secondarily, on a horizontal line, dragged behind the boat at each site in order to have sufficient materials for taxonomic identifications. The sample was filtered and the concentrate was collected in a jar of 100 mL container, and fixed with 5% formalin solution. The jar was labeled (name of site, date, ...). For the systematic study, it was essential to keep one part of the material without fixation because most flagellates, for example, can only be determined on live samples [12]. The periphyton and algae attached to rocks or woods' pieces on the water were also collected. For this, we scrapped floating plants or submerged rocks and woods; with a small brush we detached the epiphytic algae in a basin. A part of the algae collected was rinsed and conserved in a 30 mL bottle and then fixed with 5% formalin [4].

For the quantitative analysis, the sampling was carried out like this: at each site, a volume of 8 L of water was taken from the euphotic zone with the Van Dorn bottle (capacity: 2 L) and then filtered. The filtrate is placed in a jar and fixed with formalin solution, and then labeled for density calculation.

2.2.2. Laboratory works

- **Qualitative analysis**

The phytoplankton samples were observed under a microscope optic (model Nikon eclipse E200), drawn, photographed and identified from the identification keys. First, a drop of the concentrate sample for each site was taken using a "Pasteur pipette" after homogenization. This drop, deposited between blade and lamella, was observed under the microscope. For a complete determination, this operation was repeated five times of each sample. We used appropriate determinations keys for [13-15, 12, 16-19].

- **Quantitative analysis of phytoplankton**

The numeration consisted in a numeration of the algal cells in the different samples in order to assess their density. For this, before feeling the tank of the counting, we homogenized sample for a correct result as possible. The Neubauer cell was used for counting. The phytoplankton abundances or density was expressed as the number of cells per liter (L). The numeration was repeated four times in each sample and the average was taken.

The density calculation is expressed by the following formula: $D = Ni \times 1000 / v$, with, D = density in number of individuals per liter; Ni = average number of individuals of a species; 1000 = conversion factor in liter; v = volume of sediment sample in mL.

2.2.3. Data analysis and statistical treatments

- *The taxonomic richness S* was determined as the number of species in inventoried in the hall lagoon or at each site/month.
- T*he density D* is the number of cells per liter of filtered water per month/site. It allowed us to calculate the relative density (Dr in %) as the ration of the cells density obtained in a site/month and the total density obtained.
- *The Frequency or occurrence of taxa*: The percentage of occurrence (C) was calculated for each species as a percentage between the number of samples (p) where species i appears and the total number of samples (P) of the lagoon [10]. It is obtained according to the formula:

$$C = \frac{p \times 100}{P}$$

According to the value of C, we distinguish three groups of species: (i) constant species ($C \geq 50\%$); (ii) accessory species ($25\% \leq C < 50\%$) and (iii) accidental/rare species ($C < 25\%$).
- *The Shannon diversity index* (H') for measuring the degree of organization of the population. It is calculated according to the relation (Shannon and Weaver, 1963): $H' = \sum [Pi \log2 (Pi)]$ with $Pi = ni / N$, Ni = number of individuals representing taxon i, N = total number of individuals. The Shannon index is expressed in bits.
- The *Pielou evenness* is: expressed : $Eq = H' / \log2 S$, with S = total number of species H' = Shannon diversity index. It is between 0 and 1. It tends towards 0 when almost all the numbers are concentrated on one species and towards 1 when all the species have the same abundance.
- *Community structure*: to determine the different phytoplankton communities present, we performed a biotypology. The Self Organizing Maps (SOM) algorithm or Kohonen maps [20] was used to order the study sites according to the presence-absence matrix of taxa. Only taxa appearing in at least 5% of the samples were taken into account. Unlike conventional methods such as principal component analysis (PCA), SOM takes into account rare species often contained in ecological databases [10] and the formation of groups is done without a priori hypothesis. The technic consists in an input matrix (6 campaigns × 6 sites) containing the presence-absence data of the taxa collected (xij) for each group of sampling sites selected. We obtained the distribution profile of phytoplankton taxa.

Indeed, the classification technic is nonlinear, and capable of showing simplified patterns from complex databases by identifying similar groups [21]. The choice of the size of the map is a determining parameter for best detecting the difference between the data [22]. Once the Kohonen map has been obtained, a hierarchical classification analysis (ACH) algorithm based on the Ward method as an aggregation criterion and the Euclidean distance allow to highlight assemblages of real objects on the map [23]. These groupings were made on the basis of the similarities between the sampling sites projected on the map. The analysis was performed with the SOM Toolbox (version 2) for Matlab® [24].

At the end, the Kruskal-Wallis test was used to globally compare the faunal richness and abundance between sites, months and clusters. STATISTICA software version 4.5 was used.

3. Results

3.1. Taxonomic composition and density of the different phylum of phytoplankton

Table 1 (in annex) presented the list of phytoplankton taxa in the lagoon during the study. Figure 2 below illustrated the richness (A) and the density (B) of the different groups identified. In total, 160 taxa (genera and varieties) belonging to 8 phyla, 11 classes, 22 orders and 30 families have been identified. The identified phyla were Cyanophyta, Chlorophyta, Euglenophyta, Chrysophyta or Bacillariophyta, Pyrrophyta, Diatomophyta, Rodophyta and Dinophyta. Four phyla were the richest ones during the study (Fig. 2A). There were Diatomophyta, Cyanophyta, Chlorophyta and Eugenophyta, which respectively have 41.78%; 26.95%; 18.06% and 11.32% of the total richness. Cyanophyta, Eugenophyta and Pyrrophyta were each represented by only one class which were respectively Cyanophyceae, Euglenophyceae and Dinophyceae. Chlorophyta (4 classes) and Bacillariophyta (3 classes) were the richest phyla. The different classes of Chlorophyta identified, consisted of Chlorophyceae, Zygnemophyceae, Bryopsidophyceae and Ulvophyceae. Those of the Bacillariophytes were Coscinodiscophyceae, Mediophyceae and Bacillariophyceae (or Diatomophyceae).

A total of 118,600,000 cells/L were collected during the study. As shown in Figure 2B below, Diatomophyta exhibited the highest densities (53,100,000 cells/L). Then come the Chlorophyta and Cyanophyta with respectively 34,000,000 and 26,500,000 cells/L.

