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Relationship of pelagic diatom communities to environmental variables in Aby lagoon system (Ivory Coast)

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Abstract

Present study was conducted to determine the pelagic diatoms and factors that influence their dynamics in the Aby lagoon system, southern-central Ivory Coast for one annual survey period (2006-2007). The phytoplankton was collected using a plankton net (mesh size: 20 µm) tied unto a motorized boat and towed slowly for five minutes at 13 different stations. Overall, a total of 69 diatom taxa belonging to 28 genera and three families were recorded. From a generic point of view, 22 taxa were pennates while six were of centric forms. Multivariate analysis showed that there were significant positive and negative relationships ($P<0.05$) between some physicochemical parameters and diatom species in this lagoon. The results of Redundancy analysis (RDA) showed that some taxa such as *Ulnaria biceps*, *Gomphonema gracile*, *Gomphonema parvulum*, *Gomphonema* sp., *Pinnularia viridis*, *Navicula lanceolata*, *Navicula heimansioides*, *Navicula* cf. *peregrina* and *Aulacoseira islandica* were closely associated with soluble reactive Si (SRSi) and temperature whereas the determining factors for *Ulnaria* sp.1, *Ulnaria* sp.2, *Frustulia rhomboides*, *Gyrosigma* cf. *balticum* and *Nitzschia sigma* were salinity and pH. Other taxa, *Actinocyclus* sp., *Aulacoseira granulata, Aulacoseira granulata* var. *angustissima, Aulacoseira granulata* var. *curvata*, *Cyclotella meneghiniana*, *Cyclotella ocellata* and *Tryblionella levidensis* were closely associated with $NO3^{-}$ and soluble reactive phosphate (SRP).

Keywords: Community structure, pelagic diatoms, environmental factors, freshwater flow, restricted lagoon, Ivory Coast

1. Introduction

Coastal lagoons are areas of close contact between a river and the open sea, mixing freshwater from continental drainages and seawater with high levels of salinity [1]. These systems are often characterized by extended intertidal mud- and sand-flats [2]. These ecosystems are especially rich and diverse [3, 4] and they serve as feeding, nursery and breeding grounds for finfish, shellfish and even migratory and shore birds [5, 6]. All these living forms are directly or indirectly dependent on phytoplankton for energy supply and therefore, performing vital functions. Phytoplankton is also the most important producer of organic substances in the aquatic environment and the rate at which energy is stored up by these tiny organisms determines the basic primary productivity of the ecosystem. In coastal lagoons like creeks, the main photosynthetic algal groups of the phytoplankton include the diatoms, cyanobacteria, dinoflagellates and green algae. Among these the diatoms are usually the dominant assemblage in the aquatic environment. And various studies on phytoplankton communities in aquatic systems have concluded that diatoms are the most important taxonomic groups, either in terms of abundance or in terms of diversity or both [7-10]. In fact, diatoms grow in a wide range of habitats, which could be oligotrophic or eutrophic, acidic or alkaline, fresh, brackish or marine, standing and flowing waters.

To date a lot of published works indicate diatoms and algae as indicators of water quality [11, 12]. Indeed, diatoms are valuable indicators of environmental conditions, since they respond directly and sensitively to many physical, chemical and biological changes that occur in the aquatic environment. This is further supported when significant correlations are observed between diatoms species and water quality of the ecological system.

The Aby lagoon system is one of the notable lagoons in Ivory Coast in terms of drainage anthropogenic stressors viz-a-viz their effects. Few ecological studies have been carried out on the creek and its environs. These studies include Kouadio *et al.* [13]; Koné *et al.* [14].

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Algal related materials in the area include Seu-Anoï *et al.* [15-17], Komoé *et al.* [18] and Konan *et al.* [19]. More importantly, algal studies in the Lagoons area have indicated high levels of phytoplankton production in terms of biomass by number especially in the Aby lagoon [20].

Presently, there is a dearth of literature on the diatom assemblage regarding the water quality characteristics of the Aby lagoon system, hence the need to attempt filling the gap in knowledge. The aim of this study was to investigate the water quality characteristics in relation to the spatio-seasonal diatom community of the Aby lagoon system.

