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Spatial and temporal distribution of pelagic diatoms and their relationship with environmental parameters in the Ebrié Lagoon (south-eastern Ivory Coast, West Africa)

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Abstract
The diatoms of Ebrié Lagoon for the first time were studied at seasonally intervals for one year (year 2006 to 2007). Overall, 44 (28 were pennates while 16 are centric) diatom taxa belonging to 22 genera were recorded from 13 different stations in the Ebrié Lagoon. Among the pennate diatoms, the most frequent genera were Nitzschia and Surirella. The central were ably represented by *Aulacoseira* genera. The Shannon-Wiener and Equitability indices indicated pollution stress and dominance by a few species. The seasonal variations were not correlated with water temperature, although it varied between 0 and 27.5 °C, but with nutrient concentrations and salinity. The spatial fluctuations mostly were influenced by water transparency. *Aulacoseira*, *Coscinodiscus* and *Surirella* were the dominant genera. *Aulacoseira ambigua* (Auam), *Aulacoseira granulate* (Augr), *Aulacoseira granulata* var. *curvata* (Augc), *Aulacoseira islandica* (Auis), *Coscinodiscus centralis* (Coce), *Coscinodiscus nodulifer* Schmidt (Cono) constituted an interesting case as it correlated with nutrient concentrations.

Keywords: Pelagic diatom, Ebrié Lagoon, water quality

1. Introduction
Among unicellular microalgae, diatoms represent one of the most diverse groups with a number of estimated species varying between 10,000 and 100,000 [1]. They are known to be generally species-rich [2, 3, 4] and widespread in fresh waters, brackish and marine environments [5-8]. Thereby they form an ideal group to study their own biodiversity [9-12]. Diatoms have been used as indicators for multiple environmental parameters during several decades [2-4, 13]. Indeed, the qualitative associations of their species composition are highly influenced by abiotic factors. According to Van Den *et al.* [4], the composition of diatom communities reflects an entire complex of ecological parameters at a given site. Moreover, diatoms have tolerance limits and optima with respect to some environmental factors such as nutrients, organic pollution, acidity and salinity [14]. Therefore, they 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. Lagoon and coastal ecosystems are the most productive zone of any marine environment due to the high anthropogenic inputs and shallowness of this zone which allows effective light penetration for photosynthesis by phytoplankton.

To date a lot of published works indicate diatoms (and algae) as indicators of water quality [15, 16]. The Ebrié Lagoon is one of the notable lagoons in south-eastern Ivory Coast in terms of drainage anthropogenic stressors viz-a-viz their effects. However, very few ecological studies have been carried out on this lagoon [17, 18]. Algal related materials in the area include Seu-Anoï [19], and Seu-Anoï *et al.* [8]. So far, data about the checklist of diatoms is still lacking for the Ebrié lagoon. The aim of this paper was to: i) provide the checklist of diatom communities in the Ebrié lagoon, a highly disturbed hydro system by human activities, with respect to space and seasons, and ii) relate the main physico-chemical variables which influence the spatial and temporal changes.

2. Materials and Methods

2.1 Study area description

Ebrié lagoon system is located in the far east of the coast of Ivory Coast between 5°02'5°42'N and 3°47'-5°29'W (Figure 1). The lagoon system encompasses three lagoons namely: Potou Lagoon, Aghien Lagoon and the Ebrié Lagoon. The main characteristics of these lagoons and tributary rivers are shown in Seu-Anoï *et al.* [8]. With a superficies of 524 km2, the Ebrié Lagoon is the largest lagoon of West Africa so far. It is connected to the sea by an artificial channel (Vridi channel) [20]. This lagoon system falls under the "restricted lagoon" categories according to the Kjerfve's [21] classification. It extends over 140 km of the coastline with a means depth and a width of 4.8 m and 7 km respectively [20]. This lagoon is surrounded by mangrove forests and the annual freshwater inputs from the Comoé river, which is estimated to be ~7 km3 representing ~3 times the total volume of the lagoon system, while the flow of seawater represents ~14 times this volume [23]. The lagoon is highly polluted by domestic and industrial waste due to anthropogenic activities [20]. The waters around Abidjan, the economic capital of Ivory Coast, are highly eutrophicated leading to frequent oxygen depletion, massive fish kills and repelling sulphuric smells [24], and have been included in the recent compilation of coastal "dead zones" [25]. It is important to highlight that the Ebrié lagoon is a restricted lagoon system where marine influence is important. The climate in the study area is typical to an equatorial climate-type, which comprises two rainy seasons and two dry seasons [26]. A long rainy season (LRS) lasts from May to July and is followed by a short dry season (SDS) which varies from August to September. A short rainy season (SRS) starts in October and ends in November while the long dry season (LDS) is comprised between December and April. The annual rainfall is about 2000 mm.