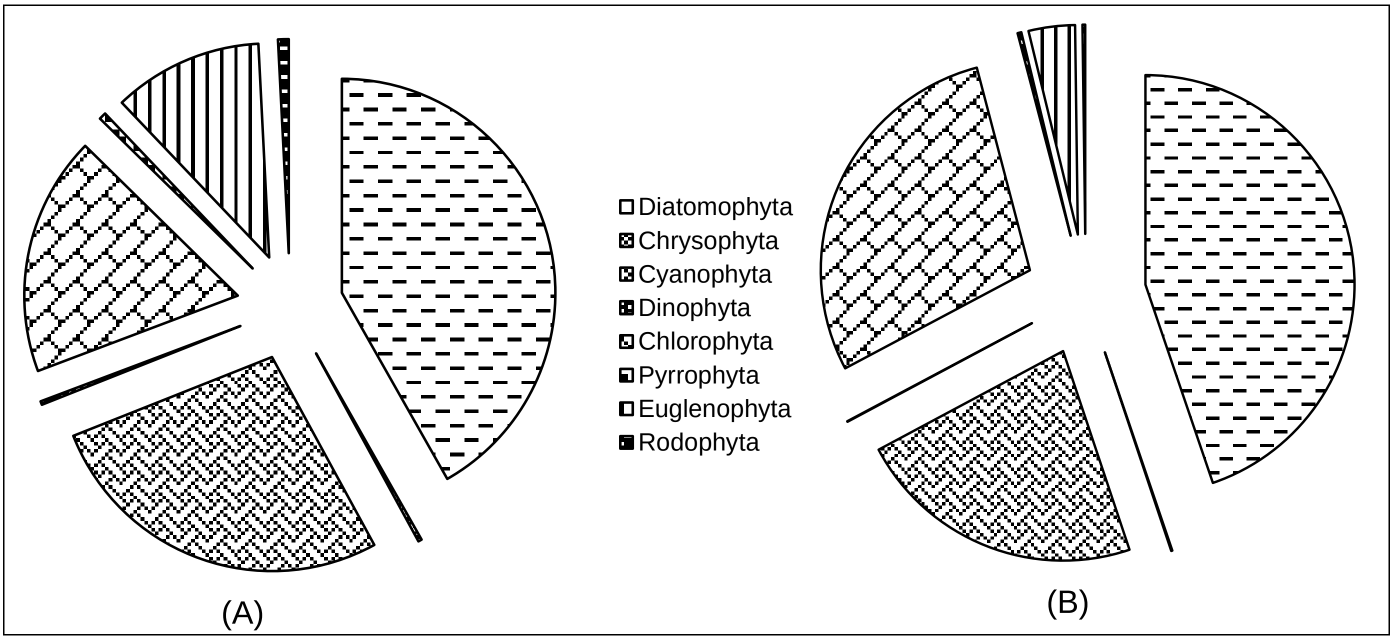

Fig 2: Taxinomic composition (A) and relative density (B) of the different alguae phyla of the Porto-Novo Lagoon.

3.2. Occurrence of taxa

In terms of habitat preferences, no species was constant (Tab. 2). Eight taxa were accessories, i.e. presented an occurrence of at least 25%. Accidental/rare species represented nearly 97% of the total species inventoried.

Table 2: Accessories and accidental/rare species of the phytoplankton of the lagoon.

Accessoires taxa	Accidental or Rare taxa
Coscinodiscus rudolfii (33.33%)	*Melosira* sp. (19,44)
cillatoria subtillissima (33.33%)	*Gyrosigma accuminatum*. (19.44)
Closterium kuetzingii (30.55%)	*Chaetoceros muelleri* (19.44)
Microcystis aeruginosa (27.78%)	*Nostoc piscinale* (19.44)
Microcystis sp. (27.78%)	*Stephanodiscus* sp. (16.67)
Lepocinclis ovum. (27.78)	*Anabaenopsis elenkinii* (16.67)
Gonatozygon sp. (25%)	*Trachelomonas intermedia* (16.67)
Spirogyra sp. (25%)	

N.B.: Only accidental/Rare taxa having at least 15% of occurrence were presented in the table.

3.3. Main families and species of phytoplankton collected in the lagoon

Seven families were the main ones during the study. The Desmidiaceae family was the most abundant with 21% of relative density. Coscinodiscaceae family with 14.04% of the density was the second main family obtained. Other families such as the Chaetoceraceae and Naviculaceae (Dr = 9.70%), the Nostocaceae (Dr = 9.06%), the Chroococcaceae and the Oscillatoriaceae (Dr = 6%) were equally important. The Euglenaceae (Dr = 3.71%) and the Nitzschiaceae (Dr = 3.03%) were not negligible families of this ecosystem.

As regarding the main species in the lagoon, only 3 species were abundant during the study. There were *Closterium kuetzigii* (17.44%); *Chaetoceros muelleri* (9.93%); *Coscinodiscus rudolfii* (7.815%). Other taxa were also important in the ecosystem. Among them, we have *Nostoc piscinale* (4.231%); *Anabaeneopsis elenkinii* (3.325%); *Microsystis* sp. (3.022%); *Cyclotella meneghiniana* (2.763%) and *Ankistrodesmus fusiformis* (2.677%). Other taxa have less than 0.5% of the relative density during the study.

Fig. 3A presented the spatial variations in the taxonomic richness and relative density of phytoplankton listed. The specific richness varied from 116 species at the PN1 site (Djassin) to 31 species at the PN6 site (Face Douane). The density, strongly correlated with taxonomic richness, ranged from 37.350,000 cells/L at PN1 to 8.600,000 cells/L at PN6. These spatial variations were not significant (p > 0.05%, Kruskal-Wallis).

Temporal variations in taxonomic richness and phytoplankton density in the lake are illustrated in Fig. 3B. The specific richness of phytoplankton showed its highest value (124 taxa) in March and its lowest value (31 taxa) in July. It was also in March that the high cell density (49,950,000 cells/L) was observed and in July, its lowest value (3,450,000 cells/L). These temporal variations were significant (p <0.05%, Kruskal-Wallis).