2. Materials and Methods

2.1 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 (Fig1). The main characteristics of these lagoons and tributary rivers are listed in Seu-Anoï *et al.* [15]. 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 [21]. The main Aby lagoon system is the largest, covering a surface area of 305 km^2; it has a total shoreline of 24.5 km, is 15.5 km wide and has a mean depth of 4.2 m [22]. Agriculture (coconut, oil palm, plantain, cocoa and coffee plantations) is the main human activity for the lagoon area and its river catchments. The Aby lagoon system is surrounded by mangrove forests in the southern part and is connected to the sea via a long channel. This lagoon system could be classed as a choked lagoon and is permanently stratified, particularly in its central part [14]. The climate in the study area is close to equatorial, having two rainy seasons separated by two dry seasons [23]. 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. Thirteen stations were chosen as sampling sites (Fig1) in order to cover most of the system except the Ehy Lagoon.

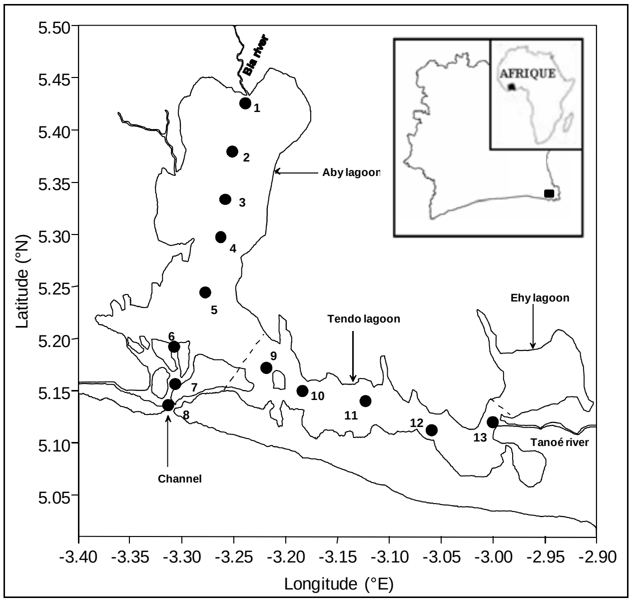

Fig 1: Location of the study stations in Aby lagoon system, Ivory Coast.

2.2 Water sampling

Temperature, salinity and pH were determined *in situ* using a WTW COND 340-i conductivity meter for temperature and salinity, and an ORION 230-A meter for pH. Two standard buffer solutions (NBS4 and NBS7) were used for pH meter calibration each day before sampling [14]. Water transparency was measured using a Secchi disc. Water samples for nutrient measurements were filtered through Sartorius cellulose acetate filters, refiltered through 0.2 µm pore size polysulfone filters, and preserved with HgCl2 for NO3$^-$ and soluble reactive phosphate (SRP), and with HCl for soluble reactive Si (SRSi). Concentrations of NO3$^-$ were measured on a Technicon Auto Analyser II [24], with an estimated accuracy of ±0.1 µmol l^{-1} and a minimum detection limit of 0.05 µmol l^{-1}. soluble reactive phosphate (SRP) and soluble reactive Si (SRSi) concentrations were obtained by using standard colorimetric methods [25], with an estimated accuracy of ±0.01 µmol l^{-1} and ±0.1 µmol l^{-1}, respectively. Minimum detection limits for soluble reactive phosphate (SRP) and soluble reactive Si (SRSi) were both 0.1 µmol l^{-1}.

2.3 Collection of plankton samples

Water samples were collected in the whole lagoon system, except for Ehy Lagoon, in plastic bottles with screw caps at seasonal intervals for a period of one year (2006-2007) at the 13 stations. All sample collection was done between 9a.m and 12 noon each time. Plankton samples were collected horizontally with hauls made using a plankton net of mesh size (20 µm) tied unto a motorized boat and towed slowly for 5 min at the 13 stations. Each 5 minutes haul filters approximately 500 liters of water. The plankton samples were then transferred immediately to 250 ml screw capped plastic containers, labeled and preserved in 4% unbuffered formalin before transfer to the laboratory for analysis.

2.4 Diatoms analysis

Samples for diatom (Bacillariophyta) analyses were treated with 10% nitric acid on a hot plate for 10 min and then left to cool. Then, after several rinses with distilled water, 1 ml of the sample was spread on a cover slip and left to dry at room temperature before being permanently mounted using Naphrax, a highly refractive mounting medium.

Before counting, the preserved sample was brought to a final volume of 200 ml with distilled water and homogenized at low speed until the sediment was thoroughly mixed [26]. The results were expressed as the number of diatom cells l^{-1}. Three water-mounted slides for each sample were counted at 400× magnification [27]. Diatoms were identified to the species level at 1000× magnification by phase-contrast optics with an OLYMPUS ×100 PlanApo oil-immersion objective following standard diatom preparation methods [28]. Identifications were made following, Krammer and Lange-Bertalot [29, 30], Tomas [31]; Hartley *et al.* [32]; Prygiel and Coste [33].

