International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 20 No. 4 Jul. 2017, pp. 1198-1209

http://www.ijias.issr-journals.org/

Spatial and seasonal dynamic of phytoplankton abundance in Aghien lagoon, Côte d'Ivoire

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ABSTRACT: Phytoplankton abundance in relation with physico-chemical parameters were investigated at 11 stations monthly from May 2014 to april 2015 in Aghien lagoon. Distribution of phytoplankton abundance had homogeny within the entire lagoon. However it notices differences between seasons. The high abundance was recorded in the low rainy season (2.3 10^7 cells/mL) and the low one in the high dry season (1.1 10^7 cells/mL).The seasonality is confirmed by Indicator value and RDA. Three groups were determined according seasons. The high rainy season assemblage was influence by conductivity and high temperature. Ammonium, BOD, dissolved oxygen and pH influence species of low dry season. Concerning the group 3 (high dry season and low rainy season), abundance of species is associated to high value of turbidity and nitrate. Indeed, the phytoplankton community of Aghien lagoon is still dominated by Cyanobacteria such as *Microcystis wesenbergii* (Komarek.) Komarek., *M. aeruginosa* (Kützing) Nägeli., *Microcystis* sp., *Aphanocapsa incerta* (Lemm.) Cronb. & Kom. and *Anabaena circinalis* Rabenh.ex Born. & Flash. These species are responsible for different blooms recorded in the Aghien lagoon. It also important to identified the kind of toxins these bloom-forming cyanobactorial produce in this lagoon.

KEYWORDS: Aghien lagoon; Côte d'Ivoire; dynamic; Indval; Phytoplankton; spatial and temporal.

1 INTRODUCTION

Aquatic ecosystems are very vulnerable environments due to human activities which represents one of the major causes of stress [1]. So many water bodies are irreversibly damaged by pollution and / or eutrophication [2]. Lagoons, transition areas and exchange between the oceanic and continental domain [3] are threatened on one hand by the continental pollution (solid waste, waste water, pesticides ...) and on the other hand by marine pollution (ballast water, petroleum products ...). Aghien Lagoon, part of Ebrié Lagoon system in Ivory Coast is not immune to pollution. Its watershed has both urban and agricultural areas that could harm the water quality of the lagoon [4]. Physico-chemical studies of the lagoon show the impact of runoff from farmland on water quality [5]. However, the biological communities, considered as integrators of environmental perturbations ([6]; [7]) have not been studied, among those listed in good stead phytoplankton. These organisms are the basis of the pelagic food chain and therefore responsible for a substantial part of primary production in aquatic environments. Changes made in their abundance and specific composition will therefore affect the upper levels of the trophic network. Their use, as biological indicators of freshwater quality, has become common in the management of aquatic environments ([8]; [9]). When certain conditions are favourable (high temperatures associated with calm weather, high nutrient levels of anthropogenic or natural origin), some species can grow significantly [10]. Thus phytoplankton information is essential to understanding the functioning of aquatic ecosystem. Despite these multiple interests, algal studies still arouses little interest in Africa and particularly in the Ivory Coast. Lagoon phytoplankton studies in Ivory Coast have for the most part concerned the Ébrié lagoon ([11]; [12]; [13]; [14]) and to a lesser extent the Aby lagoon [14], Fresco [15] and Grand-Lahou ([16]; [14]). Recent studies on Aghien lagoon have focused among others on morphological analysis, sedimentological environment of surface sediments, on the physical, chemical and bacteriological parameters [5] and the determination of the protection perimeters of the lagoon Aghien by the calculation of water transfer time hike over to lagoon [4]. No microflora studies of the Aghien lagoon have been conducted. Ignorance of the first link in the food web therefore justifies the interest of this study that aims to investigate the phytoplankton population of the Aghien lagoon and their abiotic factors.

2 MATERIAL AND METHODS

2.1 STUDY AREA

Aghien lagoon (Fig. 1) is situated on the Ivorian coast of Atlantic Ocean, northern of Ebrié lagoon, in Abidjan district, between 5°22'N to 5°26'N and 3°49'W to 3°55'W. The lagoon has a surface area of about 19 km², and is 32 km long the median axis. Its shallow basin is not directly connected with the sea. The Aghien lagoon is separated from the Atlantique Sea by the Potou lagoon and the Ebrié lagoon. Salinity is always zero. Three rivers Mé, Djibi and Bété are effluents of Aghien lagoon. The area climate is divided in four seasons: High rainy season (April to July), Low dry season (August to September), Low rainy season (October to November) and High dry season (December to March).

