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Spatial and Temporal Distribution of Cyanobacteria and Their Relationship with Environmental Parameters In The Aby System Lagoon (south-eastern Ivory Coast, West Africa)

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3-4points
Abstract
Background: Cyanobacteria have an important role in aquatic ecosysystems and they make up part of the planktic, metaphytic, or benthic communities, representing the base of trophic chain; they are responsible for part of primary productivity of aquatic systems and are relevant in biogeochemical cycles. Due to their capacity for photosynthesis, Cyanobacteria can rapidly become dominant in aquatic and terrestrial habitats by forming intensive blooms. These can have a strong negative effect on water quality, as certain species of Cyanobacteria are capable of producing toxins. **Objective:** This work aims to investigate at Cyanobacteria composition, abundance and physical and chemical factors influencing phytoplankton dynamics in the Aby lagoon system for possible biological monitoring. **Results:** Seasonal and spatial variability of nutrient concentrations in the Aby system were influenced by freshwater inflow from the Bia and Tanoé rivers. The decrease in the salinity gradient in Aby Lagoon, which is permanently stratified during the long dry season, increased the bottom inputs of soluble reactive phosphate and soluble reactive silicate which, in combination with good light penetration during the long dry season, enhanced phytoplankton production in the system. During the long rainy seasons, fresh water discharges into the system washed phytoplankton biomass out, preventing the development of blooms. A total of 24 taxa belonging to 3 orders, 9 families and 16 genera were recorded in the Aby lagoon system. The Cyanobacteria composition was dominated by the orders Chroococcales (42%) and Oscillatoriales (37%). During the long dry season, Oscillatoriales cells comprised >50% of the phytoplankton abundance. Redundancy analysis was applied to analyze the relationships among the variables. The results suggested that salinity and transparency were key drivers of the cyanobacterial community composition in Aby system lagoon in dry period. In addition, the concentration of nitrates and PRD in the lagoon had a profound effect on the cyanobacterial abundance as a non-limiting factor in rainy periods.
Conclusion: The results of the physical, chemical, and biological variables show that the water of the Aby Lagoon is under pollution stress.

Keywords: Cyanobacteria distribution, Diversity, Abundance, Choked lagoon, Environmental variables, river inputs.

INTRODUCTION

Cyanobacteria are often significant components floating microphyte communities, contributing to the biological diversity and, in some cases, providing most of the carbon sources that sustain aquatic food webs (Seu-Anoï, 2012). In terms of morphology, physiology and metabolism, Cyanobacteria (blue-green algae) are one of the most diverse groups of gram-negative photosynthetic prokaryotes (Singh *et al*., 2011). Cyanobacteria have an important role in aquatic ecosystems and they make up part of the planktic, metaphytic, or benthic communities, representing the base of trophic chain; they are responsible for part of primary productivity of aquatic systems and are relevant in biogeochemical cycles (Seu-Anoï *et al*., 2017; Grzesik *et al*., 2017). Moreover, some species of Cyanobacteria have ability to incorporate nitrogen. Indeed, *Cylindrospermopsis raciborskii* has the capacity to fix atmospheric nitrogen (N2) through heterocytes, as do other Nostocales, conferring a competitive advantage in nitrogen-depleted environments relative to *P. agardhii*, which cannot fix nitrogen (Whitton and Potts, 2000). Due to their capacity for photosynthesis, Cyanobacteria can rapidly become dominant in aquatic and terrestrial habitats by forming intensive blooms. The development of cyanobacterial blooms has become a serious problem in recent decades, because many bloom-forming species are reported to be able to produce secondary metabolites toxic to many organisms, including humans (Bollina *et al*., 2012). Temperature increases in the range of 0.2 °C per decade, and their effects on water mixing regimes, are expected to increase the occurrence, frequency and duration of cyanobacterial blooms in several regions of the planet (Markensten *et al*., 2010). These future changes in climate are also predicted to cause shifts in the species composition of cyanobacterial blooms in favour of invasive species (Mehnert *et al*., 2010). These can have a strong negative effect on water quality, as certain species of Cyanobacteria are capable of producing toxins. Increased dominance of cyanobacteria on coastal lagoon is a continuing phenomenon in near shore tropical environments, particularly in areas impacted by humans (Béginet *al*., 2016). In the Aby Lagoon, northern hemisphere summer blooms of Cyanobacteria have been observed (Seu-Anoï, 2012); they usually are dominated by

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Aphanizomenon flos-aquae and *Microcystis aeruginosa*. Freshwater habitats in Aby lagoon are relatively poorly known from a Cyanobacteria ecology perspective, although the phycological from this lagoon have been documented by Seu-Anoï (2012). In Southern region of Ivory Coast, studies include Seu-Anoï *et al*. (2011; 2013; 2014; 2017) who studied phytoplankton of Aby, Ebrié and Grand-Lahou lagoons respectively. Komoé (2010) reported the Chlorophyta of Grand-Lahou Lagoon; Konan (2014) studied the phytoplankton of Fresco lagoon. Of the entire aforementioned checklist, none specifically reported the Cyanobacteria ecology in Aby lagoon. The present study was undertaken to investigate the structureand dynamic of Cyanobacteria of Aby lagoon for possible biological monitoring since the lagoon is a source of fish supply for people of South Western states and beyond.