2.5 Data analysis

The Shannon-Wiener index (*H*'; log base = e) and Pielou's evenness index (*J'*) were calculated from relative abundance values (RA, %). Differences in *H*' and *J'* values were tested using a non-parametric Kruskal-Wallis ANOVA median test. Diatom counts of all 52 samples were first converted into RA. The RA values were used in the multivariate analysis and were the means of 3 replicate samples. Only the taxa which had an RA of at least 1% in any single sample were taken into consideration. In total, 60 taxonomic entities were distinguished, of which 20 were used as active taxa in the numerical analysis.

To test differences in physicochemical variables (except pH), between the stations and the four seasons, the non-parametric Kruskal-Wallis test was used, because the data were not distributed normally [34]. Concerning pH, the parametric Turkey test was used because the data were distributed normally (Shapiro-Wilk test).

Redundancy analysis (RDA) was used to identify statistically significant directions of variations within the 52 samples. RDA is a powerful, statistically robust procedure for analyzing complex biological data (e.g. diatom percentages) and their relation to environmental variables (e.g. salinity, temperature). It provides a simultaneous low-dimensional representation of diatom taxa, samples, and environmental variables [35]. A code was assigned to the species used in the RDA analyses (see Table 2). Species abundance data were log ($x + 1$) transformed prior to the analysis.

All statistical analyses were conducted using the Statistica 7.1 software (StatSoft, Tulsa) and the CANOCO 4.5 package [36]. Significance was accepted at $p \leq 0.05$ for all statistical tests used in this study.

3. Results

3.1 Physical and chemical characteristics

Physical and chemical values measured in the lagoon Aby system during the period June to November 2006 and in February 2007 are presented in Seu-Anoï *et al.* [15]. Temperature varied slightly (26-31.2 °C) from one sampling station to another. However, the highest values were obtained during the long dry season (LDS) and the lowest during the short dry season (SDS). This parameter did not differ significantly between seasons (p>0.05). In general, pH values were high (>7) except during the long rainy season (LRS) in the immediate vicinity of the Tanoé River mouth (stations 12 and 13). There was a significant pH difference (p<0.05) between the long rainy season (LRS) and the other seasons. Transparency showed no clear spatial or temporal pattern. Values ranged from 0.3 to 1.1 m. However, transparency was consistently lower at Stations 12 and 13 during all seasons. With respect to NO^{3-} and soluble reactive phosphate (SRP) concentrations, the highest values (14 µmol l^{-1} and 1.2 µmol l^{-1}, respectively) were recorded during the long rainy season (LRS) at or near the mouth of the Bia River (Stations 1 and 2) and the Tanoé River (Stations 10 to 13). Both varied significantly over season (p<0.05). Concentrations of soluble reactive Si (SRSi) were significantly higher during the long dry season (LDS), with values ranging from 150 to 189 µmol l^{-1}, and lower during the short dry season (SDS), with values ranging from 14 to 75 µmol l^{-1}. Salinity in the near shore regions at Stations 7 and 8, was much higher (up to 12) than that at the other stations. The highest values were recorded during the long dry season (LDS) and lowest during the long rainy season (LRS). Notable differences were observed between seasons (p<0.05).

