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Spatio-Temporal Variation of Dinoflagellates of the Genera *Ceratium* (Schrank 1793) and *Protoperidinium* (Bergh 1881) in Relationship with Some Abiotic Variables in the Atlantic Coast of Kribi (South Region—Cameroon)

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Abstract

A study to list Dinoflagellates species belonging to the genera *Ceratium* and *Protoperidinium* and some abiotic factors associated with them was carried out in the Kribi coast from February 2020 to February 2021 following a monthly sampling frequency. For the inventory, 60 L of water including 20 L on the surface, 20 L in the trophogen layer and 20 L in the tropholytic layer were filtered through a sieve of 20 µm and the retentate obtained was fixed whith lugol for identification and counting operations using an Olympus microscope. The morphotypes of the taxa were filmed using an Omax Toupvix eye camera. Physico-chemical results showed very good water oxygenation (89.35%), low Suspended Solid concentration (6.36 ± 4.71 mg/L), basic pH (8.53 ± 0.4 U.C), average salinity of 15.87 ± 3.1 g/L and conductivity around 26.73 ± 4.96 mS/cm. The average water temperature hovered around 29.51˚C ± 1.28˚C. The average values of nitrates and orthophosphates showed a progressive enrichment of the waters of the studied section with nitrate (1.52 ± 0.87 mg/L) and orthophosphate (1.84 ± 3.98 mg/L). This work allowed to identify 17 species of the genera *Ceratium* and 22 of *Protoperidinium*. The genera *Protoperidinium* was the most diverse while it was the taxa belonging to the genera *Ceratium* that had the highest densities. *Ceratium furca* was the only spatially and seasonally regular species with occurrence frequencies of

75.31% and 79.16% respectively. According to similar studies, 06 species reconized harmful were inventoried during this study. These are *Ceratium furca*, *Ceratium fusus*, *Ceratium tripos*, *Protoperidinium divergens*, *Protoperidinium steinii*, *Protoperidinium crassipes*. Temperature and oxygen are the abiotic factors that showed more affinities with the taxa inventoried in view of the significant correlations obtained. With a view to preventing blooms on the Cameroonian Atlantic coast, regular monitoring of the harmful species identified is desirable.

Keywords

Ceratium, *Protoperidinium*, Abiotic Factors, Atlantic Coast, Kribi

1. Introduction

The coast of Kribi, being a geostrategic area, the State of Cameroon in its structuring plan has located on its facade many development and industrial projects (the deep-water port of Kribi, the gas Power Plant of Kribi several cement plants, agro-industries, fisheries) [1]. In favour of its industrialisation, the demography of Kribi is and will be constantly galloping and statistical models indicate forecasts of about 140,049 inhabitants in 2025 and 194,306 inhabitants by 2050 [2]. This rapid industrialisation and population growth creates significant pressure on the marine coastal environments, marked by high water pollution and considerable changes in biological compartments [3] [4]. One of the most visible changes within biological compartments among many others could be the appearance of algae bloom.

In recent years, an increase in algal bloom events has been noticed in marine and estuarine waters, posing a serious threat to environmental health [5] [6]. The root cause is attributed to the eutrophication of water bodies by the bioavailability of nutrients, mainly phosphorus and some forms of nitrogen in excess concentrations from agricultural, industrial and domestic sources [7] [8]. These blooms are caused either by dinoflagellates, diatoms or cyanobacteria that have long been considered the main drivers of biodiversity changes [9] [10].

Indeed, the genera *Ceratium* is one of the most common and widespread phytoplankton in the marine environment, along with the genera *Protoperidinium* [11]. Due to the larger cell size of species belonging to the genera *Ceratium* and their relatively well-known latitudinal geographical distributions, they have been used as biological indicators of water masses and currents in many rather well-known cases [12]. It has therefore been suggested as an excellent, if not the best kind of dinoflagellates to use for biogeographical study and as a tool for defining ocean currents, temperature ranges and also be used in studies of global change [11] [13]. It consists of species capable of flowering and forming red tides [14]. The genera *Protoperidinium* is one of the most diverse and widespread groups among marine phytoplankton [15] [16]. Its species are distributed around the world and often dominate coastal ecosystems [17]. Some reports indicate the flowering of species belonging to this genera in Indian waters namely; *Protoperidinium divergens* [18], *Protoperidinium biconicum* [19], *Protoperidinium pallidum* [20], *Protoperidinium quinquecorne* [21]. Studies carried out to determine these harmful species are rare in Cameroon, yet knowledge of these groups is essential for the preservation of biodiversity and the prevention of blooms.

In particular, this work will make it possible to identify species belonging to the genera *Ceratium* and *Protoperidinium* along the stretch of the coast studied and to measure some abiotic factors that can influence their biodiversity, a first step towards the monitoring of blooms and their prevention.

2. Materials and Methods

2.1. Physical Environment

The coastal of Kribi is located on the edge of the Gulf of Guinea, in the South Cameroon Region and in the Ocean Department [22].

In the region experiences an equitorial climate of Guinean type characterized by the existence of four seasons, 02 dry seasons (from December to March for the long season and from July to August for the short season) and 02 rainy seasons (from September to November for the long season and from April to June for the short season) [23]. The average daily duration of sunstroke varies from 8 to 10 hours all year round [23]. Average daily maximum temperatures range from 25˚C to 33˚C while average daily minimum temperatures range from 15˚C to 22˚C [23]. As for rainfall, it reaches monthly values of 504 mm in September.

The vegetation is made of marsh forests, mangrove forests and evergreen forests creating a specific environment at the beach levels, making them attractive to tourists [24]. The hydrology is dominated by the Atlantic Ocean whose tidal range is low with small waves. The presence of the Lobé and Kiénké rivers is remarkable, as are the Ngoyè, Abondé, Wamié, Nzami, Bidou rivers, which receive household waste and wastes from agroindustrial companies [24].

2.2. Choice and Description of Sampling Points

The sampling points were chosen based on their economic, tourist and industrial importance (**Table 1**). Thus, 08 sampling points (**Figure 1**) were selected, including 04 in urban areas and 04 in peri-urban areas. In the urban environment, the points chosen consist of two beaches, a hotel site and an artisanal net fishing site (**Figures 2(A)-(C)**). In the peri-urban area, on the other hand, the points selected consist of a fish market, an artisanal fishing site, a beach (**Figure 2(D)**) and the northern limit of the deep-water port.

2.3. Water Sampling and Measurement of Abiotic Variables

After determination of the euphotic layer using a Secchi disc, 03 sampling levels were retained, the first on the surface (surface-0.5 m) and the other two deep in the trophogenous and tropholytic layers. Sampling in the deep layers was made possible by a 6 L bottle of van dorn.

Table 1. Geographic coordinates and description of each sampling point.