MATERIAL AND METHODS

Description of study site:

The Aby lagoon system consists of the main Aby Lagoon, Tendo Lagoon and Ehy Lagoon. It is located in the far east of the coast of Ivory Coast, and forms a natural border between Ivory Coast and Ghana (Figure 1). The main characteristics of these lagoons and tributary rivers are shown in Seu-Anoï *et al*. (2011). The Aby lagoon system extends over 30 km of the coastline and covers an area of 424 km^2, with a mean depth of 3.5 m and width of 5.5 km (Avit *et al*., 1996). The main Aby Lagoon is the largest, covering a surface area of 305 km^2; it has a total shoreline of 24.5 km, 15.5 km of wide and a mean depth of 4.2 m (Chantraine, 1980). Agriculture is the main human activity for the lagoon area and its river catchments. Coconut, oil palm, banana, cocoa and coffee plantations cover most of the arable land. The Aby lagoon system is surrounded by mangrove forests in the southern part and is connected to the sea via a long channel. In general, tides are low (<1 m) and the residence time is probably high due to its shallow connection to the sea, with low surface salinity values (<5, except during the long dry season when surface salinities can reach 10). Because of this, Koné *et al*. (2009) suggested that this lagoon system could be classed as a choked lagoon. Salinity values in the bottom waters are high, ranging from 15 to 27. The Aby lagoon system is permanently stratified, particularly in its central part (Koné *et al*., 2009). The climate in the study area is close to equatorial, having two rainy seasons separated by two dry seasons (Durand and Skubich, 1982). The long rainy season (LRS) from May to July is followed by the short dry season (SDS) from August to September. The short rainy season (SRS) is from October to November, while the long dry season (LDS) is from December to April. The annual rainfall is about 2 000 mm. For the study, thirteen stations were chosen as sampling sites (Figure 1) in order to cover most of the system, except for Ehy Lagoon.

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Water chemistry:

Temperature, disolved oxygen, salinity and pH were determined *in situ* using a WTW COND 340-i conductivity meter for temperatureand salinity, and an ORION 230-A meter for pH. Twostandard buffer solutions (NBS4 and NBS7) were used forpH meter calibration each day before sampling (Koné *et al*.,2009). Water transparency was measured using a Secchidisc. Water samples for nutrient measurements werefiltered through Sartorius cellulose acetate filters, refilteredthrough 0.2 µm pore size polysulfone filters, and preservedwith $HgCl_2$ for NO_3^- and soluble reactive phosphate (SRP),and with HCl for soluble reactive Si (SRSi). Concentrationsof NO_3^- were measured on a Technicon Auto Analyser II(Tréguer and Le Corre, 1975), with an estimated accuracy of±0.1 µmol L^{-1} and a minimum detection limit of 0.05 µmol L^{-1}.SRP and SRSi concentrations were obtained by usingstandard colorimetric methods (Grasshoff *et al*., 1983), withan estimated accuracy of ±0.01 µmol L^{-1} and ±0.1 µmol L^{-1},respectively. Minimum detection limits for SRP and SRSi were both 0.1 µmol L^{-1}.

Cyanobacteria sampling and analysis of biotic variables:

One sample per sector was collected in the whole lagoon system, except for Ehy Lagoon, during four seasons in 2006-2007. The samples were collected during the period from June, September and November 2006 and in February 2007 using phytoplankton nets (20 µm mesh) in pelagic zones. The location and uses of the 13 sampling stations are reported in Table 2 and on the map of Aby system lagoon. The net was dragged horizontally for 6 m in the surface water to obtain a sample of Cyanobacteria. Samples fixed in formalin solution (5% final concentration) were collected from a dyke or from the shore. For species identification, Cyanobacteria samples were examined in the laboratory using an Olympus BX40 microscope equipped with a calibrated micrometer. The classification proposed by Compère (1974) and Komárek and Anagnostidis (2005)was adopted for systematic taxonomic arrangements above the family level, and Komárek and Anagnostidis (2005) for family and lower taxonomic levels. The quantitative estimation of the Cyanobacteria was performed by counting with an inverted Diavert microscope, using the Utermöhl (1958) technique. Subsamples (25 ml) were settled in cylindrical chambers and left to sediment for at least 16 h. Cyanobacteria community counts were made under phase contrast illumination at 400–1000× magnification. The counts of unicellular, colonial, or filamentous algae were expressed as cells L^{-1}. Tow indices were used to obtain the estimate of species diversity. The Shannon and Weaver (1949) diversity index (H) and Pielou's (1966) evenness index (J) was calculated.