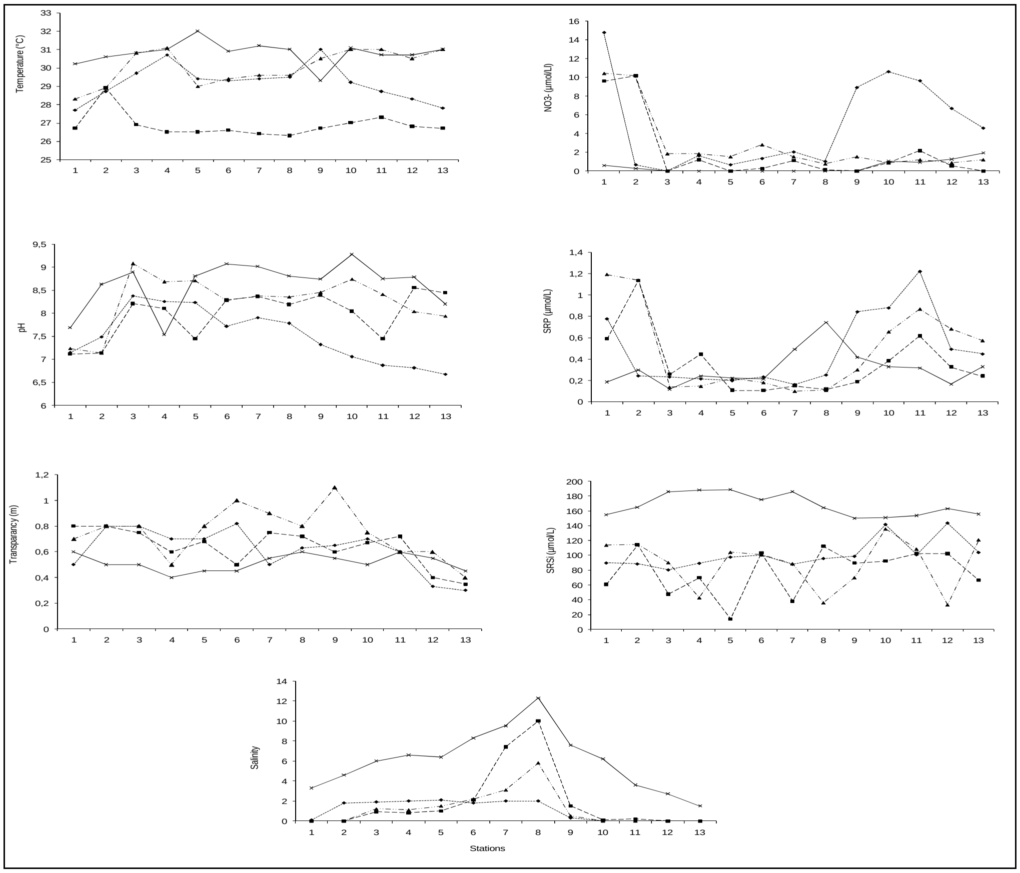

Fig 2: Seasonal and spatial variation in abiotic parameters at the study area (LRS: Long Rainy Season, SDS: Short Dry Season, SRS: Short Rainy Season, LDS: Long Dry Season).

3.2 Diatom composition and abundance

We identified 60 diatom taxa belonging to 28 genera and three families, from the four seasonal in this study (Table 1), 22 were pennates while six were centric. The pennate diatoms were ably represented by *Nitzschia* cf. *hantzschiana* Rabenhorst, *Nitzschia* cf. *palea* (Kützing) G.W. Smith, *Nitzschia punctata, Nitzschia sigma* (Kützing) G.W. Smith (G.W. Smith) Grunow, *Nitzschi a vermicularis* (Kützing) Hantzsch, *Nitzschia* sp.1, *Nitzschia* sp.2 while central observed include *Actinocyclus* sp, *Coscinodiscus centralis* Ehrenberg, *Aulacoseira ambigua* (Grunow) Simonsen *Aulacoseira granulata* (Ehrenberg) Simonsen var. *granulata, Aulacoseira granulata* var. *angustissima* (O.F. Müller) Simonsen, *Aulacoseira granulata* var. *curvata* O.F. Müller, *Aulacoseira islandica* (O.F. Müller) Simonsen, *Chaetoceros* sp., *Cyclotella meneghiniana* Kützing. The genera *Aulacoseira* (5 species), (centric diatoms), *Gomphonema* (4 species) and *Navicula* (4 species) (pennate diatoms) recorded more taxa. Diatom species composition increased from stations 1 (29 taxa) and 2 (31 taxa) through to the all stations. Station 2 recorded a higher number of species. The maximum number of species with 31 taxa was found at station 2, of which 29 taxa were also observed at station 1, which had a slightly lower number of species (2) at station 10.

Table 1 shows the occurrence of diatoms species that represented > 10% of total abundance, in terms of diversity and number with regards to the 13 stations in the Aby lagoon system. A few species were common annually in both seasons (*Aulacoseira granulata* var. *angustissima*, *Aulacoseira granulata* Ehrenberg, *Aulacoseira granulata* var. *curvata*, *Cyclotella ocellata*, *Ulnaria biceps* and *Nitzschia sigma)*.