Sampling points	GPS coordinates	Description
P1	N02˚57'50.6" E009˚24'36.9"	The busiest beach in Kribi especially on weekends. holidays and holidays.
P2	N02˚55'06.1" E009˚23'50.2"	Presence of a hotel. It's effluent that discharges its wastewater into the ocean and its private beach
P3	N02˚54'15.0" E009˚23'57.8"	Artisanal net fishing site
P4	N02˚53'31.0" E009˚23'49.9"	Presence of a hotel. a beach very close to the Lobe and influenced by its waters
P5	N02˚52'04.2" E009˚23'26.2"	Ikwike village fish market and canoe boat of local fishermen
P6	N02˚52'04.2" E009˚23'26.23"	Collecting shellfish from the rocks and artisanal net fishing. Presence of an offshore visible from the coast.
P7	N02˚52'04.2" E009˚23'12.0"	Tourist beach very clean and less crowded. Presence of an offshore visible from the coast.
P8	N02˚49'34.2"; E009˚23'10.0"	Northern boundary of the deep-water port of Kribi

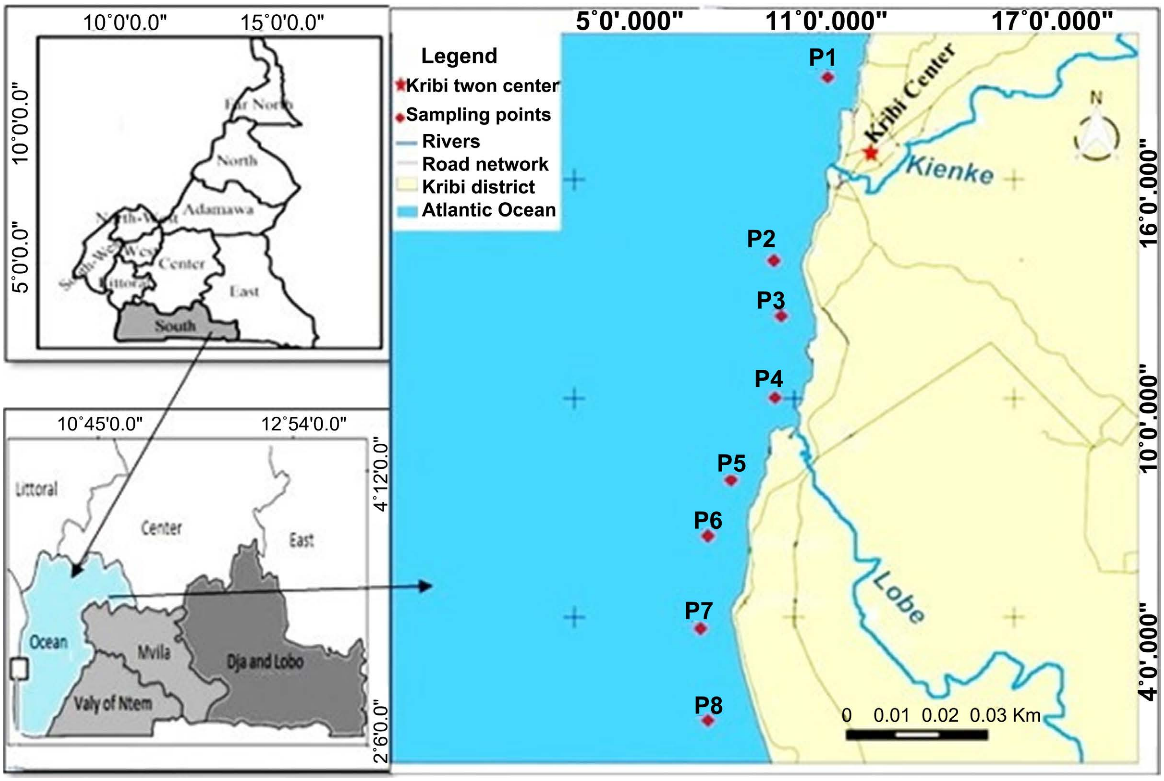


Figure 1. Geographic location of sampling points.

Figure 2. Representation of selected sampling points: Busy range (A); Artisanal fishing (B); Hotel site (C); Less crowded beach (D).

Water sampling for measurements of abiotic variables was carried out at the 03 predefined levels. The water taken made it possible to make a composite in a seal of 20 L previously washed and rinsed with water from the sample. In the composite, abiotic factors such as temperature, pH, conductivity, salinity, TDS, were directly measured using a Waterproof TESTER multiparameter and dissolved oxygen using a HACH HQ30d oxymeter. For water samples for laboratory analysis, 1000 cc of the composite was taken from a 1000 cc polyethylene vial and stored in a refrigerated chamber until the laboratory. In the laboratory, parameters such as color, Suspended Solids, nitrites, nitrates, orthophosphates were measured using the HACH DR 3900 spectrophotometer following standard analytical protocols and recommendations of Rodier *et al.* [25]. Alkalinity was measured by titration.

2.4. Sampling and Identification of Dinoflagellates of the Genera *Ceratium* and *Protoperidinium*

A total of 90 L of water, 30 L per level, were also carried out at the 03 predefined levels and then filtered using a plankton sieve with a 20 µm mesh opening. The retentât obtained, was directly fixed adding lugol. In the laboratory, the sample was left to settle for 48 hours and then the supernatant was siphoned off and the resulting cap was sedimented in a 25 mL sedimentation tank. After homogenization of the sediment, 1 mL was pipetted and then observed under the Olympus CK2 microscope at 200× magnification using the Sedgewick-Rafter counting cell with left-right scans alternating transects of the counting cell. Taxa have been identified using specialized literature by Okoloddkov [11]; Evagelopoulos [26]; Phan-Tan *et al.* [27]; Al-Kandari *et al.* [28]; Komoé [29]; Lakkis [30]. The different morphotypes were photographed using an OMAX ToupView eye camera and those of the taxa of the genera *Ceratium* in particular were processed using Photoshop 2020 image processing software. The densities of the different taxa identified were calculated from the following formula:

$$D = N_i \times S \times 1000/(v \times s)$$

with D = density (ind./L); S = area of the counting cell (1000 mm^2); N_i = number of individuals counted; 1000 = conversion factor in litres; s = field area of the cell counted and v = volume of sediment (25 mL).

The frequency of occurrence (F) expressed as a percentage, which provides information on the constancy of a species or taxon in a given habitat, was calculated using the formula of Dufrêne & Legendre [31]. A distinction is made between ubiquitous (100%), regular (75% to < 100%), constant (50% to <75%), accessory (25% to <50%) and rare (<25%) [32]. This index is based on the presence/absence matrix and is calculated by the relationship:

$$F = \frac{P_i \times 100}{P_t}$$

with: P_t = the total number of samples taken

The influence of abiotic variables on the organisms studied was tested using SPSS 20.0 software. Nonparametric tests made it possible to establish the distribution of the data and the Spearman correlations made it possible to show the links between the abiotic factors and the different taxa identified. To test the effect of the space represented by the stations and the seasons, the ANOVA test was used for each of the parameters.

In order to give a synthetic image of all the affinities between the different populations of the genera *Ceratium* and *Protoperidinium* on the one hand, then to highlight the so-called correspondence relationships between taxa and sampling points on the other hand, Factor Analyses of Correspondences (AFC) were carried out whit the R software version 4.1. The least frequent and least dominant taxa were excluded since their share of information is very small since the AFC requires the simplification of the table of basic data especially when it comes to a huge number of taxa.

All data from the abiotic variables, diversity and density of the genera studied were grouped into seasons according to the climatic breakdowns of [23]. The Box Plots to illustrate the seasonal variation of abiotic factors were made using GraphPad Prism 8.0.2.

3. Results

3.1. Abiotic Characteristics

3.1.1. Spatio-Temporal Variations in Abiotic Factors

The range of variations of abiotic variables of the waters of the Kribi coast is presented in **Table 2**. These results show overall little variation in the average values of the physico-chemical parameters measured from one point to another. A slight increase of temperature, TDS, Suspended Solid and orthophosphate from P6 to P8 (**Table 2**).