Statistical analyses:

To explore the principal patterns of the phytoplankton distribution and their relation with theenvironmental variables, we selected redundancy analysis (RDA) using CANOCO software (ter Braak and Smilauer equal to or above 2% of the total numbers were taken into account (Table 2). Abundance values were transformed by log ([100 × abundance] + 1). Pearson correlation analysis was used to test the significance of relationships between biological and physicochemical parameters. The analysis was based on pH, soluble reactive phosphorus (SRP), NO_3^-, salinity, transparency, temperature and dissolved silicate (SRSi).

Results:

Water chemistry:

Spatial and temporal variations of physical and chemical parameters of water in the Aby Lagoon surveyed are showed in Seu-Anoï *et al*.(2011). Transparency varied slightly (0.3-1.1 m) from one sampling station to another (Table 1). However, the highest values were obtained during the SRS and the lowest during the LRS. Surface water temperatures were relatively stable with a range of between 26 ºC and 31.2 ºC. Whereas the surface water salinity at Aby Lagoon was relatively low and varied from 0 to 12.3. However, the highest values were recorded during the LDS and lowest during the LRS. The pH was alkaline (> 7) all through the sampling period. The disolved oxygen (DO) values were high during LDS (13 mg L^{-1}) while values were low at SDS (2.89 mg L^{-1}). With respect to NO_3^- and SRP concentrations, the highest values (14 µmol L^{-1} and 1.2 µmol L^{-1}, respectively) were recorded during the LRS than in LDS (NO_3^-:0 µmol L^{-1}) and SDS (SRP: 0.1 µmol L^{-1}) respectively. Concentrations of SRSi were higher during the LDS, with values ranging from 33 to 189 µmol L^{-1}, and lower during the SDS, with values ranging from 14 to 75 µmol L^{-1}.

Cyanobacteria dynamic:

A total of 24 taxa belonging to 3 orders, 9 families and 16 genera were recorded in the Aby lagoon system. The Cyanobacteria composition was predominated by the orders Chroococcales (42%) and Oscillatoriales (37%). The Chroococcales were ably represented by the genera Chroococcus (constituted of *Chroococcus disperses, C. limneticus, C. minutes, C. turgidus*), Aphanothece (composed of *Aphanothece* cf. *conglomerate* and *Aphanothece* cf.*variabilis*) and *Merismopedia (Merismopedia elegans* and *Merismopedia glauca)*. The distribution of the Oscillatoriales orders shows a predominance of genera oscillatoria mainly composed of *Oscillatoria* cf. *leonardii*, *Oscillatoria princeps* and *Oscillatoria limosa*. The number of cyanobacterial species observed within the Aby lagoon system was unequal between the different stations. The dominant species with relative abundance >2% of Cyanobacteria taxa for the 13 sampling sites are shown in Table2. *Microcystis aeruginosa* were dominant species in samples from the stations 1, 5 and 8 (Aby Lagoon); 10, 12 and 13 (Tendo Lagoon).In addition, *Aphanothece* cf. *conglomerata*prevailed in the stations 6, 7, 8 (Aby Lagoon) and 10, 12 (Tendo Lagoon) (Table2).The highest diversity was observed in samples from the Tendo Lagoon (stations 11, 12 and 13 comprised more than 70% of the recorded species). However, the lower diversity was found at station 5 with less than 40% of the recorded species. Four species (*Microcystis aeruginosa*, *Nostoc caeruleum* var. *planctonicum*, *Komvophoron minutum* and O*scillatoria limosa*) were present in half of the samples regardless of the nature of the area. The seasonally abundance of Cyanobacteria from Aby Lagoon was illustrated by Figure 2. The range of abundance observed was high (0.01 10^6 and 308 10^6 cells L^{-1}). The abundances of Cyanobacteria in Aby lagoon system were high during the long dry season at stations 13, 12 and 8 (302 10^6, 303 10^6 and 308 10^6 cells L^{-1}). The lowest values (0.01 10^6 cells L^{-1}) were recorded during the long rainy season at station all station. The dominant species recorded during the long dry season are *Oscillatoria princeps* and *Pseudanabaena* sp. were the most abundant taxa (16% and 16%, respectively), followed by *Microcystis aeruginosa* (13%), *Anabaena* cf. *flos-aquae* (13%) and *Nostoc caeruleum var. planctonicum* (12%). The Oscillatoriales have high proportions over (39.17%) during the studies. This group is followed by Nostocale, which represent 24.2% of absolute abundances. The range of community structure varied between 0.00 and 2.18 (Fig3). The highest diversity values were recorded during the short rainy season (station12), while lower values were obtained during the long rainy season (stations 1 and 7) and during the short rainy season (station 3).