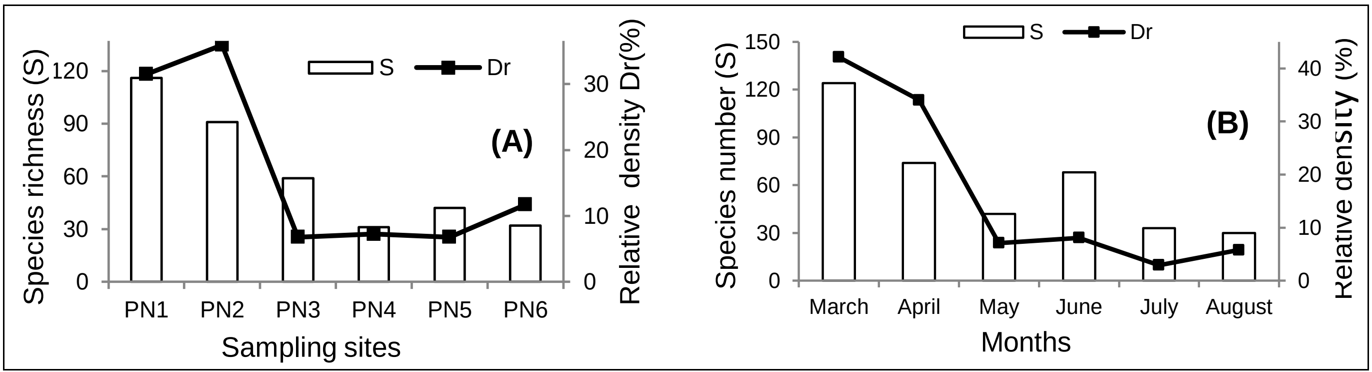

Fig 3: Spatial (A) and temporal (B) variations of the algae richness and its relative density during the study.

3.4. Diversity analysis

Fig. 4A illustrated the spatial variations of the Shannon index and the Pielou evenness. The lowest Shannon index (3.97 bits) was obtained at PN4 and the highest (5.79 bits) at PN1. As for Piélou index, it varied from 0.79 to 0.92. The minimum and maximum values of the index were recorded at PN4 and PN3, respectively.

Fig. 4B showed the temporal variations of the Shannon index and the Pielou evenness index. The lowest Shannon index (2.80 bits) was obtained in August and the highest (5.05 bits) in March. Piélou's index hovered between 0.57 in August and 0.78 in May.

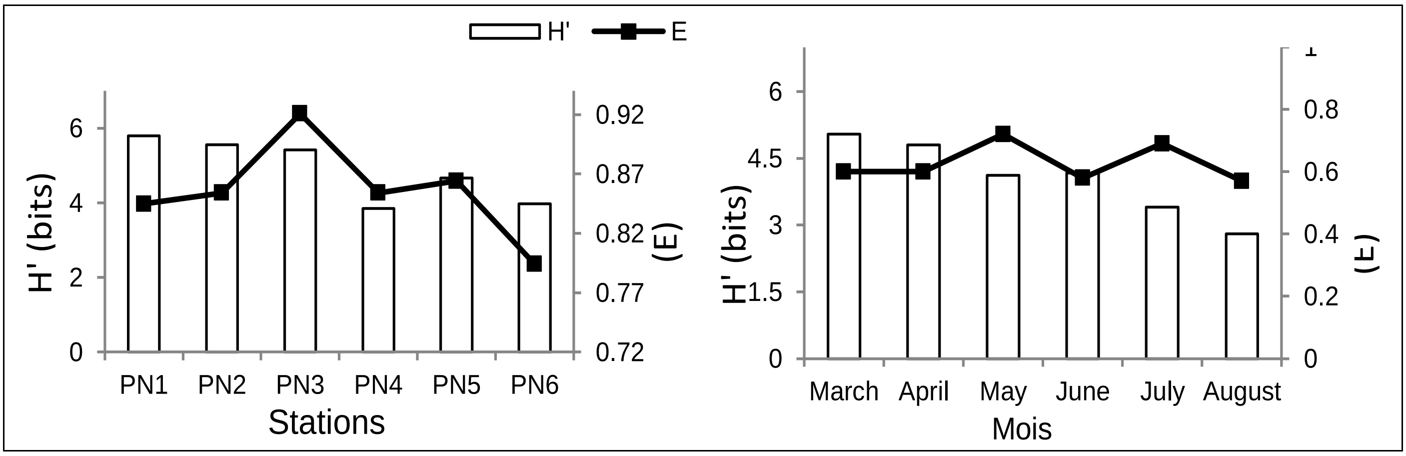

Fig 4: Shannon index (H') and Evenness (E) spatial (A) and temporal (B) variations

3.5. Community structure

3.5.1. Biotypogy

The presence-absence data of phytoplankton taxa were analyzed using SOM. In view of the quantification and topography errors presented in the Tab. 3, a map of 20 (5 rows × 4 columns) cells was retained to project the samples obtained. Fig. 5A and 3B gave the cells' numbers and the result of the hierarchical classification analysis which allowed the 20 cells of the Kohonen map to be grouped into 4 clusters (G1 to G4). Each cluster, shown on the map of the Fig. 5C with the same pattern, is made up of samples with similar taxonomic compositions. This analysis revealed a monthly distribution corresponding to the seasons covering the sampling period. Thus the clusters G1 and G2 located in the cells above the map were made of samples from June, July and August. And the two groups G3 and G4 were made of samples from March, April and May. The G1 was separated from the G2 by gathering 8 samples of which 75% come from August and 25% from July corresponding to the SDS. Group G2 was made of 10 samples from June and July, therefore from the end of the great rainy season (GRS). G3 was constituted by 11 samples from March and April (period of the end of the GDS). Finally, the G4 group was separated from the G3 by gathering 7 samples mainly from May.

Table 3: Estimation of quantification and topographical errorrs for different sizes (cells number). of the Kohonen map
Legend : The map size retained and its characteristics are in bold.