Table 2. Level of variation of abiotic variables on the Kribi coast in Cameroon during the study period.

	P1	P2	P3	P4	P5	P6	P7	P8	Moy	ET
Temp (˚C)	29.25	29.22	29.3	29	29.31	29.76	30.12	30.15	29.51	0.44
Oxy (%)	89.43	88.97	89	89.58	90.39	86.87	90.42	90.14	89.35	1.15
pH (U.C)	8.39	8.52	8.53	8.45	8.48	8.54	8.65	8.67	8.53	0.09
Cond (mS/cm)	26.71	27.49	25.24	21.97	25.56	28.7	28.95	29.25	26.73	2.45
Sal (g/L)	15.83	16.33	14.89	12.75	15.16	17.11	17.33	17.55	15.87	1.6
TDS (g/L)	19	19.55	17.95	15.59	18.16	20.45	20.63	20.88	19.03	1.77
MES (mg/L	6.31	4.69	6.23	4.69	6	6.08	8.38	8.46	6.36	1.43
Col (pt-Co)	18.15	22	16.85	22.31	25.92	18.62	12.46	17.38	19.21	4.11
NO_3^- (mg/L)	1.26	1.89	1.44	1.37	2.45	1.43	1.27	1.07	1.52	0.44
NO_2^- (mg/L	0.011	0.006	0.004	0.004	0.006	0.005	0.004	0.004	0.006	0.002
PO_4^{3-} (mg/L)	1.66	1.74	1.85	1.54	1.99	1.83	1.93	2.2	1.84	0.2
Alc (mg/L)	11.23	12	10.15	11.07	11.84	11.84	12.56	12.46	11.64	0.8
Transp (m)	2.13	2.27	2.97	2.7	2.45	2.61	2.4	3.15	2.59	0.35

Temp: Temperature; Oxy: Oxygen; Cond: Conductivity; Sal: Salinity; Col: Color, Alc: Alcalinity; Transp: Transparency; MES: Suspended Solid.

The abiotic factor recorded in this study showed no significant differences ($P > 0.05$) between the different data collection points but rather between seasons with the exception of pH and color.

3.1.2. Physical Abiotic Variables

Throughout the study period, the temperature hovered around an average value of 29.51˚C ± 0.44˚C. The lowest temperatures were recorded at P4 and the highest at P7 and P8 (**Table 2**). Seasonally, the analysis of variances of the 04 seasons in Kribi revealed a significant difference between seasons ($P = 0.000037$). The lowest value was recorded during the short dry season (SDS) (28.13˚C ± 0.4˚C) and the highest during the long dry season (LDS) (30.71˚C ± 0.15˚C) (**Figure 3(A)**). Other physical abiotic variables such as color (**Figure 3(D)**), MES (**Figure 3(C)**), TDS (**Figure 3(B)**) and water transparency (**Figure 3(E)**) varied respectively around the mean values of 19.21 ± 4.11 Pt-Co; 6.36 ± 1.43 mg/L, 20.88 ± 1.77 mg/L and 2.59 ± 0.35 m (**Table 2**). Seasonally, the analysis of variance showed significant variations for MES ($P = 0.001$) and TDS ($P = 0.0001$). The lowest values were recorded during the long rainy season (LRS) 4.21 ± 2.21 mg/L and 13.93 ± 1.74 mg/L respectively for MES and TDS, and the highest values in the short rainy season (SRS) for Suspended Solid (9.38 ± 4.09) and during the long dry season for TDS (21.25 ± 0.72) (**Figure 3(B)** and **Figure 3(C)**).

3.1.3. Chemical Abiotic Variables

Dissolved oxygen, pH, salinity, conductivity and alkalinity varied during the period

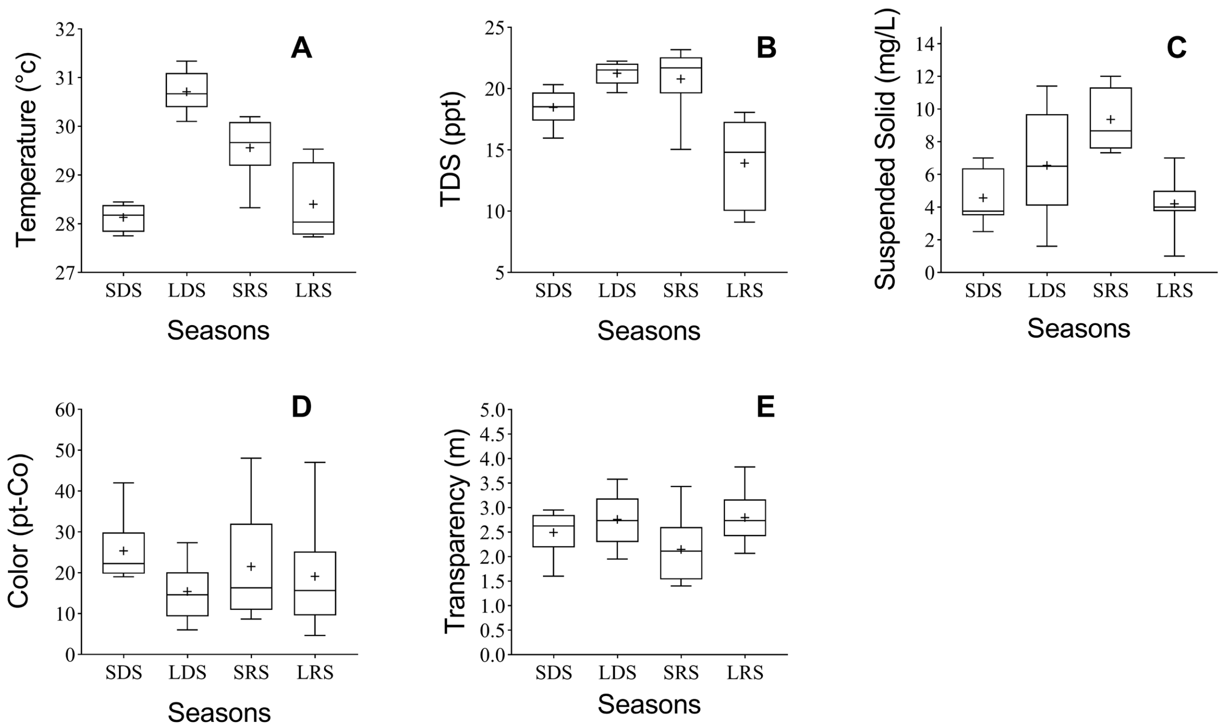


Figure 3. Seasonal variations of physical parameters: Temperature (A); Suspended Solid (B); TDS (C); Color (D); Transparency (E).

of study respectively around the mean values of 89.35% ± 1.15%, 8.53 ± 0.09 U.C; 26.73 ± 2.45 mS/cm; 15.87 ± 1.6 g/L; 11.63 ± 0.8 mg/L HCO_3^- (**Table 2**). At the seasonal scale, the analysis of variances revealed significant differences for dissolved oxygen (P = 0.000037), conductivity (P = 0.0001); salinity (P = 0.0001) and alkalinity (P = 0.0001). A slight decrease in dissolved oxygen was observed in the short dry season 85.25 ± 2.38 and the highest average value during the long rainy season 93.68 ± 1.06 (**Figure 4(A)**). As for conductivity, salinity and alkalinity, the low values *i.e.* respectively 19.36 ± 2.4; 11.24 ± 1.36; 8.08 ± 0.91 were recorded during the long rainy season and the highest in the long dry season, *i.e.* 29.89 ± 1.04; 17.89 ± 0.69; 13.4 ± 0.42 respectively also (**Figures 4(B)-(E)**).