Correlation with environmental parameters:

The distribution of Cyanobacteria taxa characteristic to the Aby system lagoon with respect to environmental variables determined on the basis of their dominance was explored in more detail using RDA and the results are plotted in Fig4. The result of the RDA ordination for 19 Cyanobacteria species (Table 2), nine environmental variables and 52 samples showed that 32.5 % of the variance in species abundance was accounted for by the first four ordination axes. The eigenvalues for RDA axes 1 and 2 are 0.52 and 0.35, and the species-environment correlations for RDA axes 1 (0.84) and 2 (0.81) are high. The temperature, salinity, pH, NO_3^-, SRP and SRSi concentrations were the most important environmental variables accounting for species distribution. Two groups of samples and taxa can be distinguished in the graph: (I) samples from the long dry season (LRS), short rainy season (SRS) and short dry season (SDS); mainly characterized by the presence of *Lyngbya martensiana* (Lyma), *Aphanothece* cf. *conglomerate* (Apco), *Aphanocapsa* cf. *grevillei* (Apgr), *Merismopedia glauca* (Megl), *Merismopedia elegans* (Meel) and *Aphanothece* cf. *Variabilis* (Apva) were the dominant taxa. These species were associated with the period of higher nitrates and PRD concentrations; (II) samples from long dry season (LDS) were dominated by taxa such as *Oscillatoria limosa* (osli), *Nostoc caeruleum* var. *planctonicum (Nocp)*,*Pseudanabaena* sp. (pssp), *Oscillatoria princeps*(ospr), *Oscillatoria* cf. *leonardii (Osle)*, *Leptolyngbya gracillima*(legr), *Anabaena* cf.*flos-aquae (Anfl)*, *Pseudanabaena* sp. (Pssp), *Anabaena* cf. *flos-aquae* (Anfl)and *Microcystis aeruginosa* (Miae). These taxa were associated with higher salinity and transparency.

Discussion and Conclusion:

Information on the variation in physico-chemical factors and hydrology of the Aby system lagoon confirms earlier observations in the Lagos lagoon that two dominant factors, fresh water discharge and tidal sea water incursions governs the physical, chemical and biological characteristics of the area (Seu-Anoï *et al*., 2017; Harris *et al*., 2016;Chia *et al*., 2015). The results presented above suggest that the temporal variability of the system is the result of the superposition of the seasonal changes in light, temperature, salinity, transparency, dissolved oxygen and dissolved nutrients which are discharged into the lagoon by the tributaries and other point sources. High water temperatures were recorded throughout the study period with relatively higher values in the dry season than in the rainy season. This could be attributed to increase cloud cover during the rainy season. The data revealed the highest values of salinity and DO during this period (LDS). According to Asmah (2010) and Oneyma (2013), this could be caused by the combined effects of high evaporation concentration especially during the dry season (associated with reduced cloud cover and increased solar insolation) and the reduction of freshwater inflow in the lagoon during this season. For instance, Nwankwo and Gaya (1996) reported that rainfall distribution determines salinity gradient in the Lagos lagoon. The pH values recorded during the study were alkaline in the dry months. Alkaline pH values recorded for the Aby system lagoon were an indication of high amount of CO_2 stored as forms of Carbonates in seawater producing a buffering effect (Onyema, 2013). A similar inference was reported by Kaźmierczak *et al*., (2015) for the Nivå Bay, Onyema *et al*. (2007) for the Lagos lagoon and Iyagbe lagoon, Asmah (2010) for the Sakumo Lagoon (Ghana).In contrast, the lowest value of transparency observed during the long rainy season (LRS) in the Aby system lagoon was due to the influence of Tendo and Bia Rivers. According to Durand and Chantraine (1982), the brown water of these rivers enriched the lagoon water in organic matter and thus reduced the transparency. The low transparency may cause the low algal cell counts and hence low values of oxygen into the lagoon. Concerning the variability of nutrients, except the SRSi (where the high value was observed during the LDS) the dissolved nutrient concentrations were relatively high in the lagoon during the LRS. Nutrient enrichment in lagoons, such as that observed in the Aby system lagoon, has been found to be strongly related to polluted freshwater input from feeder streams, changes in water flow, and effective nutrient recycling between sediments and the water column (Brito *et al*., 2010). A similar observation was reported by Yankey *et al*.(2013) in Tarkwa lagoon (Ghana).The high value of the SRSi observed during the LDS was probably due to the fact that Aby system lagoon is a permanently stratified system in its central part. However, during the long dry season the salinity gradient decreases considerably, promoting benthic nutrient fluxes that are rich in SRSi (Koné *et al*.,2009).