The range of Diatom abundance observed was high (0.04 and 4 10^6 cells l-^{1}) (Fig3). The absolute abundances of diatom in Aby lagoon system were also high during the long dry season at station 1 (4 10^6 cells l-^{1}). The lowest values (0.04 10^6 cells l-^{1}) were recorded during the SDS at station 5. Among the different families that make up the population, Coscinodiscophyceae have high proportions over (more than 50%) during the long dry season. Dominant species recorded were *Actinocyclus* sp., *Coscinodiscus centralis* Ehrenberg, *Aulacoseira ambigua* (Grunow) Simonsen, *Aulacoseira granulata* (Ehrenberg) Simonsen var. *granulata, Aulacoseira granulata* var. *Angustissima* (O.F. Müller) Simonsen, *Aulacoseira granulata* var. *curvata* O.F. Müller, *Aulacoseira islandica* (O.F. Müller) Simonsen, *Cyclotella meneghiniana* Kützing, *Cyclotella ocellata* Pantocsek and *Thalassiosira* sp. This group is followed by Bacillariophyceae, which represent 40% of absolute abundances.

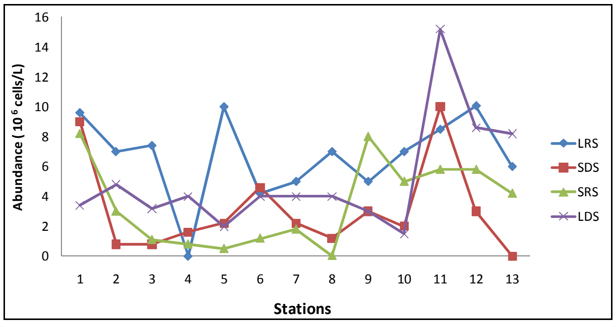

Fig 3: Seasonal and spatial variation in abundance of diatom at the study area (LRS: Long Rainy Season, SDS: Short Dry Season, SRS: Short Rainy Season, LDS: Long Dry Season).

3.3 Diatoms community structure

Annually variations in community structure are presented in Fig4. The highest and lowest diversity values were recorded during the LDS at the stations vicinity of rivers mouths (stations 1, 2, 11, 12 and 13) and at the stations vicinity of the ocean respectively. For the Pielou evenness values, the maxima values (1) were recorded during the LDS at salinity zones (stations 5, 6, 7, 8) during all seasons generally. In contrast, the minima values were noted during SRS at station vicinity of Bia river mouth (station 2). No significant differences were observed in the Shannon-Weaver diversity and the Pielou evenness values (p>0.05) between the stations. However, seasonal differences were found in both values. With regard to the Shannon-Weaver diversity values, a significant difference existed between the LDS and LRS (p = 0.01), and between the LDS and SRS (p = 0.01). With regard to the Pielou evenness values, the difference was significant between the LDS and LRS (H = 22.69; p = 0.000). For the evenness values, the maximum and minimum values were recorded during the LRS (0.86) and the LDS (0.66) respectively.

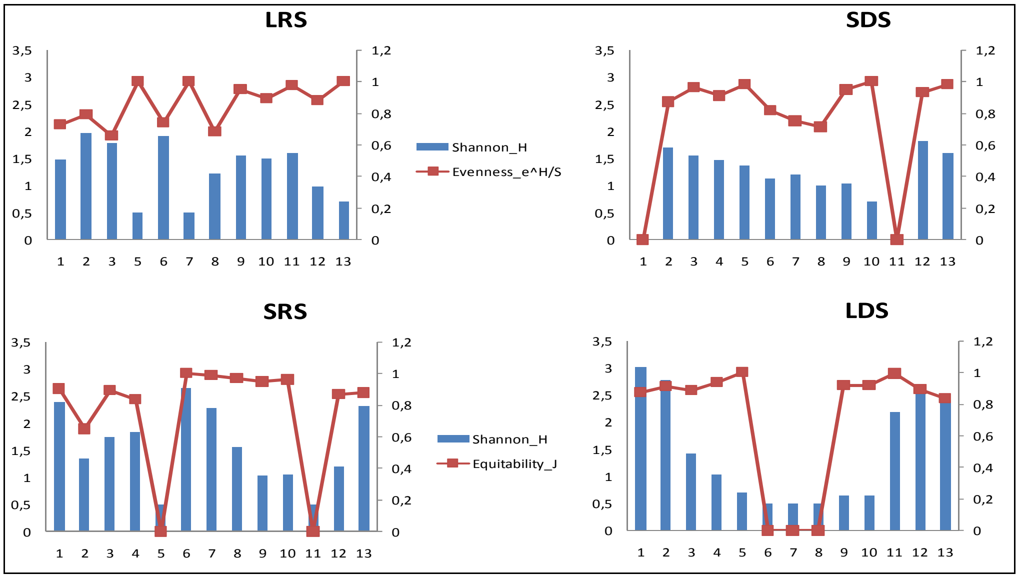

Fig 4: Seasonal and spatial variation in diversity (H') and evenness (J') of phytoplankton at the study area (LRS: Long Rainy Season, SDS: Short Dry Season, SRS: Short Rainy, LDS: Long Dry Season).