Map size (number of cells)	Quantification error	Topographic error
5×4 = 20	**2.856**	**0.000**
5×5 = 25	2.816	0.000
5×6 = 30	2.666	0.015

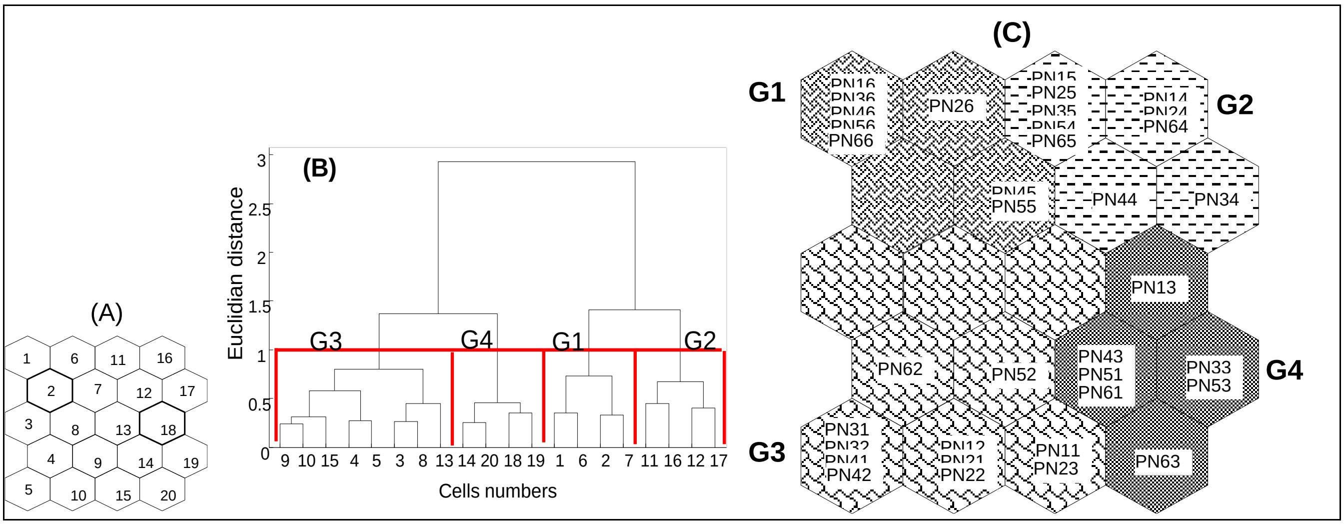

Fig 5: Hierarchical Classification (B) and sampling distribution (C) on the SOM map.

3.5.3. Taxonomic richness and relative density in each cluster

The distribution profile of the phytoplankton taxa of the lagoon realized using SOM showed the contribution of each of the 75 taxa in each group. The G1 group has been significantly characterized by the following taxa: *Anabaena piscinale, Anabaneopsis elenkinii, Bacillaria paxillifer , Campilodiscus baleanicus, Campilodiscus clypens, Chaetoceros muelleri, Closterium aciculare, Closterium kuetzingii, Coscinodiscus rudolfii, Cyclotella kuetzingi, Diatoma vulgare, Gomphonemaoli vaceum, Gyrosigma accuminatum, Komvopheron constrictum, Mastogloia braunii, Melosira granulata, Microcystis aeruginosa, Nostoc piscinal, Staureneis* sp., *Surirella capronii, Synechocystis aeruginosus, Synechocystis aqualis*.

The G2 group, was made of: *Campilodiscus clypens ,Closterium aciculare ; Coscinodiscus rudolfii ;Cryptomonas* sp. ; *Cyclotella kuetzingi ; Cyclotella meneghiniana ; Diploneis oblongella ; Euglena sp ; Euglena proxima ; Eunotia sp ; Goniochloris gigas ; Lyngbia fovealarum ; Navicula cryptocephala ; Navicula* sp.1 *;Nitzschia aqualis ; Nitzschia obtusa ; Oscillatoria limnetica ; Oscillatoria* sp.1 *;Oscillatoria probocidae ; Oscillatoria subulatum ; Petrodictyon gemma ;Pinnularia acrosphareina, Pseudanabaena limnetica ; Scenedesmus intermidius, Spirulina gigantea ;Surirella elegans.*

The G3 group was identified by: *Aulacoseira granulata ; Aulacoseira* sp. ; *Gonatozygon* sp.; *Microcystis* sp., *Nitzschia sigma, Navicula cuspidata ; Phacus longicauda ; Scenedesmus quadricauda Trachelomonas intermedia ; Trachelomonas* sp. ; *Ulothrix* sp.

And finally the G4 Group brought together: *Amphora coffaeformis ; Chroococcus* sp. ; *Closterium kuetzingii ; Euglena* sp. ; *Lyngbia aestuari ;Microcystis aeruginosa ; Oscillatoria subulatum ; Planktothrix compressa ; Spirogyra* sp. ; *Tetrstrum triangulare ; Trachelomonas intermedia, Trachelomonas* sp. ; *Ulothrix* sp.

The figure 6 presented the taxonomic richness and relative density of each cluster defined by the SOM analysis. The number of taxa varied from 1 to 6 taxa for G1 and from 4 to 15 taxa for G2. For G3, the number of taxa varied from 4 to 36 taxa and from 2 to 7 taxa for G4. The number of taxa differed significantly between clusters (Kruskal-Wallis, $p < 0.05$). And the cluster G1 was different from G2 and G3 and then, G3 was widely different from G2 and G4 (Mann-Whitney, $p < 0.05$).

On the other hand, the taxa density varied significantly between clusters (Kruskal-Wallis, $p < 0.05$). That of G1 fluctuated between 0.04 and 3.32% which differed from the density of G3 for which, the relative density fluctuated between 1.25 to 15.46%. Also, G3 differed from G2 (Dr: 0.35 to 2.63%). Finally, the group G4 (Dr: 0.52 to 4.15%) was different from those of the groups G1 and G4 (Mann-Whitney, $p < 0.05$).