The Cyanobacteria communities found in Aby lagoon system were similar to those reported in Ebrié Lagoon, Ivory Coast (e.g. Couté and Iltis 1984, 1988; Seu-Anoï, 2012, Seu-Anoï *et al*., 2017), in Qua Iboe Estuary mangrove swamp, Nigeria (Essien *et al*., 2008) and in estuarine creeks, Nigeria (Onyema and Nwankwo,2010). However, the number of Cyanobacteria taxa (27 spp.) observed in the Aby system lagoon was very low compared to works from other coastal West African lagoons and rivers published so far. The herein checklist is likely the first record of a lowest species richness of Cyanobacteria encompassing, even, some taxa under 20 μm. Aby lagoon system was characterized by the high number of Chroococcales (42%) and Oscillatoriales (37%) due to freshwater inputs from rivers that brought these genuses into the lagoon system. In general, phytoplankton species were dominated by freshwater and benthic species due to the fact that Aby lagoon system is a choked system in which marine water influence is limited to the main channel. This was also related to the high freshwater inflow from rivers into this system. Moreover, most of the dominant taxa were indicative of eutrophic conditions. Aby Lagoon is a permanently stratified system in its central part. However, during the long dry season the salinity gradient decreases considerably, promoting benthic nutrient fluxes that are rich in SRP and SRSi but very low in NO_3^- (Koné *et al*. 2009). This enhances primary production (Chantraine, 1980) and Cyanobacteria abundance. Nitrogen-fixing filamentous (heterocystous) Cyanobacteria predominated during this period because these species are able to grow in low NO_3^- conditions and have the capacity to fix atmospheric nitrogen (Berrendero *et al*., 2016). Cyanobacteria abundance values of 0.01 10^6 and 308 10^6 cells L^{-1} in Aby Lagoon are close to those observed in tropical and temperate lagoons, which varied from 1×10^6 to 32×10^9 cells L^{-1} (e.g. Odebrecht *et al*., 2010, Lehman *et al*., 2010). *Anabaena* cf. *flos-aquae* and *Oscillatoria princeps* were the most abundant taxa (29% and 16%, respectively), followed by *Microcystis aeruginosa* (13%) and *Nostoc caeruleum var. planctonicum* (12%).The lower diversity and evenness values obtained during the LRS were due to the proliferation of few Cyanobacteria species. In fact, phytoplankton assemblages decreased in number of species at most of stations in the LRS. The low number observed in the LRS may be due to the retarding influence of high dilution and turbidity during the wet season and increase in salt levels during the dry season. In fact, phytoplankton assemblages decreased in number of species at most of stations in the LRS. In general, Cyanobacteria diversity in the Aby lagoon system was similar to those observed in other coastal systems (Donadel *et al*., 2016 and Nwankwo *et al*., 2008).

The relation patterns described here represent the first observation of Cyanobacteria dynamics along the Aby system lagoon. This result provides new insight into the distribution of Cyanobacteria organisms along strong salinity gradients and allows for a better understanding of the overall pelagic functioning in saline systems which is critical for the management of these precious and climatically-stress ecosystems.

Relatively to physical and chemical parameters, the waters monitoring of the Aby lagoon system has revealed a relatively important evolution of salinity and nutrient (nitrates, dissolved reactive phosphorus, dissolved reactive silica). Stations close to the ocean are influenced by the tides and the salinity was relatively high, reaching 7 to 27.5 in the long dry season. Elsewhere, the waters was more or less oligohalines (between 2 and 7), except at the stations near the mouths where they was generally mild almost all the year (salinity inferior to 2) and relatively rich in nutritive.

A total of 24 taxa belonging to 3 orders, 9 families and 16 genera were recorded in the Aby lagoon system. The Cyanobacteria composition was predominated by the orders Chroococcales (42%) and Oscillatoriales (37%).Taxonomic compositions differed from one station to another. It should be noted that the long dry season is generally characterized by very high densities while the long rainy season with the lowest densities.The dominant species recorded during the long dry season were *Oscillatoria princeps* and *Pseudanabaena* sp. with 16% of the abundance each one. These taxa were followed by *Microcystis aeruginosa* (13%), *Anabaena* cf .*flos-aquae* (13%) and *Nostoc caeruleum var. planctonicum* (12%). The Oscillatoriales were high proportions over (39.17%) during the studies. The diversity of Cyanobacteria communities, expressed by the Shannon index, was relatively hygh in the Aby system lagoon (on average 1.12).The Redundancy analysis suggested that salinity and transparency were key drivers of the cyanobacterial community composition in Aby system Lagoon in dry period. In addition, the concentration of nitrates and PRD in the lagoon had a profound effect on the cyanobacterial abundance as a non-limiting factor in rainy periods. Finally, with regard to the physical, chemical, and biological variables studied, it can be concluded that the water of the Aby Lagoon is under pollution stress.