Table 1: Diatom taxa that represented > 10% of total abundance during the study period at stations

		Stations number												
Taxons	**Acronymes**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Bacillariophyta														
Coscinodiscophyceae														
Coscinodiscales														
Actinocyclus sp.	Atsp	0,2	0	0	0	0	0	0	0	2	3	3	0	0
Aulacoseirales														
Aulacoseira granulata var. *angustissima* (O.F.Müller) Simonsen	Auga	0	0	0	0	0	0	0	0	0	0	10	3	0
Aulacoseira granulata var. *curvata* O.F.Müller	Augc	5,2	0,4	1	0,8	1,1	1,4	0,4	0	2	2	0	4	0
Aulacoseira granulata (Ehrenberg) Simonsen var. *granulata*	Augr	17,2	4,2	4,2	3	2	7,2	6	8,4	8	4	8,8	2	3,8
Aulacoseira islandica (O.F.Müller) Simonsen	Auis	1,8	3,2	2	2	1,6	1	0	0	2	1	0	2,6	2,6
Thalassiosirales														
Cyclotella meneghiniana Kützing	Cyme	0	1,2	1,3	0,3	0	1,2	0,4	2	1	1	3	2,2	2,8
Cyclotella ocellata Pantocsek	Cyoc	0	0	0	0	0	0,2	0	0	1	0,5	3	2	1
Bacillariophyceae														
Bacillariales														
Nitzschia sigma (Kützing) G.W.Smith	Nisi	0,4	1,4	2,2	0	0	0,4	0	0	0	0	2	0	0,2
Tryblionella levidensis G.W.Smith	Trle	1	0	0,3	0,1	0	0	0	0	0	0	0	1	1
Cymbellales														
Gomphonema gracile Ehrenberg	Gogr	3	3,4	0	0	0	0	0	0	0	0	0	0	0
Gomphonema parvulum Kützing	Gopa	1	0	0	0	0	0	0	0	0	0	0	0	0
Gomphonema sp.	Gosp	0,2	2,2	0	1	0	0	0	0	0	0	0	0	0,4
Naviculales														
Navicula heimansioides Lange-Bertalot	Nahe	0,2	1	0	0	0	0	0	0	0	0	0	0	0,4
Navicula lanceolata Ehrenberg	Nala	1	0	0	0	0	0	0	0	0	0	0	0	0
Navicula cf. *peregrina* (Ehrenberg) Kützing	Nape	1,6	0	0	0	0	0	0	0	0	0	0	1	1
Pinnularia viridis (Nitzsch) Ehrenberg	Puvi	0,6	1,2	0	0	0	0	0	0	0	0	0	1	2,2
Frustulia rhomboides (Ehrenberg) De Toni	Frrh	1	0,6	0,5	0,2	0	0,2	0,4	0,44	1	1	2	8,3	6,1
Fragilariales														
Ulnaria biceps (Kützing) Compère	Ulbi	0,4	0,4	0	0	0	0	0	0	0	0	2,2	0	0
Ulnaria sp.1	Uls1	0	0,2	0,3	0,3	0	0,4	0	0	0	0	0	0	0
Ulnaria sp.2	Uls2	1	0	0,3	0,1	0	0	0	0	0	0	0	0	2