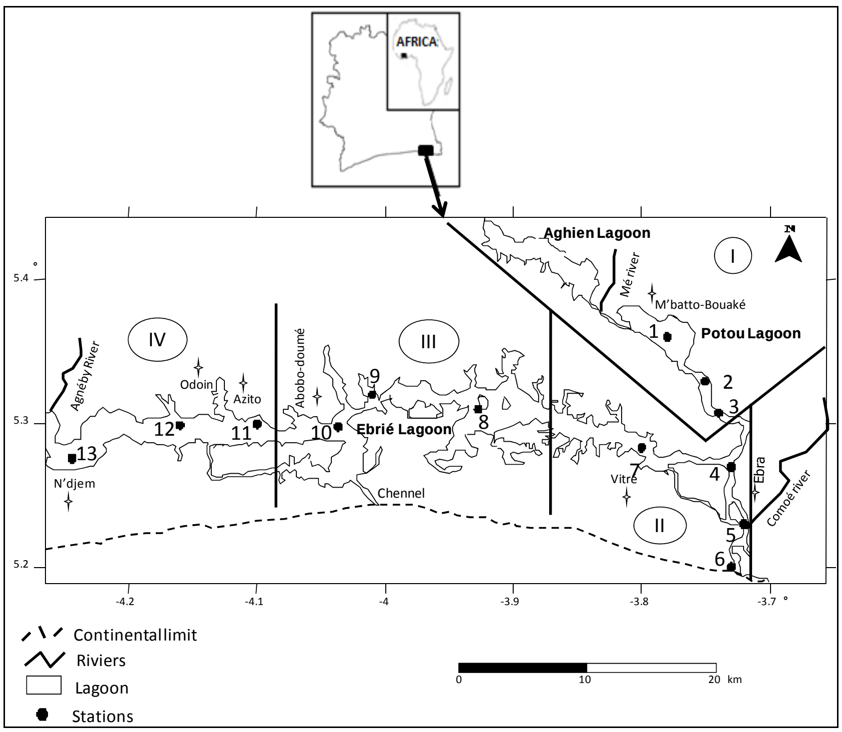


Fig 1: Location of the study stations in Ebrié Lagoon, Ivory Coast.

2.2 Sampling site

The spatial and temporal distribution of the diatom communities in the Ebrié lagoon was studied within 13 different stations (Figure 1). Based on nutrient sources and salinity gradient, theses stations represent four main regions: eastern waters (stations 1-7), which are under the influence of the Mé river, the Aghien lagoon (stations 1-3) and the Comoé river (stations 4-7); central waters (stations 8-10) are close to Abidjan city and dominated by high anthropogenic pressure, high salinity coastal/shelf seawater; western waters (stations 11-13) are influenced by the drainage of the Agnéby river.

2.3. Water sampling

The 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 [22]. The 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, preserved with $HgCl_2$ for NO_3^- and soluble reactive phosphate (SRP), and with HCl for soluble reactive Si (SRSi). Concentrations of NO_3^- were measured on a Technicon Auto Analyser II, 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 using standard colorimetric methods [27], with an 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.

Samples for chlorophyll-a concentrations were obtained filtering a known volume of water (250 to 500 mL) on glass fibber filters (Whatman GF/F) that were frozen at a temperature of -40 °C until analysis. The pigments were extracted by the spectrophotometric method described by

Lorenzen [28]. After centrifugation, extracts were obtained between 12 and 24 h in 15 mL of 90% acetone at 4 °C., Thereafter, the absorbance was measured at 665 and 750 nm, before and after acidification with 100 µL of HCl 0.1 M. The estimated accuracy of chlorophyll-a concentration was ±5%.

2.4. Collection of water and plankton samples.
Water samples were collected at 13 different stations, in the whole lagoon system, in plastic bottles with screw caps at seasonally intervals within one annual period (year 2006 to 2007). All collections were 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 minutes at each station. For every 5 minutes, haul filters reached approximately 500 liters of water. The plankton samples were then transferred immediately to 250 ml screw capped plastic containers, labeled, and were thereafter preserved in 4% unbuffered formalin for analysis at the laboratory.