Nitrates, nitrites and orthophosphates varied during the study period respectively around mean values of 1.52 ± 0.44 mg/L; 0.006 ± 0.002 mg/L; 1.84 ± 0.2 mg/L (**Table 2**). As with the other factors, the seasonal effect appeared significant for nitrates, nitrite and highly significant for orthophosphates with P = 0.002; P = 0.003; P = 0.000005 respectively. Seasonal variation had the lowest average values in the short rainy season for nitrates (0.47 ± 0.15 mg/L) and nitrites (0.002 ± 0.001 mg/L), and in the short dry season for orthophosphates (0.02 ± 0.006 mg/L). The highest average values, on the other hand, were recorded during the long dry season (LDS) for nitrates (2.43 ± 0.98) (**Figure 4(F)**) in the long rainy season for nitrites (0.008 ± 0.005 mg/L) (**Figure 4(G)**) and orthophosphates (3.16 ± 0.85 mg/L) (**Figure 4(H)**).

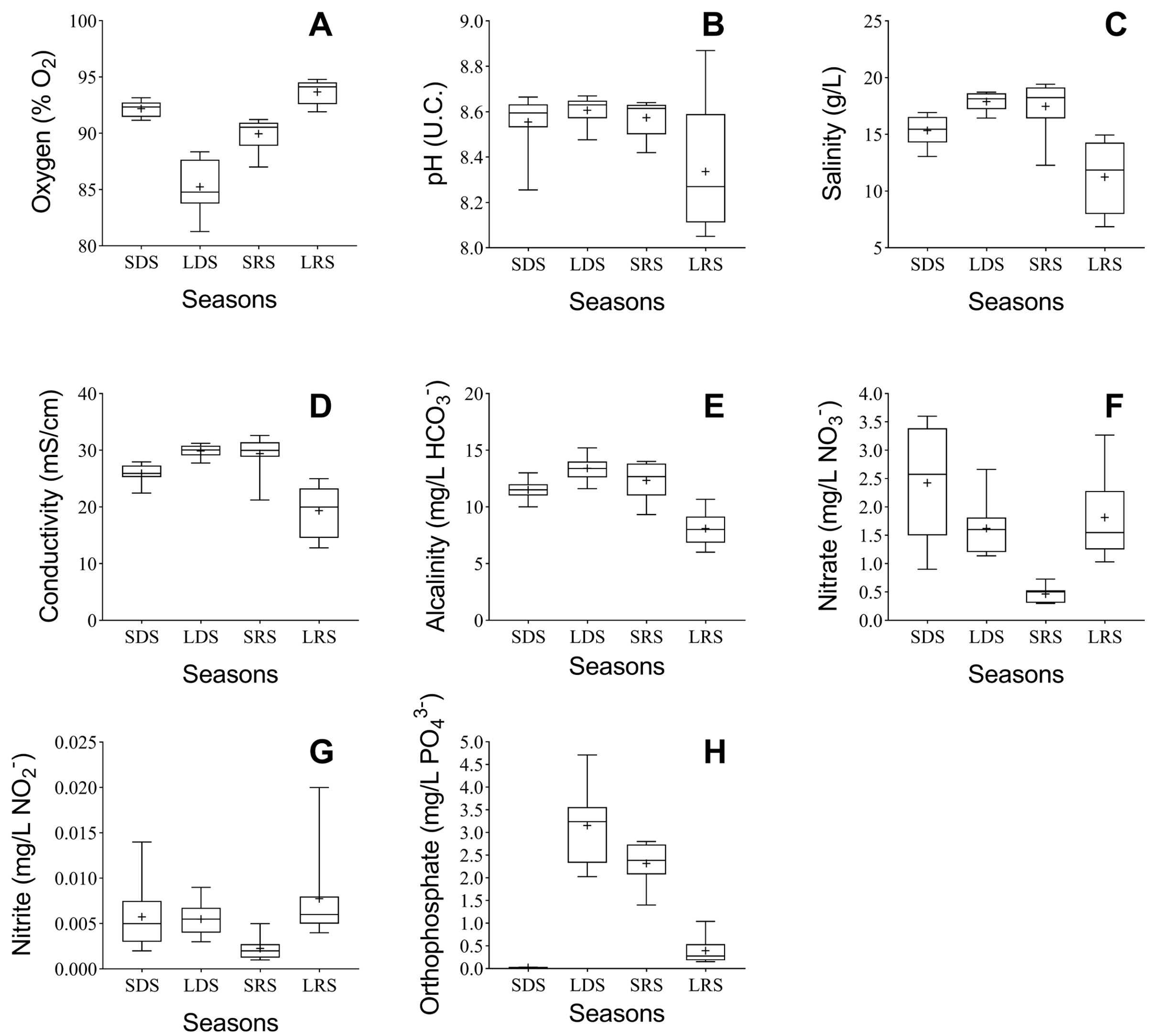


Figure 4. Seasonal variations: Dissolved oxygen (A); pH (B); Conductivity (C); Salinity (D); Alkalinity (E); Nitrates (F); Nitrites (G); Orthophosphates (H).

3.2. Inventory of Dinoflagellates Belonging to the Genera *Ceratium* and *Protoperidinium*

3.2.1. Spatial and Seasonal Diversity of Genra Studies

During the study period, a total of 39 taxa were identified, including 17 of the genera *Ceratium* (**Figure 5**) and 22 of the genera *Protoperidinium* (**Figure 6**). Between the different sampling points, the number of taxa identified was equal to the points P5, P6, P8 while that of the taxa of the genera *Protoperidinium* was higher at P1, P3 and P4. At P2 and P7, on the other hand, diversity was slightly dominated by taxa belonging to the genera *Ceratium* (**Figure 7(A)**). A higher number of species belonging to the genera *Protoperidinium* was noted in all seasons and much more during the short rainy season (**Figure 7(B)**).

3.2.2. Frequency of Occurrence of Inventoried Taxa

Overall, of all the taxa identified during this work, only one was regular (*Ceratium*