3.4 Ordination and classification

The relationships between the diatom assemblages and the environmental variables were explored in more detail using RDA and the results are plotted in Fig5. The result of the Redundancy analysis (RDA) ordination for 18 diatom species, nine environmental variables and 52 samples showed that 24% of the variance in species abundance was accounted for by the first four ordination axes. The eigenvalues for Redundancy analysis (RDA) axes 1 and 2 are 0.48 and 0.33, and the species-environment correlations for RDA axes 1 (0.87) and 2 (0.85) are high. After evaluating the importance of all nine environmental variables by forward selection of the environmental variables, Monte Carlo unrestricted permutation tests of the statistical significance, canonical coefficient and intra-set correlations between environmental variables and the axes. The temperature, salinity, pH, NO^{3-}, soluble reactive phosphate (SRP) and soluble reactive Si (SRSi) concentrations were the most important environmental variables accounting for species distribution. The distribution of species along the first axis reflects their requirements with regard to Salinity, pH and soluble reactive Si (SRSi) in which the 3 environmental variables capture about 41% of the total variance and Si concentration alone accounts for about 24%. The distributions of *Ulnaria biceps* (Kützing) Compère, *Gomphonema gracile* Ehrenberg, *Gomphonema parvulum* Kützing, *Gomphonema* sp., *Pinnularia viridis* (Nitzsch) Ehrenberg, *Navicula lanceolata* Ehrenberg, *Navicula heimansioides* Lange-Bertalot, *Navicula* cf. *peregrina* (Ehrenberg) Kützing and *Aulacoseira islandica* (O.F. Müller) Simonsen are positively correlated to soluble reactive Si (SRSi) and temperature. Also, *Ulnaria* sp.1, *Ulnaria* sp.2, *Frustulia rhomboides* (Ehrenberg) De Toni, *Gyrosigma* cf. *balticum* (Ehrenberg) Rabenhorst and *Nitzschia sigma* (Kützing) G.W. Smith were strongly positively correlated to salinity and pH. *Actinocyclus* sp., *Aulacoseira granulata (*Ehrenberg*) Simonsen, Aulacoseira granulata* var. *Angustissima* (O.F. Müller) Simonsen, *Aulacoseira granulata* var. *curvata* O.F. Müller, *Cyclotella meneghiniana* Kützing, *Cyclotella ocellata* Pantocsek and *Tryblionella levidensis* G.W. Smith are positively correlated to NO^{3-} and soluble reactive phosphate (SRP) (Fig4).

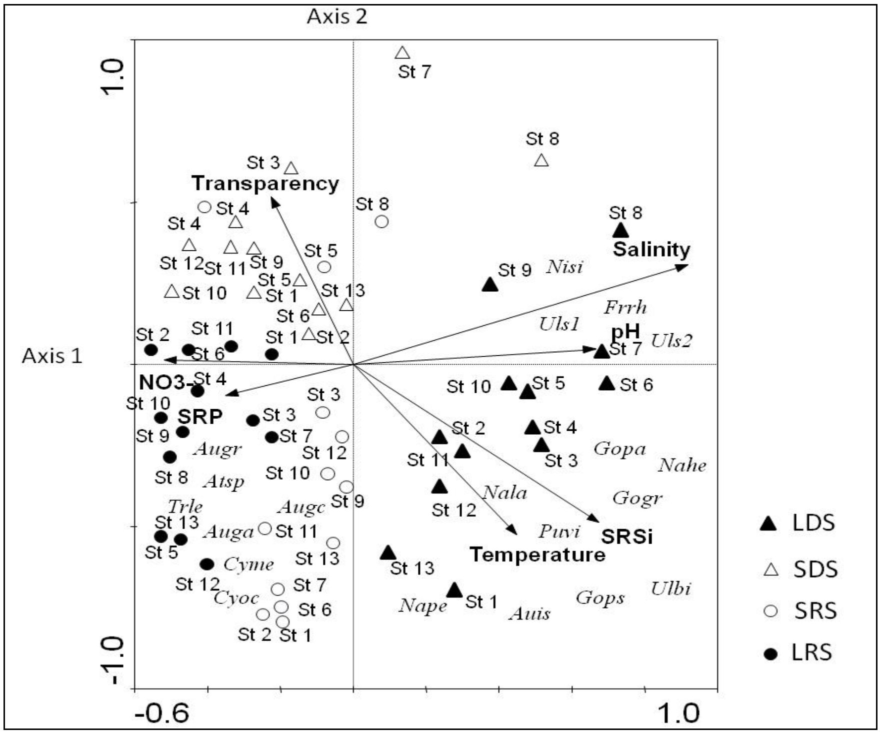

Fig 5: Triplots obtained through the Redundancy analysis (RDA) of physico-chemical variables, stations and phytoplanktonic abundance in Aby lagoon system (see table 1 for abbreviations).