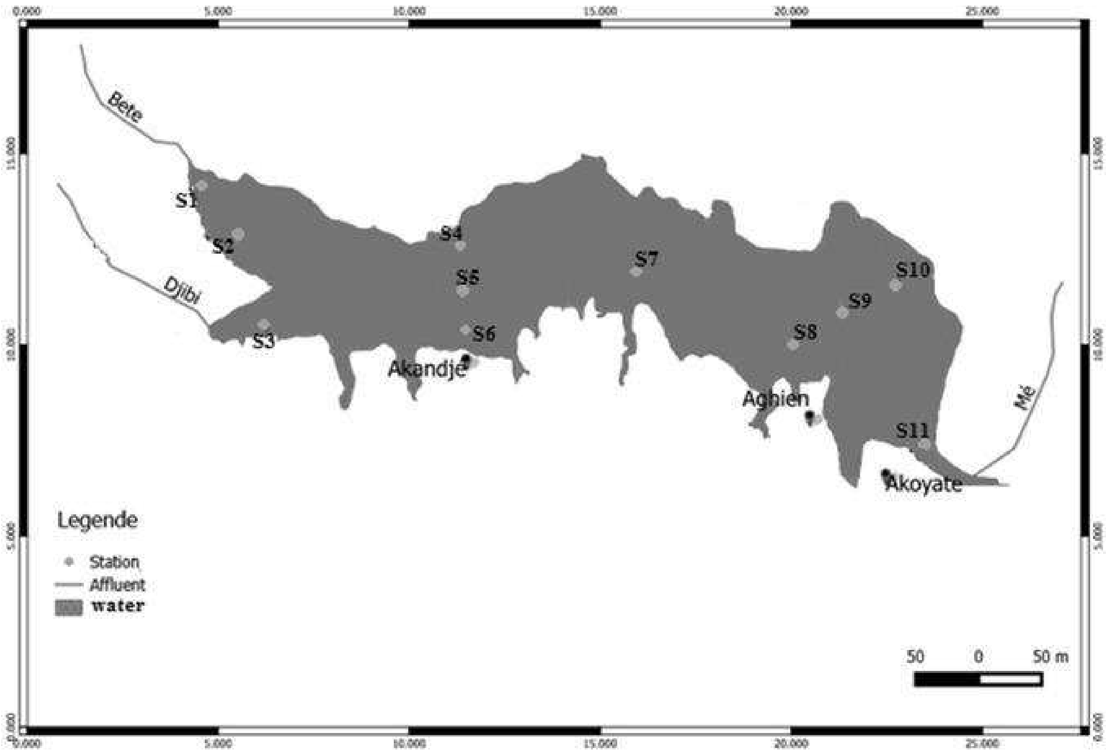

Figure 1: Distribution of sampling point in the Aghien lagoon

2.2 MEASURING PARAMETERS ABIOTIC

Twelve sampling campaigns were carried out from June 2014 to May 2015. These campaigns cover the four climatic seasons (high dry season, high rainy season, low dry season, low rainy season). The physico-chemical parameters were measured using various devices. A GPS MLR SP 12X was used to locate the sites. Conductivity and temperature were measured using HACH CO 150 conductimeter type. A pH meter Hach HQ 40 d was used to measure the pH. Dissolved oxygen was determined using a WTW OXI 320 oxymeter. A Wagtech turbidimeter was used to measure turbidity. For nitrate, ammonium and ortho-phosphate concentrations, surface water samples were taken and kept in one liter bottles of one liter at a temperature of 4°C. In the laboratory, the concentrations were determined according to standard T90-110 for nitrate, T90-015-1 for ammonium, NF EN ISO 6878 for ortho-phosphates (AFNOR, 1994). DBO5 was determined using standard NF EN 1899-1.

2.3 SAMPLE, OBSERVATION, IDENTIFICATION AND PLANKTON COUNTING

Phytoplankton was collected using a hydrological type Niskin bottle of 1.5 liter capacity and plankton net. In the laboratory, samples were cleaned of organic matter with hydrogen peroxide and rinsed several times before mounting in Naphrax. The samples were stored in 30 ml pill and fixed in formalin 5%. Observation of taxa was performed using a microscope triocular type Olympus BX40. Identification of taxa was made at the specific or infraspecific level using (keys and / or description) ([17], [18]), [19], [20], [21]), [22], [23], [24]), [25], [26], [27]. The phytoplankton counting was performed after homogenization of samples. Only samples collected using the hydrological bottle were taken into account. A fraction was taken, mounted on Malassez cell and observed under a microscope triocular. Phytoplankton density is expressed as number of cells per unit volume (cells / mL).

2.4 CHARACTERIZATION OF STAND-ALGAL

Species richness, diversity index of Shannon-Wiener (H ') and the evenness (E) were calculated to characterize the phytoplankton structure. Species richness is a good indicator of the capacity of a site. Shannon-Wiener index measures the degree of organization of settlement and fairness to study the regularity of the distribution of species.

$$H' = \sum_{i=1}^{R_s} (q_i) \times Log_2 (q_i)$$

q_i = proportion of the i species (i varying from 1 to Rs), Rs = total number of species. The diversity is minimum when H 'tends to 0 and maximal when H 'tends to infinity

$$E = \frac{H'}{(Log_2 R_s)}$$

H' = diversity index Shannon-Wiener, Rs = total number of species.

Low evenness indicates that the population is dominated by a few species. E tends to 1 when all species have the same abundance.

2.5 STATISTICAL ANALYSES

Taxa occurring in at least three samples with a relative abundance of 1% or more in at least one sample were included in the statistical analyses in order to minimize the influence of rare taxa. Of the 132 taxa recorded in quantitative phytoplankton samples, 81 met this criterion.

Principal Component Analyse (PCA) was used to classify species abundance according to sites and seasons. A cluster analysis was performed on the PCA first two axes. This permited the definition of the different groups according to assemblages determined by the PCA. A Kruskal Wallis test was applicate to abundance matrix to see if there is difference between sites or seasons. If significant differences were detected, pairwise Mann Whitney-U post hoc tests were implemented. The tests are significant at $p < 0.05$. The software R i386 3.1.3 [28] with the package ade 4 [29] was used for this analysis.

To identify species assemblages that characterize each season, the Indicator Value index (IndVal, [30]) was calculated for each species based on the observation classification. The IndVal index combines the species relative abundance (the so-called specificity, Ajk) with the species relative frequency of occurrence in a given group of observations (the so-called fidelity, Bjk):

$IndVal_{jk} = A_{jk} \times B_{jk} \times 100$

The IndVal analysis identifies the most characteristic species in each season not only on the basis of their highest abundance but also on their regular occurrence in that period. Therefore, the IndVal index is maximum when all individuals of a species are found in a single group of observations and when the species occurs in all observations of that group. Following Dufrêne and Legendre [30], only indicator values 25% were retained.

Canonical redundancy analysis (RDA) was applicate to meet a relation between phytoplankton abundance and physico-chemical parameters using the program CANOCO 4.5. The Monte Carlo permutation test (499 permutations) was used to obtain the P-value, carried out for all canonical axes.