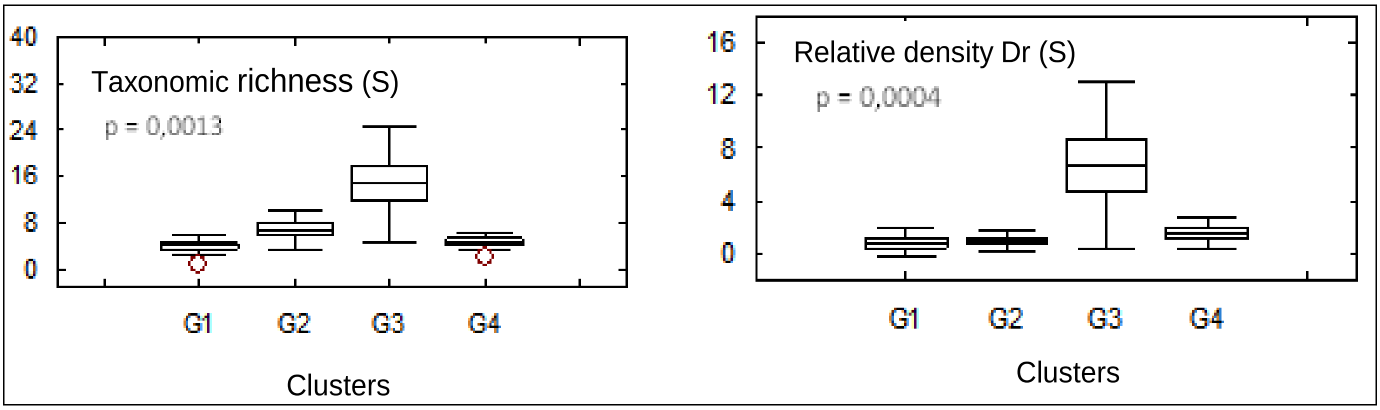

Fig 6: Taxonomic richness (S) and relative Density relative (Dr) of the phytoplankton identified in the different clusters of the Kohonen map

4. Discussion

The algae community of the Porto-Novo Lagoon studied here allowed us to collect 160 taxa divided into 31 families. This phytoplankton composition exceeded the richness obtained by [25] who had 39 species in the Totchè channel and by [26] who collected 52 species in the Nokoué Lake. These differences would be explained by the different sampling periods. The analysis of the taxonomic composition of the phytoplankton population places the Diatomophyceae in the first position, followed by the Chlorophyceae. The classes of Euglenophyceae, Rodophyceae, Chrysophyceae and Dinophyceae are poorly represented. The large representation of diatomophyceae, Chlorophyceae could be explained by the fact that these classes are in a physico-chemical point of view, polluo-tolerant taxa; they are characteristics of polluted environments, rich in organic matters [27]

The variations in taxonomic richness and density obtained by site and by month are significant. The highly significant variations in density between months and sites are related to the season effect and hydrology. Similar results were obtained with [28] for phytoplankton communities in an Ivory-Coast dam and by [26] in Nokoué Lake in Benin. Phytoplankton community's shows its highest densities in the dry season and a considerable collapse in the rainy season [4] and our results well corroborate with these statements made. With regards to taxonomic richness, the increasing evolution over time must be given by the recruitment of water from the Ouémé river that is the principal water input of the lagoon.

The Shannon and Pielou indexes calculated although high at some sites also revealed low biodiversity. Similar values of these indexes have already been obtained by [28] in heavily polluted environments in Ivory-Coast. These results justify the absence of constant taxa in the lagoon. This lagoon is about an environment weakened by numerous human activities (spills, domestics wastes inputs, navigation, markets, hotels, bridges, and fishing activities and their corollaries). The lagoon as a whole ecosystem suffers from eutrophication. Indeed, the phytoplankton communities of the Porto-Novo Lagoon are made up of 4 seasonal communities as revealed by the SOM analysis. Clusters G1, G2 and G4 come from rains and were rich in Diatomophyta polluo-resistant taxa with less rich samples. This period is therefore favourable to the proliferation of algae marked by light sunshine after the rains. [17, 4] had obtained the same results. But all the taxa shown in the different clusters were polluo-resistant taxa indicating that the lagoon not offers to the organisms which live in it a good quality water. The environment undoubtedly receives water discharges and runoffs, rich in nitrogenous nutrients from the leaching of floodplains which in turn constitute a good support for the development of these algae. Also, the high water depths in these two seasons (long rainy season and short dry season) which are not too different are favorable to their development [29, 30].

The cluster G3 stands out from other clusters by its high richness and density. These observations are mainly due to the sampling period which goes from the end of the great dry season (March) and the beginning of the great rainy season (April), a period that favours the proliferation of algae which benefits sedimented nutrients in the environment with shallow depths. Chlorophyceae, Cyanophyceae and Euglenophyceae are characteristic of polluted environments rich in organic substances [27, 31]. This is due to the release into this ecosystem of large amounts of untreated domestic waste water coming from hotels, market, villages around, and factory. The extraction of lagoon sediments and navigation developed in this ecosystem contribute to resuspend the fines particles of sediments which increases the turbidity, parameter that limits the light penetration in the water that favors the photosynthesis. Representatives of these groups and in particular the genera *Scenedesmus*, *Microcystis* and *Lepocinclis*, are known for their predilection for eutrophic environments sensu lato [32]. This eutrophy is justified not only by the high algal proportion but also by the presence of the genus *Nitzschia* which exhibits its optimum growth in highly eutrophic waters [33, 34, 32]. We note here isotropic sites where species tend towards equiprobability; therefore, an absence of dominance in the community is noticed.

Annex : **Table 1:** List of Algae taxa collected in the Porto-Novo Lagoon. Legend : %Oc = Frequency ; PN1, PN2, PN3, PN4, PN5 and PN6 are sites codes.