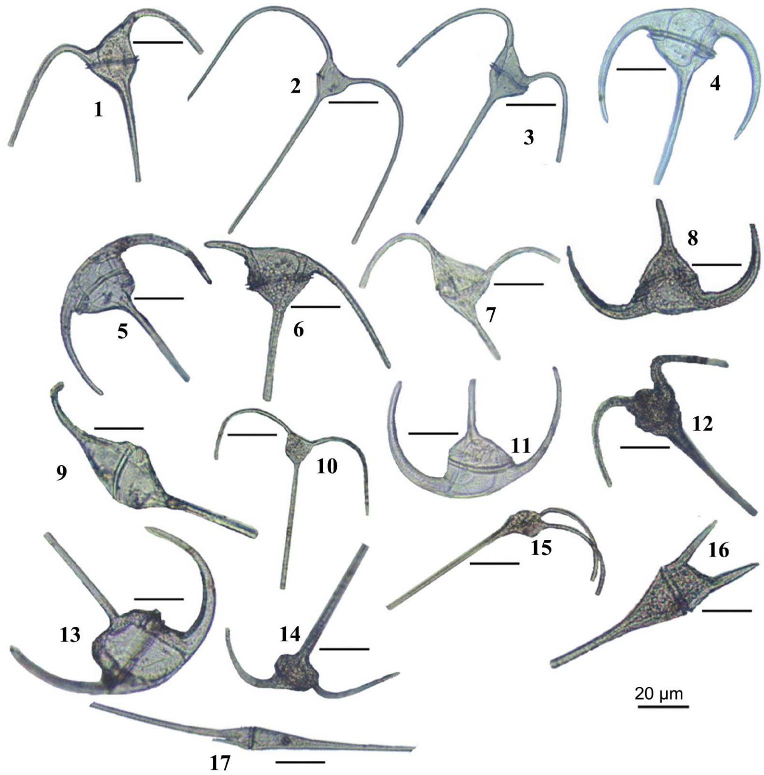
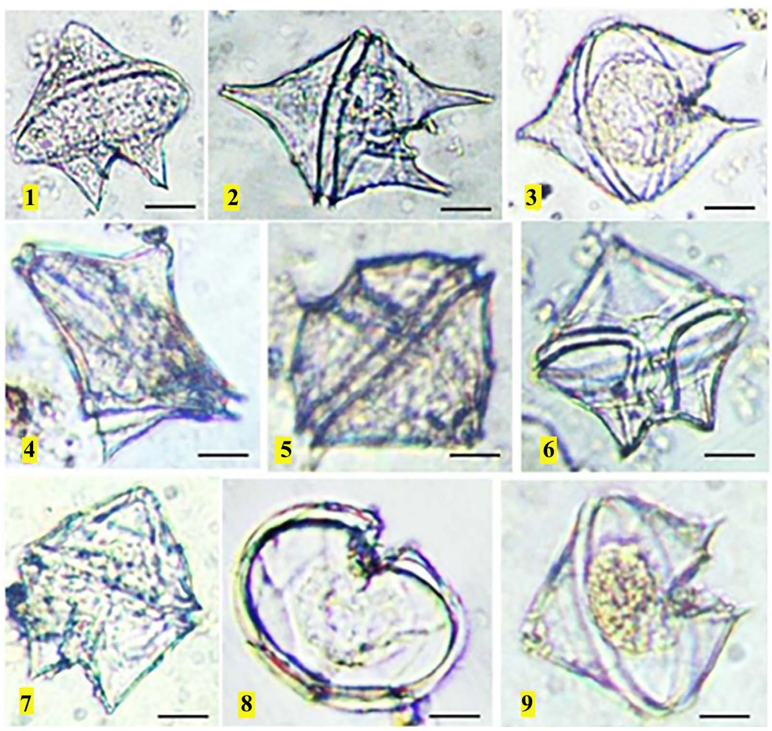


Figure 5. Morphotypes of genera *Ceratium* identified. **Legend:** *Ceratium horridum* (1); *Ceratium massiliens* (2); *Ceratium macroceros* (3); *Ceratium tripos* (4); *Ceratium symmetricum* (5); *Ceratium dens* (6); *Ceratium contortum* (7), *Ceratium declinatum* (8); *Ceratium bigelowii* (9); *Ceratium trichoceros* (10); *Ceratium breve* (11); *Ceratium* sp.1 (12); *Ceratium* sp.2 (13); *Ceratium* sp.3 (14); *Ceratium* sp.4 (15); *Ceratium furca* (16); *Ceratium fusus* (17).



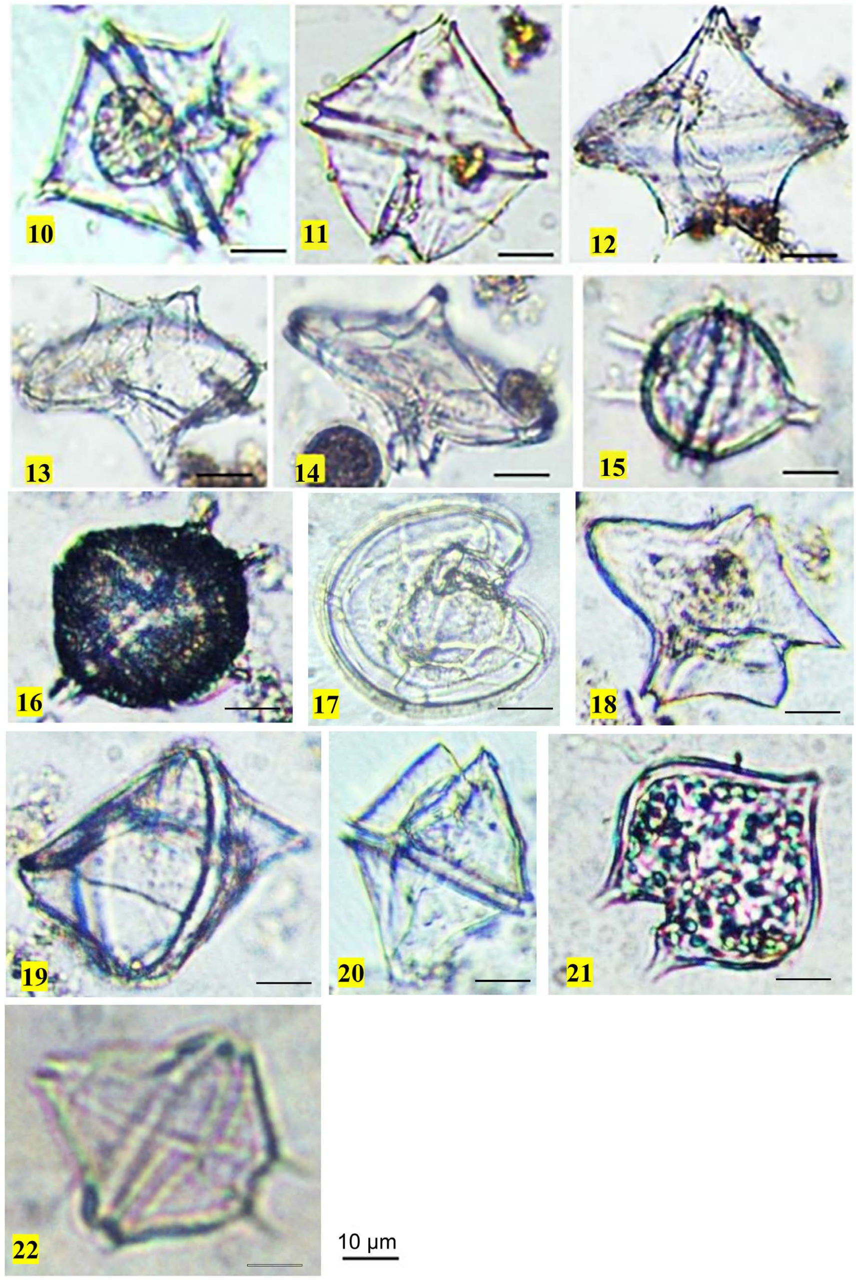


Figure 6. Morphotypes of genera *Protoperidinium*. **Legend:** *Protoperidinium conicum* (1); *Protoperidinium divergens* (2); *Protoperidinium claudicans* (3); *Protoperidinium crassipes* (4); *Protoperidinium punctulatum* (5); *Protoperidinium latissimum* (6); *Protoperidinium conicoides* (7); *Protoperidinium curtipes* (8); *Protoperidinium obtusum* (9); *Protoperidinium leonis* (10); *Protoperinium vulgare* (11); *Protoperinium pentagonum* (12); *Protoperinium depressum* (13); *Protoperinium curtipes* (14); *Protoperinium steinii* (15); *Protoperinium cerasus* (16); *Protoperinium biconicum* (17); *Protoperinium* sp.1 (18); *Protoperinium* sp.2 (19); *Protoperinium* sp.3 (20); *Protoperinium* sp.4 (21); *Protoperinium* sp.5 (22).

furca (75.31%)) and 04 were accessory (*Ceratium fusus* (44.37%), *Cereatium symmetricum* (37.19%), *Protoperidinium conicum* (31.67%) and *Protoperidinium biconicum* (41.25%) (Table 3). The other taxa were generally rare (Table 3).