3 RESULTS

3.1 SPATIO-TEMPORAL VARIATION OF ABIOTIC PARAMETERS

Monitoring data from 2013 to 2014 show that temperatures in the high dry season were lower in site 10 than in the low rainy season (LRS) for the same site (Table 1). Mean values for conductivity ranged from 59.95 µS⁄cm in the low dry season at site 10 to 146 µS⁄cm in high rainy season (HRS) at site 6. Turbidity values were low (11.12 NTU) at site 10 in high dry season (HDS) and high (64.1 NTU) at site 4 in low dry season (LDS). The Aghien lagoon water was acid in HRS at site 11 (6.6) and basic in LRS at site 10 (8.5). Dissolved oxygen was generally higher in site 9 (15.01 $mgO_2\ L^{-1}$) contrasting with site 11 (4.11 $mgO_2\ L^{-1}$) in HRS. There were high variations in phosphates with concentrations varying from site 4 in HRS (0.34 $mgPO_4\ L^{-1}$) to site 5 in LRS (0.04 $mgPO_4\ L^{-1}$). The lowest values for nitrate were recorded in HDS at site 8 (0.23 $mgNO_3\ L^{-1}$) whilst the highest (2.6 $mgNO_3\ L^{-1}$) were recorded in LRS at site 10. The ammonium concentrations, which were generally low, varing between 0.08 $mgNH_4\ L^{-1}$ in HDS at site 7 and 0.57 mg $NH_4\ L^{-1}$ in LRS at site 4. The lowest and highest BOD concentrations, 6.53 $mgO_2\ L^{-1}$ and 34.45 $mgO_2\ L^{-1}$, were recorded in LDS at site 4 and in HDS at site 8.

Table 1: Selected paramaters describing the seasonal and spatial variation in the phytoplanktonic environment in Aghien Lagoon. Abbreviations and units: T (°C) = water temperature, Cond = Conductivity (µS/cm); Turb = Turbidity (NTU); PO_4 = Phosphates ($mgPO_4\ L^{-1}$); DO = Dissolved Oxygen ($mgO_2\ L^{-1}$); NO_3 = Nitrate ($mgNO_3\ L^{-1}$); NH_4 = Ammonium ($mgNH_4\ L^{-1}$); BOD = Biological Oxygen Demand.

Sites	Season	T (°C)	Cond	Turb	pH	PO_4	DO	NO_3	NH_4	BOD
S1	HRS	27.2	67.9	42.33	6.97	0.1	5.28	1.21	0.13	16.52
	LDS	26.35	60.35	54.25	7.35	0.07	6.25	1.43	0.09	15.01
	LRS	29	68.85	18.8	7.65	0.32	6.95	1.02	0.25	18.25
	HDS	26.3	76.98	16.28	7.75	0.095	7.93	0.87	0.14	17.83
S2	HRS	27.6	71.77	40.37	6.97	0.08	4.42	1.09	0.16	11.25
	LDS	26.4	62.85	38.35	16.6	0.05	6.8	2.49	0.099	9.95
	LRS	29.15	69.15	18.75	7.55	0.06	6.75	1.07	0.25	15.85
	HDS	26.35	69.35	13.47	7.55	0.09	7.25	0.26	0.15	15.13
S3	HRS	27.73	69.1	47.1	7.03	0.1	4.9	1.62	0.15	16.29
	LDS	27.45	60.6	61.45	7.35	0.08	6.35	1.32	0.09	10.71
	LRS	29.2	69.3	20.05	7.8	0.06	8	0.72	0.15	16.15
	HDS	27.45	70.15	16.78	8.2	0.07	8.08	0.51	0.34	15.83
S4	HRS	29.6	71.93	54.3	7.47	0.12	4.82	1.18	0.27	12.03
	LDS	27.05	61.2	64.1	7.5	0.07	6.45	1.89	0.1	6.53
	LRS	29.55	68.6	20.6	7.9	0.07	7.5	0.89	0.57	17.2
	HDS	27.53	64.95	12.6	7.4	0.34	7.38	0.56	0.2	15.69
S5	HRS	29.6	72.25	59.72	7.37	0.11	4.52	1.17	0.28	10.26
	LDS	27.07	61.53	62.2	7.43	0.07	6.38	2.22	0.11	12.74
	LRS	28.85	67.18	18.93	8.03	0.04	7.7	0.59	0.29	17.63
	HDS	27.65	69.68	14.45	7.88	0.09	8.3	0.43	0.28	16.13
S6	HRS	29.4	146.33	54.6	7.8	0.07	4.63	0.98	0.23	19.29
	LDS	26.75	61.5	63.15	7.35	0.08	5.9	1.36	0.12	19.6
	LRS	28	67.7	13.38	6.75	0.05	6.2	0.93	0.29	15.9
	HDS	27.3	70.47	13.27	7.53	0.08	7.35	0.32	0.14	18.69
S7	HRS	29.77	72.17	54.91	7.4	0.1	4.77	1.12	0.23	13.78
	LDS	26.72	63.62	55.47	7.25	0.06	5.93	1.91	0.1	15.28
	LRS	29.3	67.95	17.6	7.9	0.06	7.7	1.23	0.23	33
	HDS	27.75	69.8	12.73	7.95	0.07	8.02	0.34	0.08	16.75
S8	HRS	29.47	71.2	62.37	7.43	0.11	5.31	1.09	0.12	18.16
	LDS	26.55	60.3	58.5	7.3	0.07	6.15	1.19	0.099	9.17
	LRS	29.05	65	23.65	7.1	0.06	6.9	0.79	0.36	33.3
	HDS	25.1	71.63	17.55	6.78	0.08	7.43	0.23	0.1	34.45
S9	HRS	29.72	116.98	58.59	7.12	0.1	15.01	1.11	0.22	14.95
	LDS	26.7	60.25	53.55	7.45	0.05	6.05	1.94	0.099	14.55
	LRS	29.73	65.05	25.525	8.27	0.06	7.83	0.69	0.54	33.85
	HDS	24.3	70.43	13.08	7.57	0.07	7.8	0.31	0.11	18.38
S10	HRS	27.81	71.38	34.49	7.68	0.09	6.83	0.99	0.2	17.07
	LDS	26.9	59.95	57.3	7.4	0.06	6.4	1.35	0.099	12.4
	LRS	30	67.15	23.5	8.5	0.06	7.3	2.61	0.56	17.65
	HDS	24.1	69.63	11.12	7.43	0.07	8.05	0.38	0.11	23.23
S11	HRS	29.27	60.1	56.93	6.63	0.13	4.11	1.66	0.12	24.46
	LDS	26.58	63.33	41.93	7.53	0.05	6.47	1.29	0.099	10.87
	LRS	28.55	69.73	28.75	7.18	0.07	6.4	0.81	0.51	26.95
	HDS	26.35	75.05	22.4	7.13	0.09	6.83	0.37	0.16	27.65

3.2 SPATIAL AND SEASONAL VARIATION OF PHYTOPLANKTON ABUNDANCE

One hundred sixty-five (165) taxa were recorded in all sites from qualitative and quantitative phytoplankton samples. In the 11 sites of Aghien lagoon, cyanobacteria present the high abundance in all seasons followed by diatoms (Fig. 2).