		Sampling sites						
Phyla/Classes/Orders	**Families /species**	**PN1**	**PN2**	**PN3**	**PN4**	**PN5**	**PN6**	**%Oc.**
Diatomophyta								
Coscinodiscophycea								
Coscinodiscales								
	Coscinodiscaceae							
	Coscinodiscus rudolfii (Brachmann, 1938)	*	*	*	*	*	*	33.3
Meloseirales								
	Meloseiraceae							
	Melosira moniliformis	*	*		*			8.33
	Melosira granulata (Ehr.) Halfs	*						2.78
	Melosira sp.	*	*	*	*			19.44
Mediophyceae								
Thalossiorales								
	Stephanodiscaceae							
	Cyclotella meneghiniana Kütz	*	*	*			*	22.22
	Cyclotella kuetzingiana Thw.	*	*			*		11.11
	Thalassiosira sp1.		*					2.78
	Stephanodiscus sp. Ehrenberg	*	*	*			*	16.67
	Aulacauseiraceae							
	Aulacoseira sp.	*						2.78
	Aulacoseira granulata Thwaites		*	*	*		*	13.89
Diatomophyceae								

Naviculales								
	Nitzschiaceae							
	Nitzschia sigmoidae (Ehr.) W. Sm	*	*					5.56
	Nitzschia aqualis Hust.	*						2.78
	Nitzschia levidensis (W. Sm.) Grun.	*	*	*		*		11.11
	Nitzschia sigma (W. Smith 1853)					*		2.78
	Nitzschia lacustris Hust.		*					2.78
	Nitzschia oblongtus		*	*				5,56
	Nitzschia obtusa W. Sm.	*						2.78
	Nitzschia intermedia Hantzsch	*				*		11.11
	Nitzschia vermicularis					*		2.78
	Nitzschia sp.	*			*			8.33
	Synedra ulna (Nitzsch) Ehrenberg	*						2.78
	Naviculaceae							
	Navicula cryptocephala (Kützing, 1844)	*	*					11.11
	Navicula heufleri	*						2.78
	Navicula cuspidata Kütz		*					2.78
	Navicula sp1.	*	*	*				13.89
	Amphora coffaeformis (Ag.) Kutz	*		*				5.56
	Amphora sp.	*						2.78
	Neidium dibium (Eh.) Cl.	*						2.78
	Staureneis anceps Ehr.		*					5.56
	Pinularia cardinalis (Ehr.) W. Sm.	*						5.56
	Pinularia acrosphaeria W. Sm.		*					2.78
	Pinularia borealis Ehr.	*						2.78
	Pinularia sp1.	*						2.78
	Diploneis sp1.	*						2.78
	Diploneis sp2.	*						2.78
	Diploneis oblongella (Hilse) Ross	*	*					5.56
	Gyrosigma attenuatum (Kutz.) Rabh	*	*	*	*	*	*	22.22
	Gyrosigma accuminatum	*						2.78
	Gyrosigma scalproides (Rabh.) Cl.					*		2.78
	Gyrosigma sp.	*						2.78
	Anomoneis sphaerophora (Ehr.) Pfitz.					*		2.78
	Gomphonema Olivaceum (Horn.) Brèb			*				2.78
	Gomphonema angustatum (Kutz.) Rabh.	*			*			8.33
	Gomphonema parvulum (Kütz.) Kutz.	*	*					11.11
	Cymbelle ventricosa (C. Agardh, 1830)					*		2.78
	Petrodictyon gemma	*					*	8.33
	Mastogloia braunii	*	*	*	*			16.67
Surirellales								
	Surirellaceae							
	Surirella capronii Bréb.	*				*		8.33
	Surirella ovalis Erh.	*						2.78
	Surirella elegans Erh.	*	*	*				8.33
	Surirella debesii Hust.		*	*	*			11.11
	Campylodiscus balearicus		*					5.56
	Campylodiscus clypens		*					2.78
	Stenopterobia rautenbachiae Choln.			*				2.78
Diatomales								
	Diatomaceae							
	Bacillaria paxillifer (T.Marsson, 1901)	*	*					5.56
	Bacillaria sp1.	*						2.78
	Fragilaria construens (Ehr.) Grun.		*					2.78
	Fragilaria crotonensis Kitton	*						2.78
	Fragilaria sp.		*					2.78
	Diatoma sp.	*						2.78
	Diatoma vulgare Bory	*	*					5.56
Buddiphiales								
	Chaetoceraceae							
	Chaetoceros muelleri (Ehrenberg, 1844)	*	*	*			*	19.44
	Achantoceraceae							
	Achantoceras zachariasii		*					2.78
Eunotiales								
	Eunotiaceae							
	Eunotia sp.	*		*				5.56
Achnanthales								
	Achnanthaceae							

	Cocconeis placentula Ehrenberg	*	*					5.56
	Achnanthes exiguoides Compbre, Bull. Jard.					*		2.78
Cyanophyta								
Cyanophyceae								
Oscillatoriales								
	Oscillatoriaceae							
	Lyngbia fovealarum Agard ex Gomont	*						2.78
	Lyngbia majiscule Agard ex Gomont	*						2.78
	Lyngbia aestuarii Agard ex Gomont	*	*	*				8.33
	Lyngbia circumecrata Agard ex Gomont	*						2.78
	Lyngbia transvaalensis Agard ex Gomont					*		2.78
	Lyngbia foveolarum Agard ex Gomont					*		2.78
	Lyngbia cebennensis Agard ex Gomont			*				2.78
	Planktolyngbia sp.	*						2.78
	Planktothrix compressa Komárek 1988			*			*	5.56
	Oscillatoria taxa Vaucher ex Gomont	*						2.78
	Oscillatoria limosa Agardh ex Gomont 1892	*		*				5.56
	Oscillatoria pseudogeminata			*				2.78
	Oscillatoria sp1.	*	*	*				8.33
	Oscillatoria sp2.	*		*				5.56
	Oscillatoria angusta					*		2.78
	Oscillatoria subtillissima	*	*	*	*	*	*	38.89
	Oscillatoria animalis	*						2.78
	Oscillatoria probocidae	*		*				8.33
	Oscillatoria limnetica		*				*	5.56
	Pseudanabaenaceae							
	Pseudanabaena limnetica Komárek 1974	*	*					11.11
	Pseudanabaena schmidlei					*		2.78
	Borziaceae							
	Komvophoron constrictum	*	*	*				11.11
Nostocales								
	Nostocaceae							
	Nostoc piscinale	*	*		*	*	*	22.22
	Nostoc entophylum			*				2.78
	Anabaenopsis arnoldii		*				*	5.56
	Anabaenopsis elenkinii	*	*	*	*	*		19.44
	Anabaena piscinale	*		*				5.56
Chroococcales								
	Chroococcaceae							
	Synecocystis aqualis		*					5.56
	Synechocystis sp.					*		2.78
	Synechococcus sp.		*					2.78
	Microcystis aeruginosa Kützing 1846	*	*		*	*	*	30.56
	Microcystis sp. Kützing ex Lemmermann		*		*	*	*	33.33
	Synechococcus aeruginosus	*	*	*				8.33
	Chroococcus sp. Nägeli 1849		*	*	*			11.11
Hormogonales								
	Cyanophyceae							
	Spirulina gigantea Schmidle	*						2.78
	Spirulina meneghiniana Zanardini 1892			*				2.78
Chlorophyta								
Conjugatophyceae								
Desmidiales								
	Desmidiaceae							
	Closterium aciculare T. West	*	*				*	11.11
	Closterium lanceolatum Halfs	*	*	*				8.33
	Closterium kuetzingii Bréb.	*	*	*	*	*	*	36.11
	Closterium gracile [Bréb.] Ralfs	*			*			8.33
	Closterium subulatum (Kütz) Bréb.					*		5.56
	Closterium lineatum Ralfs			*				2.78
	Closterium strigosum Bréb.						*	2.78
	Pleurotaenium trabecula		*					2.78
CHLOROPHYCEAE								
Zygnematales								
	Zygnemataceae							
	Spirogyra sp. Link	*	*	*	*	*		27.78
	Mougeotia sp. Trans.	*						2.78
	Mesotaeniaceae							