2.5. Diatoms analysis
Diatom samples (Bacillariophyta) were treated with 10% of 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 with 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 throughly mixed [29]. The results were expressed as the number of diatom cells l^{-1}. Three water-mounted slides for each sample were counted at 400× magnification [30]. Diatoms were identified to the species level at 1000× magnification by phase-contrast optics with an OLYMPUS×100 Plan Apo oil-immersion objective following standard diatom preparation methods [31]. Identifications were made following Prescott [32], Krammer and Lange-Bertalot [33, 34], Tomas [35] and Hartley *et al.* [36].

2.6. 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 the non-parametric Kruskal-Wallis ANOVA median test. Diatoms resulting from of all 52 samples were first converted into RA. The RA values were used in the multivariate analysis with means of 3 replicate samples. Only taxa which had an RA of at least 1% in any single sample were taken into consideration. Overall, 44 taxonomic entities were distinguished, of which 11 were used as active taxa in the numerical analysis.

To test differences in physico-chemical variables (except pH) with respect to stations and seasons, the non-parametric Kruskal-Wallis test was used because data were not distributed normally [37]. Concerning pH variations, the parametric Tukey test was used because data were distributed normally (Shapiro- Wilk test).

The redundancy analysis (RDA) was used to identify statistically significant directions of variations within all 52 samples. The RDA is a statistically robust procedure for analyzing complex biological data (e.g. diatom percentages) and their relation with respect to environmental variables (e.g. salinity, temperature). It provides a simultaneous low-dimensional representation of diatom taxa, samples, and environmental parameters [38]. A code was assigned to species that were used in the RDA analyses (see Table 2). Species abundances were log ($x + 1$) transformed prior to the analysis. All statistical analyses were conducted using the Statistica 7.1 software (Stat Soft, Tulsa) and the CANOCO 4.5 package [39]. For all statistical tests used in this study the significance was accepted on the threshold of probability $p \leq 0.05$.

3. Results
3.1. Physical and chemical characteristics
Spatial and temporal variations of physical and chemical parameters of water in the Ebrié Lagoon surveyed are showed in Seu-Anoï *et al.* [8]. There was very little seasonal variation of all parameters ($p > 0.05$). The temperature at the water surface varied significantly across seasons in all stations (Figure 2). During the survey, the temperature fluctuated between 26.3 and 31.1 °C. The higher values were obtained during the long dry season in all stations. Generally, the short dry season was characterized by lower temperature values. The temperature did not differ significantly between the regions while significant differences were noted between the long rainy season (LRS) and the long dry season (LDS). A clear temporal and spatial variation in pH and salinities was observed in all seasons. Those parameters were higher during the long dry season (LDS) and lowest during the rainy season at all stations. The pH oscillated between 6.54 to 8.11 (Figure 2), and there was a significant difference between these two seasons and between the station ($p < 0.05$). The salinities values fluctuated between 0 and 27.5. Notable differences of this parameter were observed between the stations 11, 12, 13 and other stations and between the long rainy season (LRS) and the long dry season (LDS) ($p < 0.05$). Transparency was lowest (close to 0.15) in all stations during the long dry season (LDS) and high (up to 1.7) in stations 1, 2 and 3 during the short dry season (SDS). Notable difference was noted between stations 1, 2, 3 and stations 11, 12 and 13 between LRS and LDS. Nitrate (NO_3^-) concentration exhibited a clear seasonal variation in all stations, with the lowest (0 µmol L^{-1}) during the long dry season (LDS) and the highest (21.56 µmol L-1) during the long rainy season (LRS) (Fig.2). Significant difference was found between the long dry season (LDS) and the long rainy season (LRS) ($p < 0.05$). Soluble reactive phosphate (SRP) concentration (showed no clear spatial or temporal pattern. However, soluble reactive phosphate concentration was low (0.04- 0.2 µmol L-1) in station 1, 2, 3, 4, 5 and 6 during the long dry season. Generally, the soluble reactive silicate (SRSi) concentration was significantly higher during the long rainy season in all stations ($p < 0.05$), while the lowest values were recorded in stations 11 and 12 during the short rainy season (SRS). The concentrations ranged between 20.72 and 143.31 µmol L^{-1}.