The spatial variation of phytoplankton abundance indicates the highest value at site 8 with 2.5 10^7 cells/mL and the lowest value at site 6 with 9.1 10^6 cells/mL. Concerning the phytoplankton communities, site 1 had a dominance of cyanobacteria *Anabaena circinalis* Rabenh.ex Born. & Flash. (7.6 10^6 cells/mL), *Microcystis aeruginosa* Kütz. (3.9 10^6 cells/mL), *Aphanocapsa incerta* (Lemm.) Cronb. & Kom. (2.2 10^6 cells/mL), *Microcystis wesenbergii* (Kom.) Kom. (6.4 10^5 cells/mL) and the diatom *Asterionella formosa* Hass. (4.5 10^5 cells/mL); site 2, the cyanobacteria *Aphanocapsa incerta* (7 10^6 cells/mL), *Anabaena circinalis* (1.8 10^6 cells/mL), *Aphanocapsa* sp. (1.5 10^6 cells/mL) and *Microcystis wesenbergii* (9.6 10^5 cells/mL) and the diatom *Aulacoseira granulata* (Ehren.) Simon. (4.2 10^5 cellules/mL). Concerning site 3, densities were dominated by cyanobacteria: *Anabaena circinalis* (5.2 10^6 cells/mL), *Aphanocapsa* sp. (2 10^6 cells/mL), *Aphanocapsa incerta* (1.7 10^6 cells/mL) as the diatom *Asterionella formosa* (2.9 10^5 cells/mL). Sites 4 and 5 present the predominance of cyanobacteria *Aphanocapsa incerta* (S4: 2.9 10^6 cells/mL and S5: 6.8 10^6 cells/mL, respectively), *Anabaena circinalis* (S4: 2.8 10^6 cellules/mL and S5: 5.9 10^6 cells/mL, respectiviely) and the diatom *Aulacoseira granulata* (2.9 10^5 cells/mL) at site 5. Cyanbacteria *Anabaena circinalis* (3.4 10^6 cells/mL), *Aphanocapsa* sp. (1.4 10^6 cells/mL), *Microcystis* sp. (1.1 10^6 cells/mL) and the diatom *Aulacoseira granulata* (1.8 10^5 cells/mL) have high abundance at site 6 while species *Aphanocapsa incerta* (7.5 10^6 cells/mL), *Microcystis* sp. (3.6 10^6 cells/mL), *Anabaena circinalis* (1.8 10^6 cells/mL) and the diatom *Aulacoseira granulata* (3.5 10^5 cells/mL) are more abundant at site 7. Sites 8, 9, 10 and 11 had the predominance of cyanobacteria *Anabaena circinalis* with respectively 9 10^6 cells/mL, 3.3 10^6 cells/mL, 3.6 10^6 cells/mL and 1.6 10^6 cells/mL ; *Microcystis aeruginosa* (3 10^6 cells/mL ; 2.1 10^6 cells/mL, 5.8 10^6 cells/mL and 9.9 10^5 cells/mL respectively) as well as the diatom *Aulacoseira granulata* (7.6 10^5 cells/mL) at site 8 and *Asterionella formosa* at sites 9, 10, and 11 with 3.6 10^5 cells/mL, 3.7 10^5 cells/mL and 6.3 10^5 cells/mL respectively.

The seasonal variation of phytoplankton abundance indicates a significate difference between high rainy season and low rainy season ($p = 0.01$) and between low dry season and low rainy season ($p = 0.001$). The high abundance was recorded in the low rainy season (2.3 10^7 cells/mL) and the low one in the high dry season (1.1 10^7 cells/mL). Seasonal phytoplankton succession was found in the Aghien lagoon. The high rainy season was marked by the abundance of *Microcystis aeruginosa* (1.2 10^7 cells/mL) and *Trachelomonas* spp. (5.6 10^5 cells/mL). In the low dry season and the low rainy season, there was a decrease in the density of *Trachelomonas* spp. and the appearance of the cyanobacteria *Anabaena circinalis* with abundance vary to 1.78 10^6 at 2.04 10^7 cells/mL. During those seasons cyanobacteria *Microcystis aeruginosa* (1.01 10^7 cells/mL), *M. wesenbergii* (3 10^7 cells/mL), *Microcystis* sp. (7.7 10^6 cells/mL) and diatoms *Asterionella formosa* (1.4 10^6 cells/mL), *Aulacoseira granulata* (7.08 10^6 cells/mL) and *Aulacoseira granulata* var. *angustissima* (2.62 10^6 cells/mL) were also abundant. Species *Anabaena circinalis* and *Asterionella formosa* decrease during the high dry season and disappear in the high rainy season from all sampling sites within the Aghien lagoon.