	Gonatozygon sp.	*	*	*	*	*		27.78
Chlorococcales								
	Hydrodictiaceae							
	Pediastrum duplex Meyen	*						2.78
	Pediastrum simplex Meyen	*						2.78
	Oocystaceae							
	Monoraphidium setiforme	*						2.78
	Scenedesmaceae							
	Scenedesmus ecornis Meyen	*			*			8.33
	Scenedesmus armatus Meyen	*	*					5.56
	Scenedesmus quadricauda	*			*			8.33
	Scenedesmus intermedius Meyen		*					2.78
	Scenedesmus aqualis Meyen	*						2.78
	Ceolastrum microsporum Niag.				*			5.56
	Chlorococcaceae							
	Ankistrodesmus fusiformis				*			5.56
	Tetrastrum triangulare Chodat		*		*			8.33
ulvophyceae								
Ulothricales								
	Ulothricaceae							
	Binuclearia eriensis Tiff.		*					2.78
	Ulothrix sp.			*				2.78
	Ulothrix zonata				*			556
	Ulothrix bipirenoidosa			*	*	*		11.11
Volvocales								
	Volvocaceae							
	Volvox aureus Linnaeus		*					2.78
	Pandorina sp. Bory de Saint-Vincent			*				2.78
Bryopsidophyceae								
Siphonocladales								
	Siphonocladaceae							
	Cladophora holsatica	*						2.78
Euglenophyta								
Euglenophyceae								
Euglenales								
	Euglenaceae							
	Euglena limnophila	*						2.78
	Euglena proxima P.A.Dangeard	*	*	*		*		13.89
	Euglena acus Ehr.	*	*	*				8.33
	Euglena ehrenbergii						*	2.78
	Euglena sp.		*	*				5.56
	Phacus caudatus Hübn.		*					2.78
	Phacus longicauda (Ehrenb.) Duj.			*		*	*	8.33
	Phacus platalea Drez.	*						2.78
	Lepocinclis ovum (E hr.) Lemm.	*	*	*	*	*	*	33.33
	Lepocincli Oxyris Marin & Melkonian		*					2.78
	Trachelomonas superba Swir.	*						2.78
	Trachelomonas intermedia Dang.	*	*	*	*		*	19.44
	Trachelomonas bernardensis					*		2.78
	Trachelomonas sabra						*	2.78
	Trachelomonas sp.					*	*	5.56
	Strombonas sp. Deflandre	*	*			*		13.89
Rodophyta								
Rodophyceae								
Xanthophylales								
	Xanthophyceae							
	Goniochloris gigas Bourr.	*				*		5.56
	Tetradriella spinigera		*					2.78
Chrysophyta								
Chrysophyceae								
Ochromonadales								
	Dinobryaceae							
	Peridiniopsis dinobryonis			*				2.78
Pyrrophyta								
Pyrrophyceae								
Cryptomonadales								
	Cryptomonadaceae							
	Cryptomonas erosa Ehr.		*					2.78

	Cryptomonas sp.		*					2.78
Dinophyta								
Dinophyceae	Peridiniaceae							
	Gymnodium sp. Klebs.							
	Peridiniaceae					*		5.56
Total par station		116	91	59	32	42	31	
Total lagune				160				

5. Conclusion

In sum, 160 taxa of algae were collected in the lagoon divided into 11 classes 28 orders and 34 families. The Bacillariophyta was the richest phylum but does not showed any dominance over the phytoplankton community observed as explained the highest values of Pielou's equitability. The great richness obtained is due to the polluo-tolerant taxa in relation to a fairly high organic pollution. The environment is full of enormous accidental/rare and accessory taxa during the study, witnesses to the instability of the environment. The study indicates high eutrophication, especially in the northern sites under the influence of the Ouémé River, Nokoué Lake and human activities. The large groups of phytoplankton sampled are mostly indicators of pollution. We recommend the pursuing of this study for a better appreciation of the ecological quality of the lagoon to allow managements making the ecosystem more sustainable.