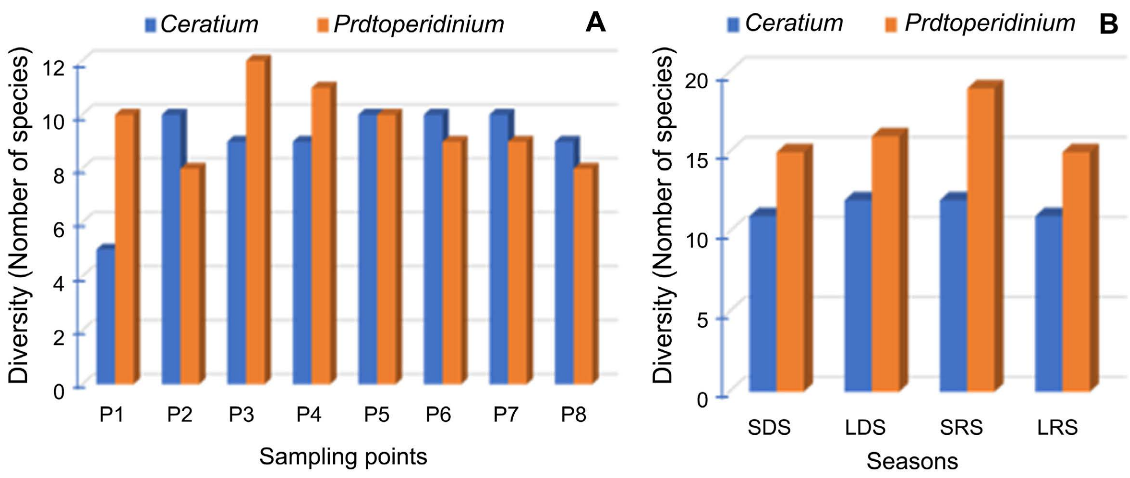


Figure 7. Spatial (A) and seasonal (B) variations in the diversity of the genera studies.

Table 3. Frequency of occurrences of taxa at different sampling points.

Taxa	P1 (%)	P2 (%)	P3 (%)	P4 (%)	P5 (%)	P6 (%)	P7 (%)	P8 (%)	GOF (%)
C. bilgelowi	0	0	0	0	5	5	0	0	1.25
C. breve	0	0	0	0	0	0	5	12.5	2.19
C. concortum	0	0	0	5	0	0	0	0	0.63
C. delicatum	0	12.5	17.5	0	0	0	0	0	3.75
C. dens	0	0	0	0	8.33	8.33	0	0	2.08
C. furca	78.33	86.67	68.33	42.5	77.5	69.17	100	80	75.31
C. fusus	31.66	76.67	43.33	26.67	30	38.33	47.5	60.83	44.37
C. horridum	0	0	0	0	0	0	16.67	25	5.21
C. macroceros	5	10	5	10	5	5	18.33	10	8.54
C. massiliens	25	20.83	13.33	8.33	34.17	25	10	8.33	18.12
C. symmetricum	51.66	13.33	33.33	38.33	42.5	50	20.83	47.5	37.19
C. trichoceros	16.67	0	0	0	8.33	0	5	8.33	4.79
C. tripos	0	25	18.33	30	0	46.67	18.33	13.33	18.96
C. sp.1	0	0	0	0	12.5	8.33	17.5	0	4.79
C. sp.2	8.33	20.83	0	0	0	0	0	0	3.65
C. sp.3	0	0	0	20.83	0	0	0	0	2.6
C. sp.4	0	24.99	0	0	0	0	0	0	3.12
P. biconicum	48.33	51.67	35.83	43.33	25.83	34.17	39.17	51.67	41.25
P. cerasus	8.33	0	0	12.5	5	20.83	13.33	0	7.5
P. claudicans	16.67	0	0	26.67	26.67	25	0	0	11.88
P. conicoides	0	0	13.33	13.33	0	0	0	0	3.33
P. conicum	22.5	31.67	30	30	26.67	26.67	44.17	41.67	31.67
P. crassipes	0	0	12.5	7.5	0	0	0	0	2.5
P. curtipes	0	20	12.5	5	0	16.67	8.33	0	7.81

Continued

P. depressum	0	0	8.33	0	17.5	0	0	12.5	4.79
P. divergens	25	18.33	23.33	18.33	25.83	35	18.33	35	24.89
P. latissimum	0	16.67	20.83	0	0	0	8.33	0	5.73
P. leonis	46.67	33.33	8.33	16.67	22.5	18.33	12.5	5	20.42
P. obtusum	0	0	0	0	0	0	13.33	0	1.67
P. steinii	0	0	0	0	0	0	0	8.33	1.04
P. pellucidum	8.33	5	0	5	0	13.33	0	0	3.96
P. pentagonum	34.17	35	21.67	0	12.5	5	34.17	17.5	20
P. punctulatum	0	21.67	0	12.5	0	0	0	0	4.27
P. vulgare	5	13.33	0	0	0	0	0	0	2.29
P. sp.1	0	0	0	8.33	0	0	0	0	1.04
P. sp.2	0	0	30.83	0	18.33	0	0	0	6.15
P. sp.3	0	18.33	0	12.5	0	0	0	0	3.86
P. sp.4	0	0	20.83	0	20.83	0	0	12.5	6.77
P. sp.5	16.67	0	0	0	0	0	0	0	2.08

C. = *Ceratium*; P. = *Protoperidinium*; GOF = Global Occurrence Frequency.

During the study period, *Ceratium furca* was ubiquitous at P7, regular at P1, P2, P3, P5, P6, P8 and accessory to P4. *Ceratium fusus* was regular at P2, constant at P8 and accessory at other points. *Ceratium symmetricum* was constant at points P1, P6 and accessory at P3, P4, P5, P8 as well as *Ceratium tripos* at P6. Amongst all the taxa of the genera *Protoperidinium* identified, only one (*Protoperidinium biconicum*) was constant at points P2 and P8. Seasonally, *Ceratium furca* was regular except during the long rainy season when it was constant (**Table 4**). *Ceratium fusus* was constant during the short rainy season while *Ceratium symmetricum* was constant in the short dry season and the short rainy season (**Table 4**). Only *Protoperidinium biconicum* has been constant in the short dry and rainy seasons in *Protoperidinium*. The other taxa were rare (**Table 4**).

3.2.3. Spatio-Temporal Densities of Identified Taxa

The densities of the different taxa identified were a function of their occurrences. Regular, constant and accessory taxea are those which have strongly contributed to the densities of the various points. The density of the genera *Ceratium* varied from 0 to 22 126 ind./L (**Figure 8(A)**). No species belonging to the genera *Protoperidinium* exceeded a density at 1600 ind./L (**Figure 8(B)**) throughout the study period. The highest densities were recorded P2, P5, P6 and marked by *Ceratium furca*.