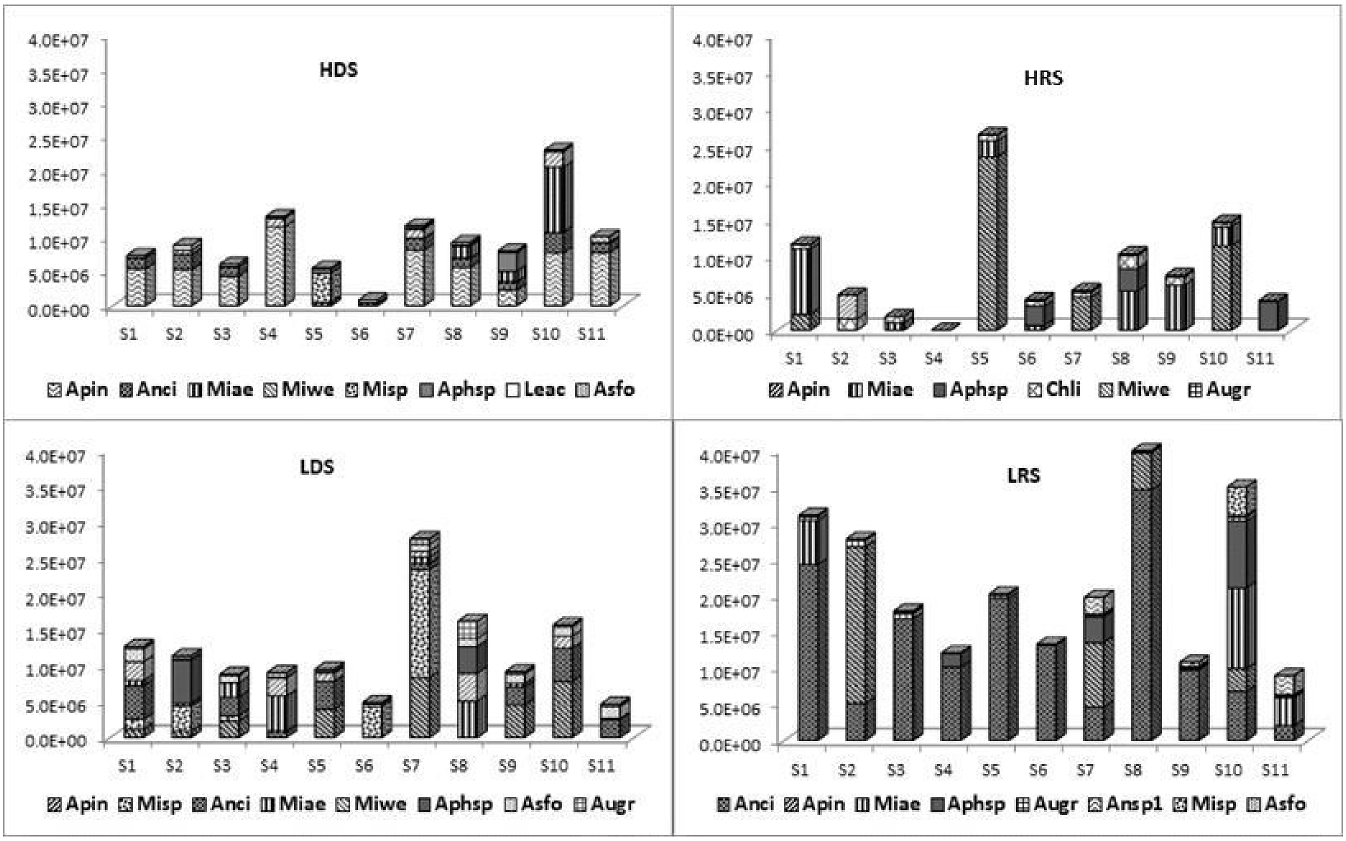

Figure 2: Spatial and seasonal variation of dominate phytoplankton taxa

Shannon index and evenness were calculated for each site and each season (Fig. 3). The low values 0.38 and 0.14 respectively for Shannon index and evenness were recorded at site 5 in the low rainy season. The high values were noted at site 11 in low dry season with respectively 2.41 and 0.77.

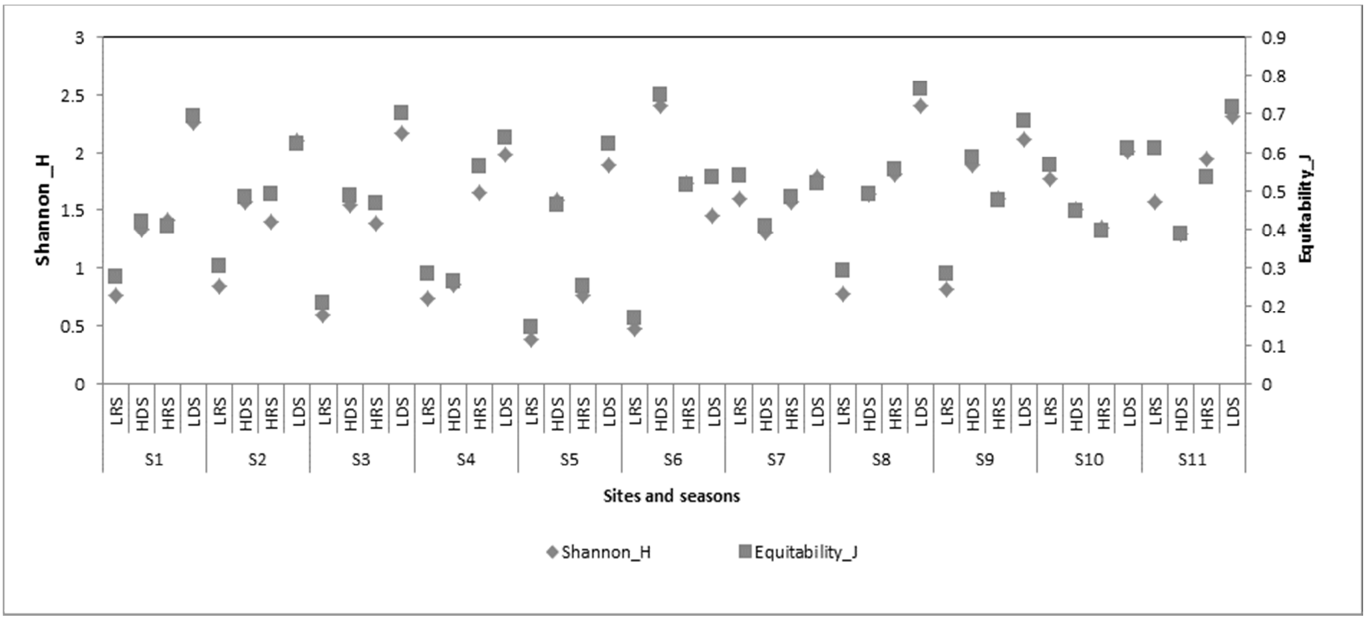

Figure 3: Spatial and seasonal variation of Shannon index and evenness in the sites of Aghien lagoon

The principal component analysis (PCA) was used to classify the samples according the abundance (Fig. 4). The two first axes give 28.5% of cumulate total inertia. PCA permitted identifying the differences between seasons (Kruskall Wallis, $p < 0.05$) but not between sites (Kruskall Wallis, $p < 0.05$). There is difference between samples of LDS and HRS and between HDS and HRS. The cluster analysis confirms these results (Fig. 5) and separates samples in three groups according season (1, 2 and 3). Group 1 was made up of high rainy season samples; group 2 consists of low dry season samples, while group 3 contained samples from both the low rainy season and high dry season.