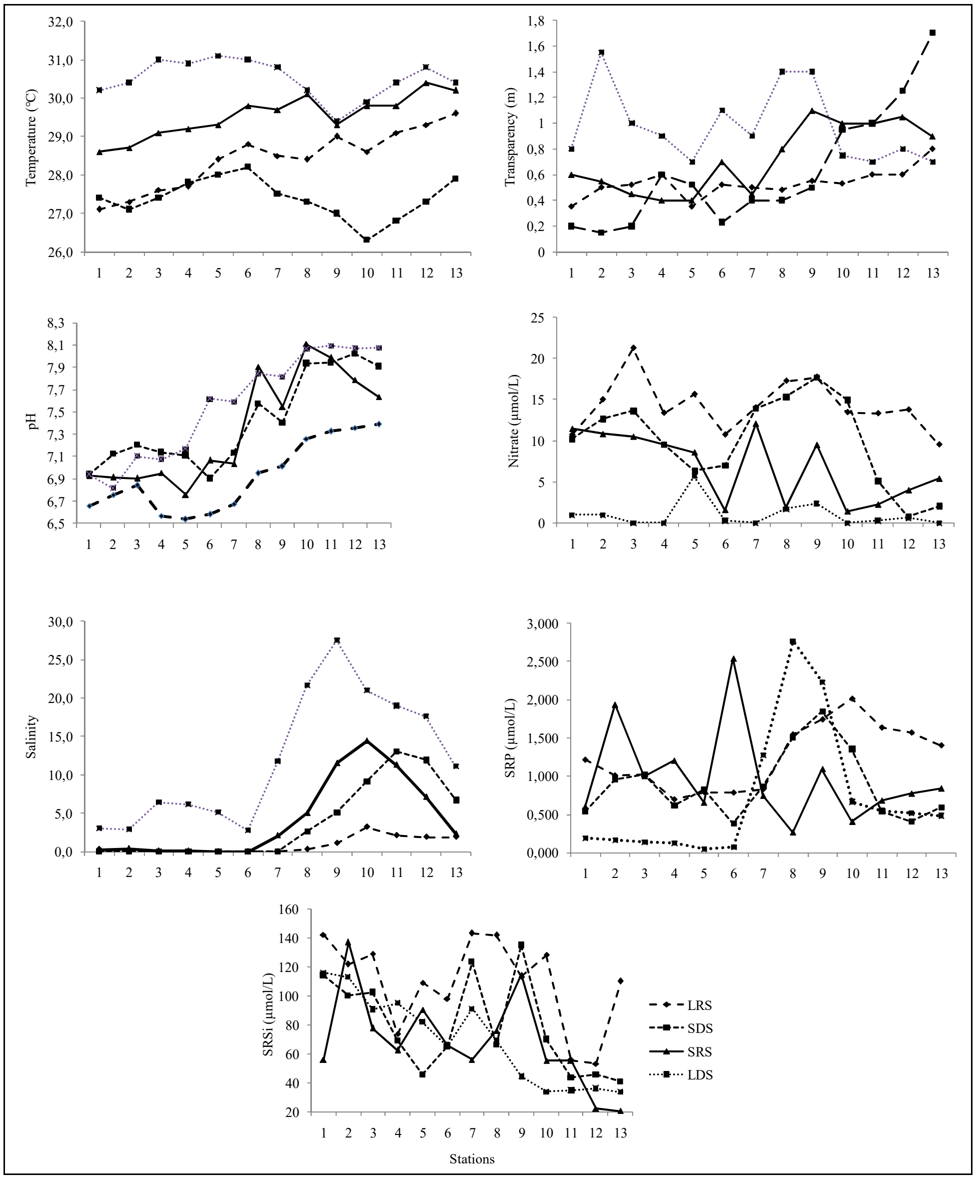


Fig 2: Seasonal and spatial variation in abiotic parameters, abundance and biomass of phytoplankton at the study area (LRS: Long Rainy Season, SDS: Short Dry Season, SRS: Short Rainy Season, LDS: Long Dry Season).

3.2 Diatoms composition, abundance and structure

The composition, abundance and distribution of diatoms in the study area are shown in Tables 1. Overall, 44 taxa belonging to 22 genera were determined from 13 different stations in the Ebrié lagoon. Among these taxa, 28 were pennates while 16 are centric. The pennate diatoms were ably represented by genera of Nitzschia (*Nitzschia* cf. *palea* (Kützing) G.W. Smith, *Nitzschia punctata* (G.W. Smith) Grunow, *Nitzschia sigma* (Kützing) G.W. Smith (G.W. Smith) Grunow, *Nitzschia vermicularis* (Kützing) Hantzsch) and Surirella (*Surirella* cf. *linearis* Smith, *Surirella* sp.1, *Surirella* sp.2, *Surirella tenera* Gregory) while centric diatoms observed included *Aulacoseira* genera (*Aulacoseira ambigua* (Grunow) Simonsen, *Aulacoseira granulata* (Ehrenberg) Simonsen var. *granulate*, *Aulacoseira granulata* var. *angustissima* (O.F. Müller) Simonsen, *Aulacoseira granulata* var. *curvata* O.F. Müller, *Aulacoseira islandica* (O.F. Müller) Simonsen). The family Coscinodiscophyceae comprised 16 species including those of *Aulacoseira*. The latter genus (5 species) was the most diverse group followed by genera *Actinoptychus*, *Nitzschia* and *Surirella* (4 species each). Considering diatom distributions along stations, the highest number of species (17 taxa) was recorded at Station 13 while the lowest species richness (4 taxa) was found at Station 11.