The study of the relationships between physicochemical and phytoplankton processes should be pursued in situations of changing environmental characteristics with pollution (discharges of domestic and industrial wastewater, and traditional and industrial agriculture) which continues to grow. In addition, the intense proliferation of Cyanobacteria is in the long run nuisances incompatible with the socio-economic activities of lagoon environments (fishing, swimming) and could have adverse consequences on the health of fish in the environment and on the health of populations. This proliferation also induces unfavorable ecological conditions for aquatic biodiversity. Therefore, a restoration study is necessary to reduce the proliferation of these Cyanobacteria considered as indicators of a eutrophyc level, by acting on the mechanisms regulating their development, that is to the nutritive resources, by carrying out a policy of reduction of the nutrients entering the lagoon system.

Table 1: The physico-chemical characteristics of surface water in Aby system lagoon during the period of June, 2006-March, 2007.

Parameters	Seasons				
		LRS	SDS	SRS	LDS
Transparancy (m)	min	0.30	0.35	1.00	0.4
	max	0.82	0.80	0.90	0.6
	Mean ±σ	0.62	0.64	0.75	0.52
Temperature (°C)	min	27.7	26.00	28.3	29.3
	max	31	28.9	31.1	31.2
	Mean ±σ	29.18	26.87	30.05	30.80
Salinity	min	0	0	0	1.5
	max	2.1	10	5.8	12.30
	Mean ±σ	1.07	1.85	1.18	6.05
pH	min	7.00	7.11	7.14	7.53
	max	8.25	8.55	9.08	9.28
	Mean ±σ	7.51	7.97	8.26	8.63
DO (mg L^{-1})	min	4	2.89	5.9	6.2
	max	9.9	7.23	10.4	13
	Mean ±σ	6.6	5.47	7.63	8.13
NO3- (µmol L^{-1})	min	0	0	0.78	0
	max	14.77	10.17	10.42	1.93
	Mean ±σ	4.81	2.00	2.83	0.47
SRP (µmol L^{-1})	min	0.16	0.10	0.09	0.16
	max	1.22	0.62	0.19	0.74
	Mean ±σ	0.48	0.36	0.48	0.31
SRSi (µmol L^{-1})	min	80.45	14.33	33.12	150.24
	max	143.53	114.43	135.72	189.0
	Mean ±σ	101.42	78.22	89.16	167.96

Table 2: Cyanobacteria taxa that represented > 2 % of total abundance during the study period at stations

Taxons	Acronymes	Stations												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Cyanoprocaryota														
Cyanobacteria														
Chroococcales														
Aphanocapsa cf. *grevillei* (Berkeley) Rabenhorst	Apgr	0	0	0	0	0	0	0	0	0	0	0	2,3	31,82
Aphanothece cf. *conglomerata*F.Rich	Apco	0	0,55	0	0	0,51	48,1	53	53,21	11	17,8	0,25	21	0
Aphanothece cf. *variabilis* (Schiller) Komarek	Apvi	0	0	0	0	0	0	0	0	0	0	0	1,3	2,63
Merismopedia elegans A.Braun	Meel	0	0	0	0	0	0	0	0	0	0	0	0,1	0,21
Merismopedia glauca (Ehrenberg) Kützing	Megl	0,7	0	0	0,2	0	0	0	0	0	1,2	1,2	29	18,1
Microcystis aeruginosa (Kützing) Kützing	Miae	21	2,22	1,13	8,03	36	3,93	4,1	31,34	1,25	13,5	18,4	32	35,42
Oscillatoriales														
Lyngbya martensiana Meneghini	Lyma	0	0	0	0	0	0	0	0	0	1,52	0	0,6	6,87
Oscillatoria limosa C.Agardh ex Gomont	Oslm	0	2	1,1	1,65	6,43	0	0	0	1,25	4,29	3,2	0,5	0,52
Oscillatoria princeps Vaucher ex Gomont	Ospr	0,11	0	1,65	0,48	0,3	2,4	10,2	0	0	0,8	0	1,3	0
Oscillatoria cf. *leonardii* Compère	Osle	1,09	0,63	32,7	20,02	0	0,7	2,05	5,64	0	0	0	2,7	0
Leptolyngbya gracillima (Zopf ex Hansgirg) Anagnostidis & Komárek	Legr	0	0	0	0	0	0	0	0	0	0	0	0	0,15
Pseudanabaena sp.	Pssp	11,7	21	6,43	8,8	12,8	2,73	19,2	33,66	0	0	0	0	0
Nostocales														
Anabaena cf. *flos-aquae* Ralfs ex Bornet & Flahault	Pssp	35.1	41	34.64	41.5	30,0	15,77	30,5	46,69	14.80	13,6	0,5	3,02	0,6
Nostoc caeruleum var. *planctonicum* (V.S.Poretsky & V.K.Tschernow) B.A.Whitton	Noca	0	0	0	0	0,7	0	0,34	0	0	0	0	0	0