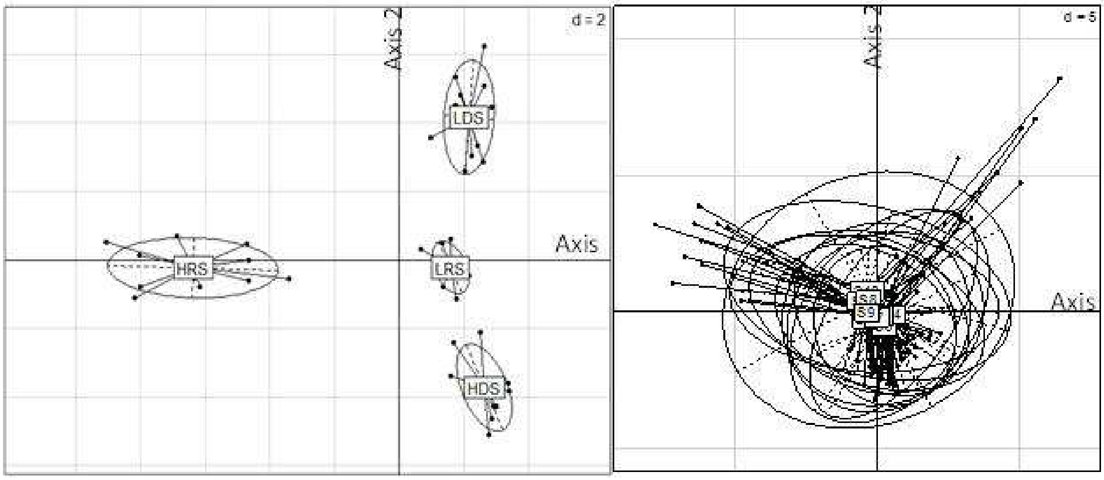

Figure 4: Principal component analysis based on abundance of phytoplankton according sites and season in Aghien lagoon. HDS: High Dry Season; HRS: High Rainy Season; LDS: Low Dry Season; LRS: Low Rainy Season.

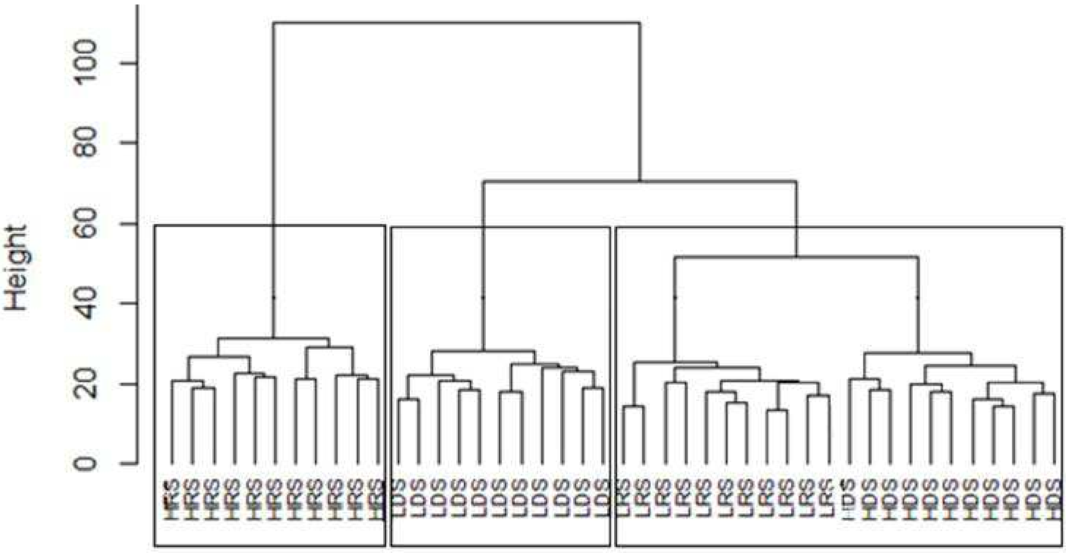

Figure 5: Dendrogram showing the relationships between the 3 groups of phytoplankton samples in Aghien lagoon.

The results of Indval based on 81 species, only 71 species were selected Ten species were present within all groups; they were all a significant indicator for all groups (37% to 99%). The species were: *Aphanocapsa* sp. (50%), *Aphanocapsa incerta* (74%), *Aulacoseira granulata* (98%), *Coelastrum microporum* Näeg. (60%), *Microcystis aeruginosa* (71%), *Scenedesmus quadricauda* (Turp.) Bréb. (60%), *Staurastrum gladiosum* Turn (78%), *Trachelomonas hispida* (Perty) Stein em. Defl. (64%), *Trachelomonas volvocina* Delf. (81%) and *Ulnaria ulna* (Nitz.) Lange-B. (99%). Repartition of species into different groups is given in the Table 2. The group 1 recorded the highest number with 20 species and 19 significant indicator species. Fourteen species were range in the group 2 with 8 significant indicators species. Seven species compose the group 3 with 6 significant indicators species.

Table 2: The most indicative phytoplankton taxa identified with the method of Dufrêne & Legendre (1997) for the Aghien lagoon defined from cluster analysis based on abundance dataset.