Of all collected individuals (15.60 10^6), Stations 6 and 7 also recorded the highest number of 1.2 10^6 and 1.4 10^6, while Station 5 (0.01 10^6) had the lowest abundance. The seasonally number of diatoms from Ebrié lagoon is illustrated in Figure 3. With respect to seasons, our results showed that the highest number (1.4 10^6 Cell. ml^{-1}; 50%) was observed during the high dry season (HDS), while the lowest number (0.01 10^6 Cell. ml^{-1}; 10%) was recorded in the long rainy season (LRS). The dominant species recorded in this period are *Actinoptychus splendens* (Shadbolt) Ralfs (Acsp), *Actinoptychus senarius* (Erhenberg) Erhenberg (Acse), *Ulnaria biceps* (Kützing) Lange-Bertalot (Ulbi), *Ulnaria* sp.1 (uls1),

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

		Stations												
Taxons	**Acronymes**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Bacillariophyta														
Coscinodiscophyceae														
Coscinodiscale														
Coscinodiscus centralis Ehrenberg	Cocen	0,27	4,05	0	1	0,51	0,45	14,19	0,3	4,05	0	1	0,51	0,44
Coscinodiscus nodulifer Schmidt	Cono	0,016	0,55	3,76	0	0	0,07	0	1	0	0	0	2,74	7,54
Aulacoseirales														
Aulacoseira granulata var. *Angustissima* (O.F. Müller) Simonsen	Auga	0	0	0	0	0	0,07	3	0	0	0	2,1	0	0,07
Aulacoseira granulata var. *curvata* O.F. Müller	Augc	0	0	0	0	0	0	1,03	0,07	0	0,41	0	0	0
Aulacoseira granulata (Ehrenberg) Simonsen var. *granulata*	Augr	0,75	1,65	2,13	0,1	0,31	0,58	0,03	0	0	0,72	0	0,14	0,21
Aulacoseira islandica (O.F.Müller) Simonsen	Auis	0,14	0	3,57	0	0	0	0	0	0	0	0	0	0
Thalassiosirales														
Cyclotella meneghiniana Kützing	Cyme	0	0	0	0	0	0	0	0	3,26	0	0	0	0
Cyclotella ocellata Pantocsek	Cyoc	0	0	0	2.22	0	0	0	0	0	0	0	0	0
Bacillariophyceae														
Bacillariales														
Nitzschia palea (Kützing) G.W.Smith	Nipa	0	0	0	1.36	0	0	0	0	0	0	0	0	0
Tryblionella levidensis G.W.Smith	Trle	0	0	1.44	0	0	0	0.45	0	0	0	0	0	0
Cymbellales														
Gomphonema gracile Ehrenberg	Gogr	2.33	0	0	0	0	0	0	0	0	0	0	0	0

		Stations												
Taxons	**Acronymes**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Surirellales														
Surirella biseriata De Brébisson	Subi	0,17	0,75	5,17	0	0,03	0,62	0	0,51	1,07	0	0,3	1,3	4,53
Surirella cf. ovata Kützing	Suov	0	0,07	0,07	0,51	0,03	3,36	0,03	0	0	0	0	0	0
Surirella sp.	Susp	0	0,07	4,7	0	0	1,17	0,17	0	0	0	0	0	0
Surirella tenera Gregory	Sute	0,21	1,61	0	0	0	1,27	0,79	0	0	0	0	0	0,34
Fragilariophyceae														
Fragilariale														
Ulnaria biceps (Kützing) Compère	Ulbi	0,14	0	0	0	0	0,07	5,8	0,5	0	0	0	0	0,07

Surirella cf. *linearis* Smith (Suli), *Surirella* sp.1 (Sus1), *Surirella* sp.2 (Sus2), *Surirella tenera* Gregory (Sute).

The values of the species diversity index varied between 0 and 2.2 (Figure 4). The lower values were noted during the long rainy season in stations 6, while higher values were obtained during the long dry season in station 1. Concerning the Pielou evenness index (J'), the values fluctuated from 0.001 to 1 during our study. The minimum (station 8) and maximum (station 6) values were observed during short rainy season (SRS) and long rainy season (LRS), respectively. During the short dry season, these indices varied slightly from one sampling station to another. Notable significant differences in the Shannon (H) values were observed ($p < 0.05$) between the stations and the others, and between long dry season (LDS) and long rainy season (LRS). Concerning the Pielou evenness values, no significant differences were detected between sectors and seasons ($p > 0.05$).