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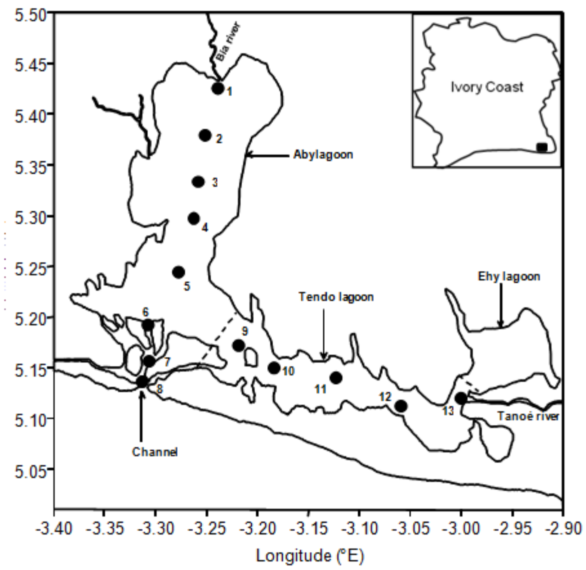

Fig. 1: Location of the study stations in Aby lagoon system, Ivory Coast.

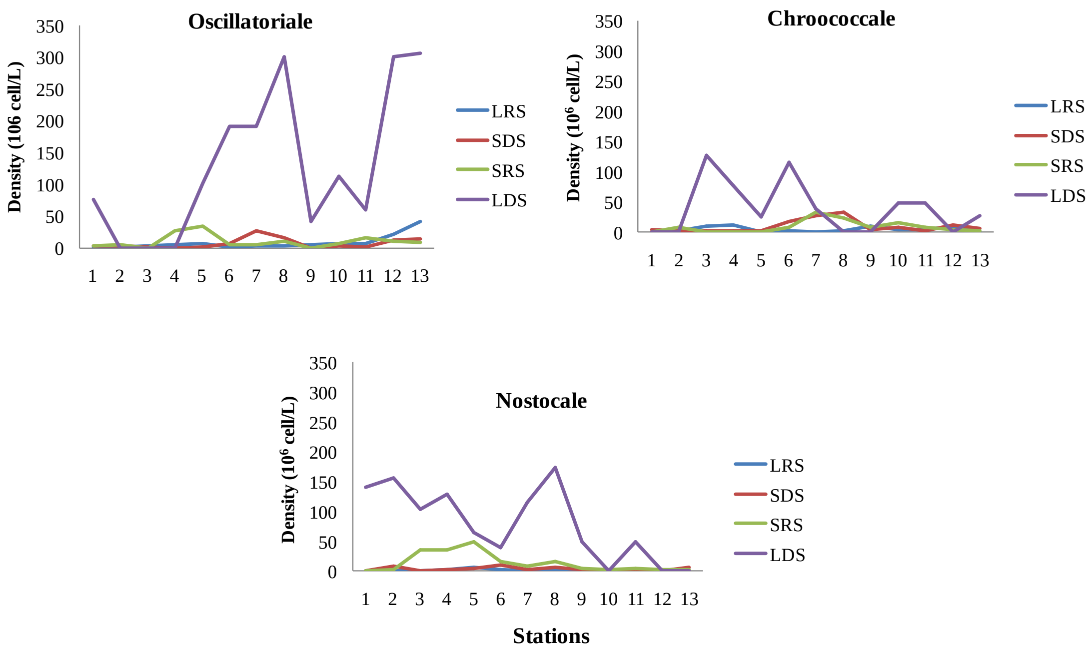

Fig. 2: Seasonal and spatial variation in abundance of Cyanobacteria at the study area (LRS: Long Rainy Season, SDS: Short Dry Season, SRS: Short Rainy Season, LDS: Long Dry Season).