Groupe	Taxa	Code	Indicator Value	P
1	*Pseudoanabaena limnetica*	Psli	98	***
	Oscillatoria proboscidea	Ospr	95	***
	Peridinium cinctum	Peci	91	***
	Chroococcus limneticus	Chli	90	***
	Spondylosum sp.	Sposp	80	***
	Golenkinia radiata	Gora	79	***
	Trachelomonas sp.	Trsp	74	***
	Staurastrum polymorphum	Stpo	74	***
	Coelastrum sp.	Coesp	72	***
	Trachelomonas volvocinopsis	Stvol	71	**
	Gyrosigma acuminatum	Gyac	67	**
	Staurastrum cingulum	Stci	67	**
	Staurastrum pseudotetracerum	Stps	67	**
	Phormidium sp.	Phosp	60	*
	Spirulina sp.	Spsp	54	*
	Oscillatoria limosa	Osli	53	*
2	*Asterionella formosa*	Asfo	89	***
	Merismopedia elegans	Meel	85	***
	Scenedesmus quadricauda	Scqu	71	**
	Acanthoceras sp1	Acsp1	68	***
	Trachelomonas planctonica	Trpl	64	**
	Microcystis sp.	Misp	61	**
	Microcystis wesenbergii	Miwe	60	*
	Merismopedia sp.	Mesp	60	**
3	*Staurastrum branchioprominens*	Stbra	64	**
	Closteriopsis longissima	Clon	56	*
	Staurastrum gracile	Stgr	56	*
	Staurastrum volans	Stvo	56	*
	Treubaria triappendiculata	Trtr	56	*
	Staurodesmus triangularis	Sttr	52	*

3.3 RELATION BETWEEN PHYTOPLANKTON ABUNDANCE AND PHYSICO-CHEMICAL PARAMETERS

Distribution according to the environmental variables, the characteristic taxa of the lagoon were determined on the basis of their abundance during the study. The Monte Carlo permutation tests (n = 1000 permutations) indicated that the results of the redundancy analysis performed were significant ($p < 0.01$). The result of the Redundancy analysis (RDA) indicates that the first two axes express 62.1% of the total variability (Table 3). The graph indicated three groups according to the season (Fig. 6). One group constituted by samples of high rainy season (HRS) was positively correlated to axis 1 and associated to conductivity and temperature. Those parameters influenced the abundance of taxa such as: *Golenkinia radiata* (Chod.) Will. (Gora), *Trachelomonas volvocina* (Trvol)*, Phormidium* sp*.* (Phsp), *Coelastrum* sp.(Coesp), *Spondylosum* sp.(Sposp) and *Scenedesmus quadricauda* (Scqa). Samples of low dry season formed group 2 that correlate positively to axis 2, with high concentrations of nitrate and turbidity. Species influenced by these parameters are for example: *Asterionella formosa* (Asfo)*, Microcystis wesenbergii* (Miwe)*, Microcystis aeruginosa* (Miae)*, Aphanocapsa* sp*.* (Apsp) and *Chroococcus* sp.(Chsp). The group 3 was composed of samples from the high dry season and low rainy season and correlated negatively to axis 2 and associated to dissolved oxygen, BOD, ammonium, pH and phosphates. Species such as: *Aulacoseira granulata* var. *angustissima* (O. Müll.) Sim. (Auga), *Anabeana circinalis* (Anci), *Aulacosiera ambigua* (Grun.) Sim. (Auam), *Trachelomonas hispida* (Trhi), *Staurastrum gladiosum* (Stgl), *Pediastrum duplex* Meyen (Pedu), *Lepocinclis acus* O.F.Müll.) Marin & Melkonian (Leac), *Treubaria triappendiculata (Schröd.) Fott & Kavá.* (Trtr)*, Gomphonema* sp*.* (Gosp) and *Staurastrum glaber* (G.S.West) Teiling (Stgla) were abundant at these periods.

Table 3: Eigenvalues and cumulative percentage variance of data

Axes	1	2	3	4
Eigenvalues	0.125	0.098	0.042	0.025
Species-environment correlations	0.805	0.897	0.885	0.729
Cumulative percentage variance of species data	12.5	22.3	26.5	28.9
of species-environment relation	34.8	62.1	73.9	80.7