On the seasonal level, on the other hand, there was high density of *Ceratium furca* during the long rainy season a low density in the short dry season. The same remark also emerges in *Ceratium furca*. A proliferation of *Ceratium macroceros* and *Ceratium massiliens* is noted during the long dry season (**Figure 9(A)**).

Table 4. Seasonal variation of frequency of occurrences of different taxa.

Taxa	SDS (%)	LDS (%)	SRS (%)	LRS (%)
C. bilgelowi	0	5	0	0
C. breve	6.25	2.5	0	0
C. concortum	0	2.5	0	0
C. delicatum	12.5	2.5	0	0
C. dens	0	0	0	8.33
C. furca	81.25	57.5	83.33	79.16
C. fusus	25	40	74.95	37.5
C. horridum	0	0	16.67	4.17
C. macroceros	0	30	0	4.17
C. massiliens	25	10	25	12.5
C. symmetricum	68.75	17.5	50	12.5
C. trichoceros	0	2.5	8.33	8.33
C. tripos	12.5	17.5	20.83	25
C. sp.1	12.5	2.5	4.17	0
C. sp.2	6.25	0	0	8.33
C. sp.3	6.25	0	4.17	0
C. sp.4	0	0	4.17	8.33
P. biconicum	50	40	54.16	20.83
P. cerasus	12.5	5	12.5	0
P. claudicans	12.5	10	8.33	16.67
P. conicoides	0	5	8.33	0
P. conicum	25	35	29.16	37.5
P. crassipes	6.25	3.75	0	0
P. curtipes	6.25	7.5	13.33	4.17
P. depressum	12.5	2.5	4.17	0
P. divergens	6.25	42.5	25.83	25
P. latissimum	6.25	0	8.33	8.33
P. leonis	41.66	15	20.83	4.17
P. obtusum	0	2.5	0	4.17
P. steinii	0	0	4.17	0
P. pellucidum	0	7.5	8.33	0
P. pentagonum	25	17.5	16.67	20.83
P. punctulatum	6.25	2.5	4.17	4.17
P. vulgare	0	5	4.17	0
P. sp.1	0	0	0	4.17
P. sp.2	6.25	0	4.17	8.33
P. sp.3	6.25	10	4.17	4.17
P. sp.4	18.75	0	4.17	4.17
P. sp.5	0	0	4.17	4.17

C. = *Ceratium*; *P.* = *Protoperidinium*; SDS = Short Dry Season; LDS = Long Dry Season; SRS = Short Rain Season; LRS = Long Rain Season.

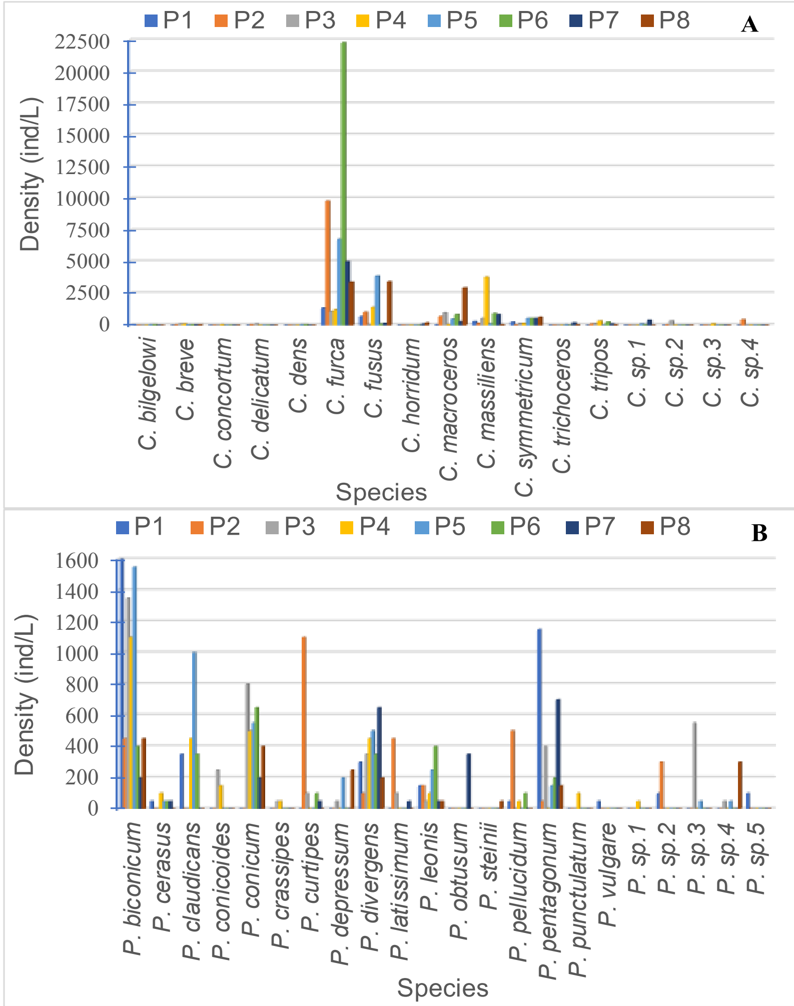


Figure 8. Spatial variations of species density: Genera *Ceratium* (A); Genera *Protoperidinium* (B).

Protoperidinium conicum, *Protoperidinium divergens*, *Protoperidinium pentagonum* and *Protoperidinium biconicum* proliferated more during the long dry season (**Figure 9(B)**).

3.2.4. Relationship betwen Abiotic Variables and Identified Taxa

The analysis of the correlations was done to highlight the links between the abiotic variables and the different taxa identified. **Table 5** shows the abiotic variables that have significatively influence in the distribution of the taxa. Temperature show a positive and significant correlations with *Ceratium fusus*, *Ceratium macroceros*, *Ceratium massiliens*, *Protoperidinium divergens* and *Protoperidinium pellucidum*. Dissolved oxygen was negatively and significantly correlated with *Ceratium macroceros*, *Ceratium massiliens*, *Ceratium bilgelowi*, *Protoperidinium conicoides*, *Protoperidinium conicum*, *Protoperidinium divergens*, *Protoperidinium pellucidun*, *Protoperidinium*, *Protoperidinium vulgarus*, *Protoperidinium biconicum*. Salinity, electric conductivity and TDS show a negative and significant influence on *Properidinium claudicans* (**Table 5**).