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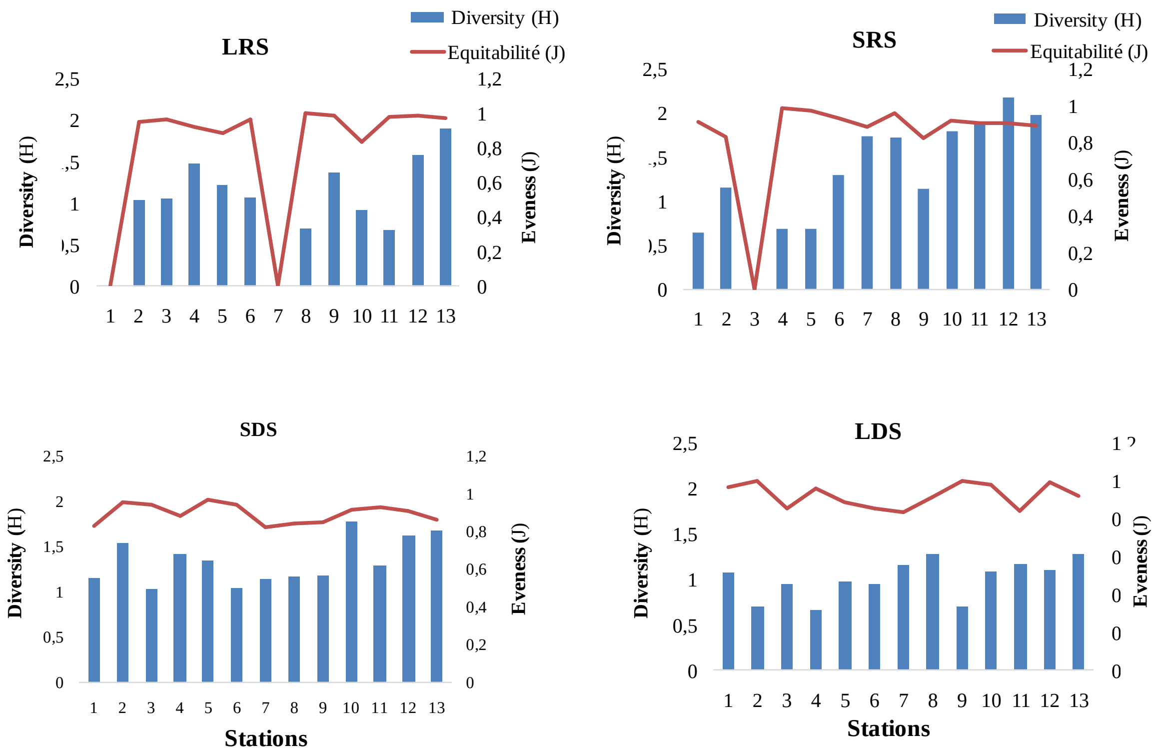

Fig. 3: Seasonal and spatial variation in diversity (H') and evenness (J') of Cyanobacteria at the study area (LRS: Long Rainy Season, SDS: Short Dry Season, SRS: Short Rainy, LDS: Long Dry Season).

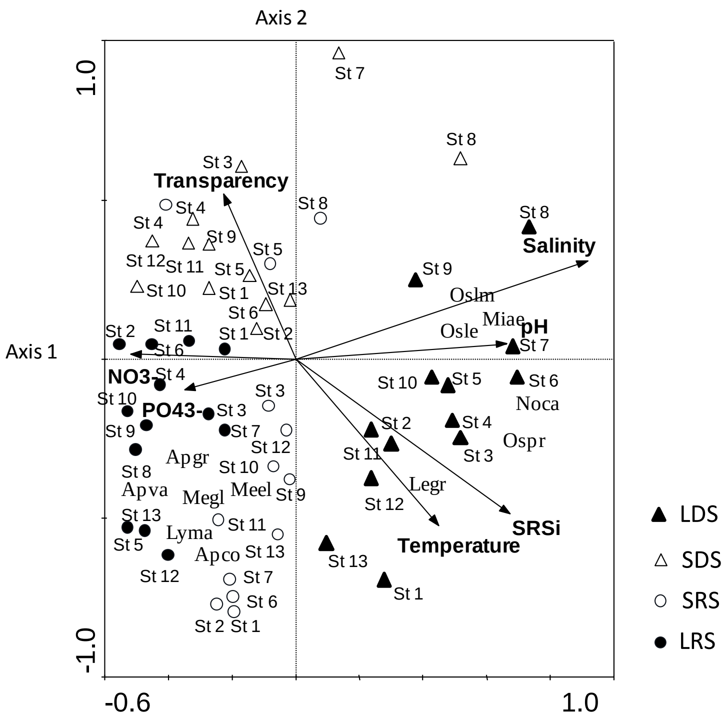

Fig. 4: Triplots obtained through the RDA of physico-chemical variables, stations and Cyanobacteria abundance in Aby lagoon system (see table 1 for abbreviations).

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