6. References

1. Olivier D, Gessner OM, François G, Eric C. Impacts of stream acidification on litter breakdown: implications for assessing ecosystem functioning. Journal of Applied Ecology. 2004;41:365-378.
2. Behrenfeld MJ, Randerson JT, McClain CR, Feldman GC, Los SO, Tucker CJ, *et al*. Biospheric primary production during an ENSO transition. Science. 2001;291:2594-2597.
3. Diaz S, Fargione J, Chapin FS, Tilman D. Biodiversity loss threatens human well-being. *PLoS biology* 2006;4:e277.
4. Niamien-Ebrottié JE, Konan KF, Edia Oi E, Ouattara A, Gourène G. Composition et variation spatio-saisonnière du peuplement algal des rivières côtières du Sud-est de la Côte d'Ivoire. Journal of Applied Biosciences. 2013;66:5147-5161.
5. Lalèyè P, Niyonkuru C, Moreau J, Teugel S. - Spatial and seasonal distribution of the ichtyofauna of Lake Nokoué, Bénin, West Africa. Afr. J Aquat. Sci. 2003;28:151-161.
6. Gnohossou P. La faune benthique d'une lagune ouest africaine (le Lac Nokoué au Bénin), diversité abondance, variation temporelles et spatiales, place dans la zone trophique. Thèse de Doctorat. Institut national polytechnique de Toulouse. Formation doctorale SEVAB. 2006, 169.
7. Niyonkuru C. Etude comparée de l'exploitation et de démographie des poissons cichlidés dans les lacs Nokoué et Ahémé au Bénin. Thèse de Doctorat en gestion de l'environnement. Université d'Abomey-Calavi. Bénin. 2007, 199.
8. Adandédjan D. Diversité et déterminisme des peuplements de macro invertébrés benthiques de deux lagunes du Sud-Bénin : la Lagune de Porto-Novo et la Lagune côtière. Thèse pour l'obtention du grade de Docteur en Sciences Agronomiques de l'Université d'Abomey-Calavi (UAC) Bénin. 2012, 260.
9. Falana NE. Etude d'un environnement lagunaire: cas de la lagune de Porto-Novo. Mémoire de maîtrise, Département de Géographie et d'Aménagement du Terroir, FLASH/UNB. 1989, 120.
10. Adandédjan D, Lalèyè P, Gourène G. Macroinvertebrates communities of a coastal lagoon in southern Benin, West Africa. Int. J Biol. Chem. Sci. 2012;6(3):1233-1252.
11. Adandédjan D, Lalèyè P, Ouattara A, Gourène G. Distribution of Benthic Insect Fauna in a West African Lagoon: The Porto-Novo Lagoon in Benin. Asian Journal of Biological Sciences. 2011;4(2):116-127.
12. Iltis A. Les algues. In: Durand J, Lévêque C. Flore et Faune aquatiques de l'Afrique Sahélo-soudanienne Tome I. Éditions O. R. S. T. O. M., Collection Initiations Doc. Tech. 44, Paris, 1980, 9-61.
13. Bourrelly P. Les algues d'eau douce : les algues vertes, éd. N. Boubée. 1966;1:572.
14. Bourrelly P. Les algues d'eau douce : les algues jaunes et brunes, éd. N. Boubée, 1968;2:517.
15. Bourrelly P. Les algues d'eau douce : les algues bleues et rouges, éd. N. Boubée. 1970;3:606.
16. Compère P. Contribution à l'étude des algues du Sénégal. Algues du lac de Guiers et du Bas Sénégal. Bulletin du jardin botanique national de Belgique. 1991;61:171-267.
17. Ouattara A, Poodor N, Teugels GG, Gourène G. Les microalgues de deux cours d'eau (Bia et Agnébi) de Côte d'Ivoire. Syst. Geogr. 2000;Pl(70):315-372.
18. Alexis B, Marie P, Koffi K, Allassane O. Cyanobacteria from a shallow Reservoir in Côte d'Ivoire. Journal of Biodiversity and Environmental Sciences (JBES). 2015;7(5):136-149.
19. Alexis B, Ouattara A, Kouhété P. Euglenozoa occurring in Adzopé Reservoir, Côte D'Ivoire. Turk J Bot. 2013, 37. © TÜBİTAK.
20. Kohonen T. Self-organized formation of topologically correct feature maps. Biology Cybernet. 1982;43:59-69.
21. Kohonen T. Self-organizing maps. 3rd ed. Springer: Berlin. 2001.
22. Wilppu E. The visualization Capacity of Self- Organizing Maps to detect Deviation in Distribution Control. TUCS Technical Report No 153, Turku Centre for Computer Science. Finland. 1997.
23. Park YS, Céréghino R, Compin A, Lek S. Applications of Artificial Neural networks for Patterning and Predicting aquatic insects species richness in running waters. Ecological Modelling. 2003;160:265-280.
24. Alhoniemi E, Himberg J, Parhankangas J, Vesanto J. SOM Toolbox. 2000. http://www.cis.hut.fi/projects/somtoolbox
25. Adjahouinou D. Diversité du Phytoplancton et degré de pollution des eaux du collecteur de Dantokpa (Cotonou-Bénin). Mémoire de Master FSA/UAC. 2010, 74.
26. Hountogan MP. Diversité phytoplanctonique et qualité écologique du lac Nokoué au Bénin. Mémoire de Master en monitoring des ressources aquatiques et aménagement des pêches continentales. Faculté des Sciences Agronomiques/UAC. 2015, 76.
27. Thomas CS. "Protist phylogeny and the high-level classification of Protozoa", Europ. J. Protistol.

2003;39:338-348.
28. Groga N. Structure, fonctionnement et dynamique du phytoplancton dans le lac Taabo (Côte d'ivoire). Thèse de Doctorat en Ecologie Fonctionnel, Université de Toulouse (France) 2012, 224.
29. Walsby AE, Dubinsky Z, Kromkamp JC, Lehmann C, Schanz F. The effects of diel changes in photosynthetic coefficients and depth of Planktothrix rubescens on the daily integral of photosynthesis in Lake Zurich. Aquat. Sci. 2001;63:326-349.
30. Walsby AE, Ng G, Dunn C, Davis PA. Comparison of the depth where *Planktothrix rubescens* stratifies and the depth where the daily insolation supports its neutral buoyancy. New Phytologist. 2004 ;162:133-145. www.newphytologist.org
31. Salsamo N, Morabito G, Buzzi F, Garibaldi L, Simona M, Mosello R. Phytoplankton as an indicator of the water quality of the deep lakes south of the Alps. Hydrobiologia. 2006;563:167-187.
32. Reynolds C, Huszar V, Kruk C, Naselli-Flores L, Melo S. Towards a functional classification of the freshwater phytoplankton. J. Plank. Res. 2002;24:417-428.
33. Jacquet S, Briand JF, Leboulanger C, Avois-Jacquet C, Oberhaus L, Tassin B *et al.* The proliferation of the toxic cyanobacterium *Planktothrix rubescens* following restoration of the largest natural French lake (Lac du Bourget). Harmful Algae. 2005;4:651-672.
34. Descy JP, Coste M. Utilisation des diatomées benthiques pour l'évaluation de la qualité des eaux courantes. Rapport final. UNECD-Namur, Cemagref, Bordeaux CEEB. 1990, 112.