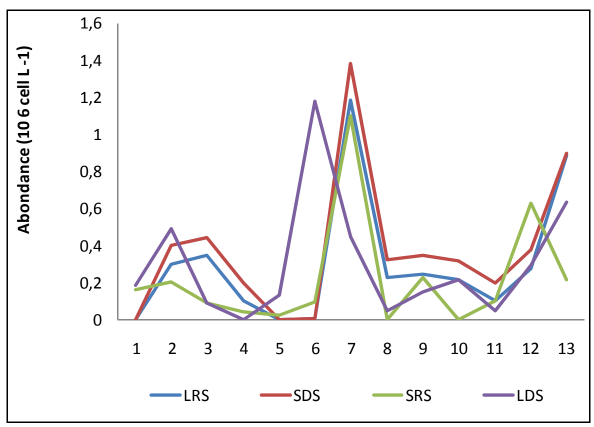
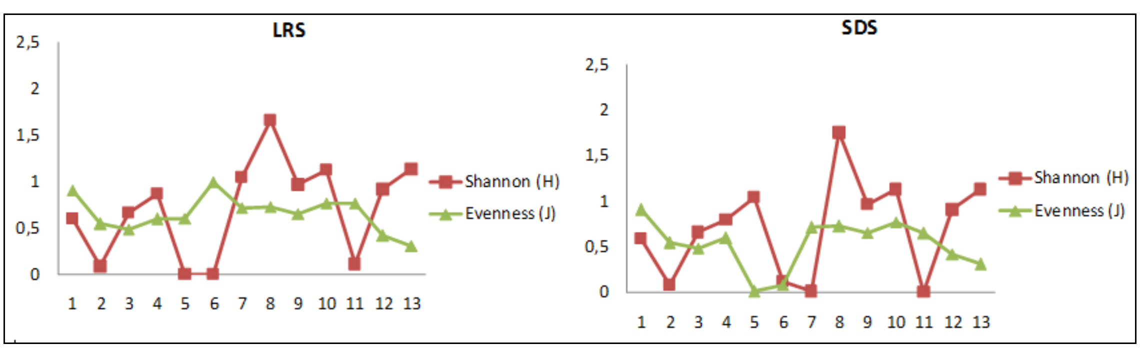


Fig 3: Seasonal and spatial variation in abundance of diatom in the Ebrié Lagoon (LRS: Long Rainy Season, SDS: Short Dry Season, SRS: Short Rainy Season, LDS: Long Dry Season).



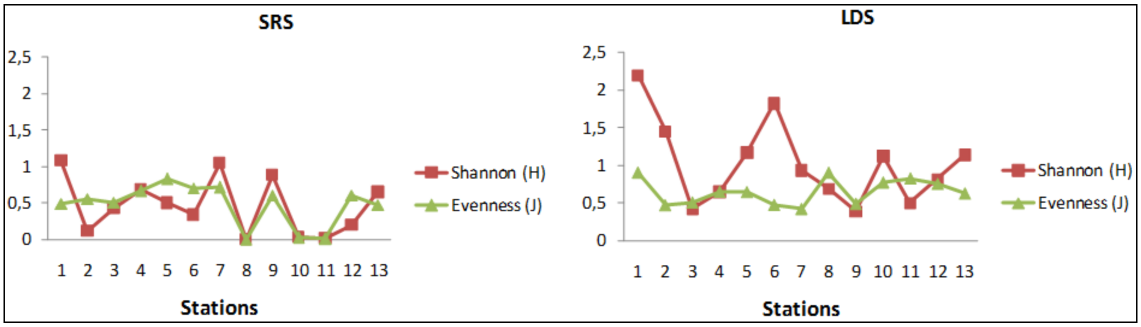


Fig 4: Seasonal and spatial variation in diversity (H) and evenness (J) of phytoplankton at the Ebrié Lagoon (LRS: Long Rainy Season, SDS: Short Dry Season, SRS: Short Rainy, LDS: Long Dry Season).