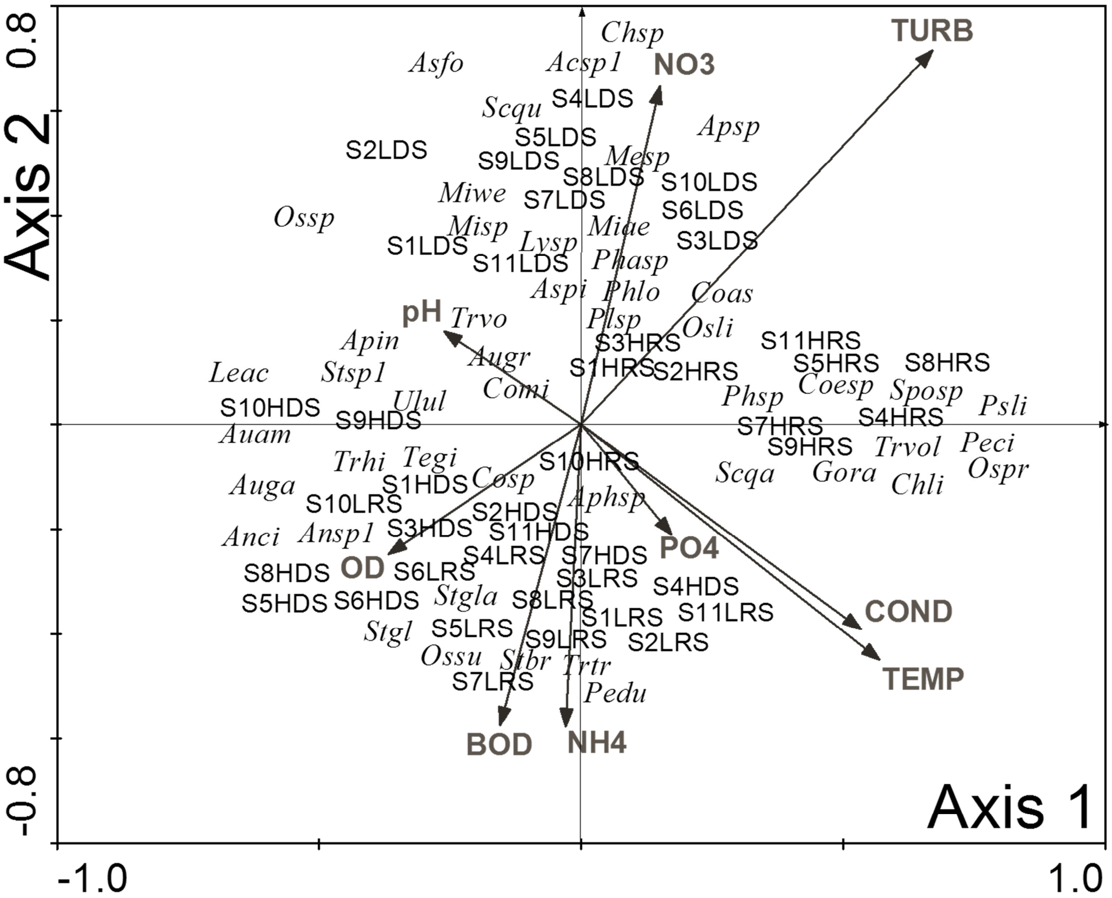

Figure 6: Redundancy analysis (RDA) between physico-chemical parameters and phtyplanktonic abundant taxa. T = water temperature, Cond = Conductivity (µS/cm); Turb = Turbidity (NTU); PO_4 = Phosphates (mgPO_4/L); DO = Dissolved Oxygen (mgO_2/L); NO_3 = Nitrate (mgNO_3/L); NH_4 = Ammonium (mgNH_4/L); BOD = Biological Oxygen Demand, (see annexe for taxa code).

4 DISCUSSION

Analysis of the phytoplankton community in Aghien lagoon reveals differences between seasons but not between sites. Distribution of phytoplankton abundance had homogeny within the entire lagoon. The seasonal variation of abundance could be attributed to the change in environmental conditions throughout the year that may affect recruitment, survival and reproduction of phytoplankton as shown by [31], [32] and [33]. This situation is confirmed by the results of Indval and RDA in this study. In fact, most African lakes have well-established seasonality in phytoplankton abundance, which is governed mainly by climate [34]. Phytoplankton density was higher in low rainy season and lower in high dry season. The same result was recorded by [35] in Grand-Lahou lagoon and opposite to Fresco lagoon [15], Ebrié and Aby lagoon [14] in Ivory Coast. Low rainy season was characterized by high temperature (mean: 29.1°C), nitrate concentration (mean: 1.03 mgNO3/L), ammonium (mean: 0.37 mgNH4/L) and pH (median: 7.44), which were favorable conditions for phytoplankton growth. According to [34] and [33], phytoplankton growth has been associated to increased water temperature and nutrients. Indeed, the phytoplankton community of Aghien lagoon is still dominated by Cyanobacteria with *Microcystis* and *Anabaena* species as reported in previous studies of Ivory Coast lagoon ([15]; [14]). This dominance is not due to the many number of cyanobacterial taxa but to the high number of cells that compose filamentous species such as *Anabaena circinalis* and colonial species *Microcystis wesenbergii, M. aeruginosa* and *Microcystis* sp. It was noticed that cyanobacteria species may be adapted to extreme environmental condition [36]. The species with the highest abundances in all stations, *Anabaena circinalis, Microcystis aeruginosa, M. wesenbergii, Aphanocapsa incerta, Asterionella formosa, Aulacoseira granulata, A. granulata* var*. angustissima, Lepocinclis acus* and *A. ambigua,* are typical to eutrophic environments according to their ecology ([24]; [37]; [38]). In fact, the dominance of these taxa is an indication of poor water quality caused by eutrophication. Eutrophic conditions favour a decrease in the diversity of phytoplankton assemblages [39], and tend to be important to the dominance of a few large, colony-forming species of cyanobacteria such as *Microcystis* and *Anabaena.* This is the case of Aghien lagoon where value of diversity and evenness is relatively low. However, the cyanobacteria *Anabaena circinalis, Microcystis aeruginosa, M. wesenbergii, Aphanocapsa incerta* are responsible for different blooms recorded in the Aghien lagoon. According to the literature, they are known for their ability to synthesize toxins that are likely to release into the environment ([40]; [41]; [42]). However, their presence does not mean a release of toxins because according to [40] environmental conditions for toxin production are still poorly known. In addition, the high density of diatoms *Aulacoseira granulata*, *Asterionella formosa* and *Ulnaria ulna* as well as Euglenophyta *Lepocinclis acus* indicates the lagoon is eutrophic. According to [43], *Aulacoseira granulata, Asterionella formosa* and *Ulnaria ulna* are indicative of eutrophication. As for *Lepocinclis acus*, like all Euglenophyta, it abounds in environments rich in organic matter. It can be inferred that much of the nutrients in the environment come from the decomposition of organic matter and all that related to the watershed.

The result of indicator value determined there were three assemblages. Some species are associated to (1) high rainy season, (2) low dry season and (3) to the combination of high dry season and low rainy season. The high rainy season (group 1) assembles has more species than the other groups. In this season, Aghien lagoon receives water for the affluent rivers and leaching from surrounding farmlands leads to water enrichment in nutrients that leads to favour phytoplankton development. The results obtained from RDA showed that conductivity and high temperature in this season influenced phytoplankton abundance. The group 2 (low dry season) is influenced by NH4, BOD, DO and pH. Concerning the group 3 (high dry season-low rainy season), abundance of species of this group is associated to high value of turbidity and nitrate.

Acknowledgements

The authors are extremely grateful for the project “Study of biological quality of Aghien Lagoon” for sponsoring this work financing by Agence Française de Développement, and are so grateful to all members of the Laboratory of Environment and Aquatic Biology of Nangui Abrogoua University (Abidjan, Ivory Coast).

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