3.5 Discussion and Conclusions

This study gives a first insight into the structure of diatom assemblages found in the Aby lagoon system during the four seasons. Moreover, she showed that the diatom composition of the Aby lagoon system appeared to be relatively homogeneous, and few species made a significant contribution to the assemblage structure. Diatom data from this investigation reveals reduction in diversity of species (69 taxa) compared with earlier works [1, 37- 42]. This low diversity could be attributed to taxa under 20 µm not collected in the plankton net and to the human activity. Indeed, agriculture is the main human activity in the lagoon area and its river catchments. Coconut, oil palm, banana, cocoa and coffee plantations cover most of the arable land. The pennales recorded higher number of taxa (22 taxa) followed by centrals (six taxa). This result is similar to those reported in Lekki Lagoon, Nigeria [43]. However, this is different from the species composition found for Lagos Lagoon diatom [37] and some coastal waters of Nigeria [44].This suggests that phytoplankton group dominance in coastal environments varies and is related to the site.

The benthic community such as *Surirella ovata*, *S. striatula*, *S. splendida*, *Cymbella affinis* and *Amphora ovalis* high in diatom species composition during this study may be due to possible stirring of the lagoon benthic phytoplankton community into the plankton. According to Sabanci [1], in very shallow water, benthic and planktonic communities are not clearly differentiated, mainly due to the continuous mixture of the shallow water column. Moreover, diatom species were dominated by freshwater community 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 (Bia and Tanoé) into this system. Indeed, Diatoms are well represented in Ivory Coast waters, especially in the Bia River [45, 46], which flows into the Aby lagoon system. Similar findings have been documented by Onyema *et al.* [47], in the Tarkwa-bay, Lagos; Ajuonu *et al.* [48], in the bonny estuary, Nigeria and Onyema [49-41], in estuarine creek, Lagos Iyagbe Lagoon, Lagos and the Onijedi Lagoon, Lagos respectivlly. In tropical coastal ecosystems, Costa *et al.* [51], showed that phytoplankton shifts were mainly controlled by freshwater inputs rather than by the availability of nutrients in the Paraiba do Sul River estuary, south eastern Brazil. In the Aby lagoon system, diatom species composition was generally higher during the dry season than the rainy season. Specifically, blooms of the centric diatom *Aulacoseira granulata* and *Aulacoseira granulata* var. *angustissima* were reported in the rainy season at most stations. In the rainy season salinity, conductivity, Total Dissolved Solids estimates were considerably lower.

According to Onyema *et al.* [43], the occurrence of pennate forms during the wet season in the Ijora creek suggests their dislodgement from the substratum probably during high water discharge. The tidal inflow accounted for the appearance of some marine forms in the plankton at the same period. A similar scenario played out for the Aby lagoon system.

In the Aby lagoon system, diatom abundance was generally lowest during the rainy season than the dry season The low diatom abundance observed during the long rainy season was more closely related to dilution processes rather than to nutrient inputs from the rivers. Diatom abundance was generally higher during the dry season than the other seasons. Specifically, blooms of the centric diatom *Aulacoseira granulata* and *Aulacoseira granulata* var. *angustissima* were reported in this season at most stations. Moreover, most of the dominant taxa were indicative of eutrophic conditions.

Several studies have investigated the spatial distribution of diatoms and revealed correlations between the species distribution and salinity and temperature [52]. These studies have compared several sites from different mudflats [53], or sampled along salinity [52] or pollution gradients [54], or with water movement [55]. The area in the present study is characterized by a highly dynamic environment, basically because of the frequent changes of physical characteristics due to shallowness. Depending on the depths of the stations, they are exposed to varying degrees of wind and wave action, which has an important effect in the regional composition of diatom species. Water turbulence can lead to biomass losses of up to 80% [56], and, at wave-exposed sites, the high water column primary productivity can be largely (90%) caused by resuspension of the benthic diatom flora [57]. In very shallow water, benthic and planktonic communities are not clearly differentiated, mainly due to the continuous mixture of the shallow water column.

Like many other lagoons system, nutrient enrichment of the catchment area of Aby lagoon system has been responsible for cultural eutrophication which may induce alteration in diatom assemblages [58]. Identifying the ecological variables that regulate diatom dynamics is essential for understanding the consequences of eutrophication problems and biological response to climate change in lagoons system. The earlier study of Resende *et al.* [59], based on a RDA analysis, while correct in broadly characterizing the ecosystem, failed to capture variability associated with different strengths of environmental forcing. The results presented in the present study add new ecological information on diatom lagoon dynamics (relationships between diatoms and environmental parameters and their space-time structures) and are of importance for the understanding of lagoon ecosystems. In further studies the inclusion of physical parameters, e.g. water column depth, spring-neap cycle as a major driver of temporal variations and diel cycles, could be interesting to explore fully the role of coastal zones.

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