3.3. Ordination and classification

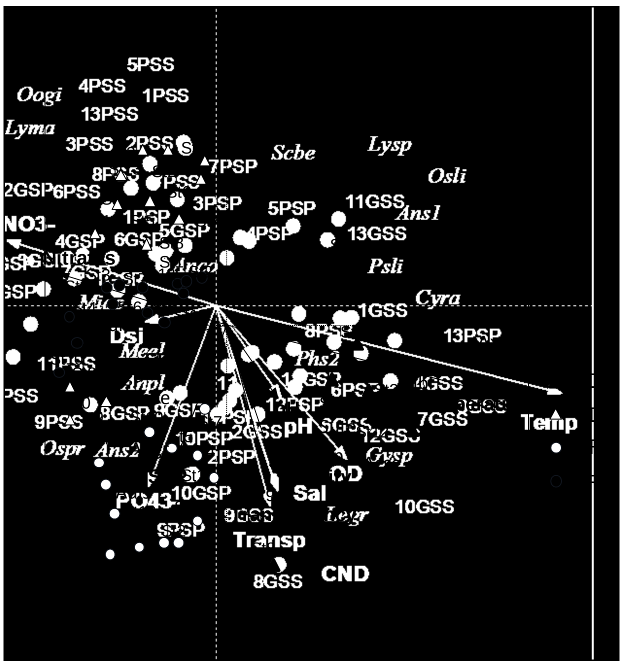


Fig 5: Triplots obtained through the RDA of physico-chemical variables, stations and phytoplanktonic abundance in Ebrié Lagoon (see table I for abbreviations). Circles (I and II) represent the groups identified based on the seasonality.

The distribution of diatom taxa characteristic to the Ebrié lagoon with respect to environmental variables was determined on the basis of their dominance during the study period. The Monte Carlo permutation tests (n = 1000 permutations) indicated that the redundancy analysis performed were significant ($p < 0.01$). The first and second axes of the Redundancy analysis (RDA) analysis performed with species and environmental parameters explained 36.1% and 16.8%, respectively, of the total variance of the species matrix. The first axis, principally defined by the nitrates and temperature, presented the strongest correlation between species and environmental variables. The second axis was defined by the nutrients SRP, transparency and salinity (Figure 5). 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 mud in which *Aulacoseira ambigua* (Grunow) Müller (Auam), *Aulacoseira granulata* (Ehrenberg) Ralfs (Augr), *Aulacoseira granulata* (Ehrenberg) Ralfs var. *curvata* Müller (Augc), *Aulacoseira islandica* Mülle (Auis), *Coscinodiscus centralis* Ehrenberg (Coce), *Actinocyclus* sp. (Atsp) were the dominant taxa. These species were associated with the period of higher nitrates and soluble reactive phosphate (SRP) concentrations; (II) samples from long dry season (LDS) were dominated by taxa such as *Actinoptychus splendens* (Shadbolt) Ralfs (Acsp), *Actinoptychus senarius* (Erhenberg) Erhenberg (Acse), *Ulnaria biceps* (Kützing) Lange-Bertalot (Ulbi), *Ulnaria* sp.1 (uls1), *Surirella* cf. *linearis* Smith (Suli), *Surirella* sp.1 (Sus1), *Surirella* sp.2 (Sus2), *Surirella tenera* Gregory (Sute). These taxa were associated higher salinity and transparency.

4. Discussion

The number of diatom taxa (44 spp.) observed in the Ebrié 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 diatoms encompassing, even, some taxa under 20 µm from a high eutrophicated lagoon. Indeed, the Ebrié lagoon system receives huge quantities of anthropogenic wastes (domestic and industries) such as raw human from its surroundings. Pennales registered the highest number (28 taxa) of taxa followed by centrals (16 taxa). This is in conformity with the species composition and phytoplankton density found for some diatom species of Ologe Lagoon in Nigeria [40], as well as some coastal waters of the aforementioned country [9]. Pennales were more prevalent and could be as a result of rainfall which introduces flooding thereby mixing up the water, boat navigation since artisanal fishing is the mainstay of the people living around the area or may be due to their possession of raphe with which they adhere to suitable substrate. The checklist of diatom communities in the Ebrié Lagoon was typical to single floristic grouping with much more species through all stations. With respect to stations, the distribution of diatoms was the most elevated at Station 13 (17 taxa) and the least at Station 11 (4 taxa). This could be explained that movements of standing water circulation allow good water renewal in the river mouth (Station 13) which is responsible for its high species richness. Such situation was not observed at Station 11.

The present investigation showed that the pelagic diatom assemblage in the Ebrié lagoon appeared to be relatively homogeneous, and few species made a significant contribution to the assemblage structure. *Nitzschia* cf. *palea* (Kützing) G.W. Smith, *Nitzschia punctata* (G.W. Smith) Grunow, *Nitzschia sigma* (Kützing) G.W. Smith (G.W. Smith) Grunow, *Nitzschia vermicularis* (Kützing) Hantzsch) and while central observed include *Aulacoseira* genera

(*Aulacoseira ambigua* (Grunow) Simonsen, *Aulacoseira granulata* (Ehrenberg) Simonsen var. *granulate, Aulacoseira granulata* var. *angustissima* (O.F. Müller) Simonsen, *Aulacoseira granulata* var. *curvata* O.F. Müller, *Aulacoseira islandica* (O.F. Müller) Simonsen were the dominant species, and the seasonally succession of these species formed the most important portion of assemblage structure. The highest number of diatoms (1.4 10^6 Cell. ml^{-1}, representing 50%) was observed in long dry season (LDS) at station 7, while the least number (0.01 10^6 Cell. ml^{-1}, representing 10%) was recorded in long rainy season (LRS) at station 5. The availability or levels of water in the lagoons to a great extent ensured a higher diatom species count. This was demonstrated where diatom diversity consistently showed high values in the dry months characterized by low water level. When water level is reduced by evaporation the amount of nutrients become more concentrated. This could lead to concentration of silicates, nitrates and phosphates. The higher diversity of diatoms in the dry months is further supported by the estimated Shannon diversity indices. A lower diversity and abundance in the rainy months could be attributed to a higher dilution level, which results in reduced amount of nutrients available for diatoms in the lagoons.

The high value of Shannon-Wiener index was recorded at Stations 1 (2.2) compared to other stations (Figure 3). Dash [41] reported that the high value of Shannon-Wiener index means the planktonic diversity. Low values of Shannon-Wiener index were recorded in long rainy season (LRS) at station 6. This may be due to heavy rain falls in the Ebrié Lagoon. Bajpai & Agarker [42] reported that the low diversity of the species could be attributable to disturbances such as floodings. Adesalu and Nwankwo [43] and Rajagopal *et al.* [44] mentioned that the low value of Shannon-Wiener's index of phytoplankton population in rainy season is due to a dilution of area. This index of diversity (H) showed a value below 3 for all stations during the study period. This indicates a low specific structure of these groups. Indeed, a low diversity characterizes, in principle, young settlements of Species. While a great diversity indicates mature settlements, the low diversity index shows a weak internal structure of populations [45, 46]. The low species richness was recorded in the lower-level stations. Entities, that had high species richness, were not the most diverse. This is due to the limited number of dominant species (7 species) at these entities. The low depth of the ecosystem accentuated by its enrichment in nutrients coming from the watershed of Ebrié Lagoon and sediments [8], favors the maintenance of community relatively immature in this ecosystem.

Diatoms in the center of the Redundancy analysis (RDA) ordination diagram are rather complex, including both fresh water species and benthic species, and even a few marine planktonic. The analyses indicated that some species in the Ebrié Lagoon respond positively to increased nutrient concentrations: *Aulacoseira ambigua* (Grunow) Müller, *Aulacoseira granulata* (Ehrenberg) Ralfs, *Aulacoseira granulata* (Ehrenberg) Ralfs var. *curvata* Müller, *Aulacoseira islandica* Mülle, *Coscinodiscus centralis* Ehrenberg, *Actinocyclus* sp. (Atsp). *Actinoptychus splendens* (Shadbolt) Ralfs (Acsp), *Actinoptychus senarius* (Erhenberg) Erhenberg (Acse), *Fragilaria biceps* (Kützing) Lange-Bertalot, *Surirella* cf. *linearis* Smith, *Surirella robusta* Erhrenberg, *Surirella* sp.1 (Sus1), *Surirella* sp.2, *Surirella tenera* Gregory grouped in the direction of higher salinity. Indeed, the nutrient loading and light levels may have been factors in diatom compositions. Furthermore, the salinity has been shown to have a strong influence on diatom community structures [46].

5. Conclusion

In summary, this study correlates diatom community assemblages appear strongly related to some environmental variables which characterize shallow environments such as the Ebrié Lagoon and could be conveniently used as biomarkers to monitor the environmental state of these coastal systems. The results showed the species diversity of diatoms is low compared to tropical regions due to drainage anthropogenic stressors and the influence of the salinity and nutrient gradient on the compositional of the diatom community. Similarities in species diversity and community structure were found across multiple sites in the Ebrié Lagoon. According to these results, Ebrié Lagoon is dominated mainly by the genera *Aulacoseira*, *Surirella*, *Cymbella*, *Ulnaria*. Cell densities of diatoms showed a decreasing gradient from the Station 1 to Station 4 due to the transformation from the state of closed lagoon to the estuary state

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