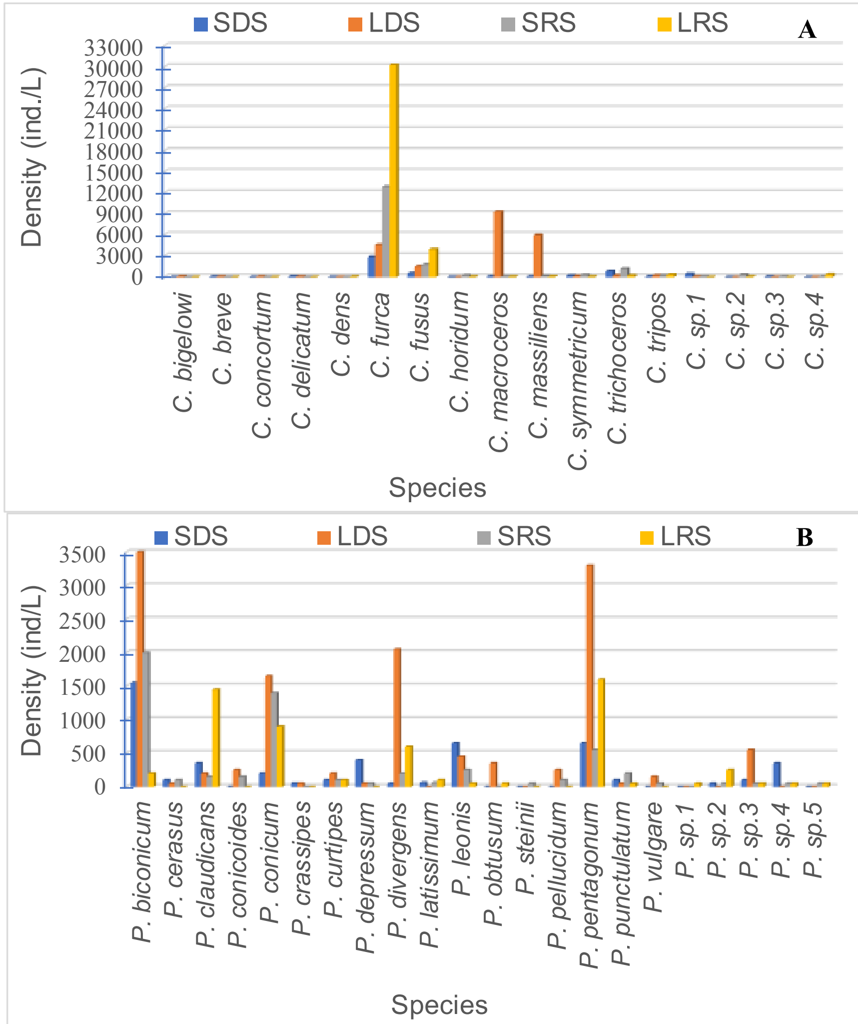


Figure 9. Seasonal variations of density: Genera *Ceratium* (A); Genera *Protoperidinium* (B).

Table 5. Correlations between identified abiotic variables and taxa.

	Temp	Oxy	pH	Cond	Sal	TDS	MES	Col	NO_3^-	NO_2^-	PO_4^{3-}	Alc	Transp
C. fusus	**0.361***	−0.305	0.18	0.184	0.176	0.19	−0.083	**−0.386***	−0.318	−0.153	**0.382***	0.159	−0.162
C. macroceros	**0.419***	**−0.380***	0.082	0.251	0.258	0.228	−0.006	−0.323	0.03	−0.066	0.202	0.278	**0.455****
C. massiliens	**0.451****	**−0.464****	0.083	0.255	0.265	0.234	0.074	−0.245	0.054	−0.107	**0.428***	0.332	**0.376***
C. symmetricum	−0.073	−0.163	−0.238	−0.066	−0.081	−0.069	0.05	0.128	−0.127	−0.095	0.044	0.129	**−0.364***
C. trichoceros	−0.212	0.072	−0.18	−0.258	−0.265	−0.249	0.049	0.064	−0.037	−0.167	−0.017	−0.016	**−0.510****
C. horridum	0.177	0.043	0.191	0.253	0.241	0.224	0.237	−0.151	**−0.385***	−0.179	−0.008	0.052	0.05
C. dens	−0.15	0.284	−0.327	−0.319	−0.319	−0.319	−0.17	0.045	0.19	0.179	−0.11	**−0.369***	0.291
C. bilgelowi	0.343	**−0.350***	0.168	0.294	0.308	0.315	−0.014	0.126	0.175	0.219	0.336	0.294	−0.168
P. cerasus	0.167	−0.109	0.27	0.344	**0.350***	**0.360***	0.318	−0.157	−0.073	−0.335	0.195	0.269	−0.249
P. claudicans	−0.238	0.198	−0.322	**−0.367***	**−0.366***	**−0.374***	−0.095	0.154	0.12	0.273	0.052	−0.141	−0.076
P. conicoides	0.208	**−0.367***	0.216	0.016	0.016	0.016	0.138	−0.2	−0.301	−0.212	0.291	−0.084	0.208

Continued

P. conicum	0.279	**−0.368***	0.264	0.122	0.126	0.129	0.035	−0.319	−0.308	**−0.363***	**0.423***	0.052	0.027
P. crassipes	0.016	−0.127	0.048	−0.094	−0.094	−0.094	**−0.393***	−0.175	0.076	0.111	−0.098	0.068	0.064
P. depressum	−0.001	−0.061	**0.350***	0.171	0.197	0.208	−0.055	0.005	0.045	−0.171	−0.095	0	0.167
P. divergens	**0.624****	**−0.415***	0.267	0.202	0.215	0.201	0.077	**−0.465****	0.138	0.094	**0.490****	0.174	**0.396***
P. leonis	−0.057	−0.184	0.06	0.245	0.252	0.26	0.187	0.341	0.016	0.025	−0.036	0.203	**−0.351***
P. pellucidum	**0.421***	**−0.471****	0.159	**0.396***	**0.386***	**0.399***	0.042	**−0.368***	−0.191	−0.223	**0.392***	0.302	−0.153
P. sp.	0.344	**−0.484****	0.152	0.338	0.338	0.339	0.183	−0.099	−0.089	−0.167	**0.366***	**0.456****	−0.105
P. vulgare	0.217	**−0.354***	−0.089	0.265	0.265	0.253	−0.005	0.051	−0.087	0.122	0.187	0.319	−0.111

**Correlation is highly significant at the 0.01 level; *Correlation is significant at the 0.05 level.

3.2.5. Factor Analysis of Matches

The distribution of taxa in the space of the sampling points of the PCA Dim.1 × Dim.2 plane is shown in **Figure 10**. As a result of this analysis, the majority of links between sampling points and species were observed at Dim.1. Thus, and in a globally, the sampling points P1, P2, P3, P5, P6, P7 and P8 offer more particulary favourable conditions for the development of the species *Ceratium furca*, *Ceratium fusus*, *Protoperidinium leonis* whereas, the species *Ceratium massiliens*, *Ceratium symmetricum*, *Ceratium macroceros* proliferate more at the sampling point P4 (**Figure 10**).

4. Discussion

4.1. Abiotic Variables

Variations in abiotic variables (temperature, pH, salinity, nitrates, phosphates, Suspended Solid) were moderate along the stretch of coast studied throughout the study period and significant with differences in concentration between different seasons.

The level of temperature variation is related to the extent of the section studied and the measuring range. The average temperature value (29.51˚C) recorded during this study shows an increase in temperature in the Kribi coast over the years compared to those obtained by similar studies [33] in 2004, 2005 and 2006 (27.2˚C; 27.4˚C; 28.6˚C) respectively. This difference observed between the two studies could be justified by the frequency of measurements or the effects of climate change on temperature. A difference that would be justified by the fact that the measurements were made on an ad hoc basis from one station to another and at irregular times at times when the sun was at its zenith [34].

The levels of water pH variation recorded during this study reflect a pH illustrating a halin domain. Sudden changes in pH have often caused many disturbances in the biological compartment. Although flowers are generally considered non-toxic to marine invertebrates, they have been suspected of being related environmental damage through pH changes, mild reduction, and oxygen depletion, which contributed to the deaths of various phytoplankton, fish, zoobenthos, shellfish [35].

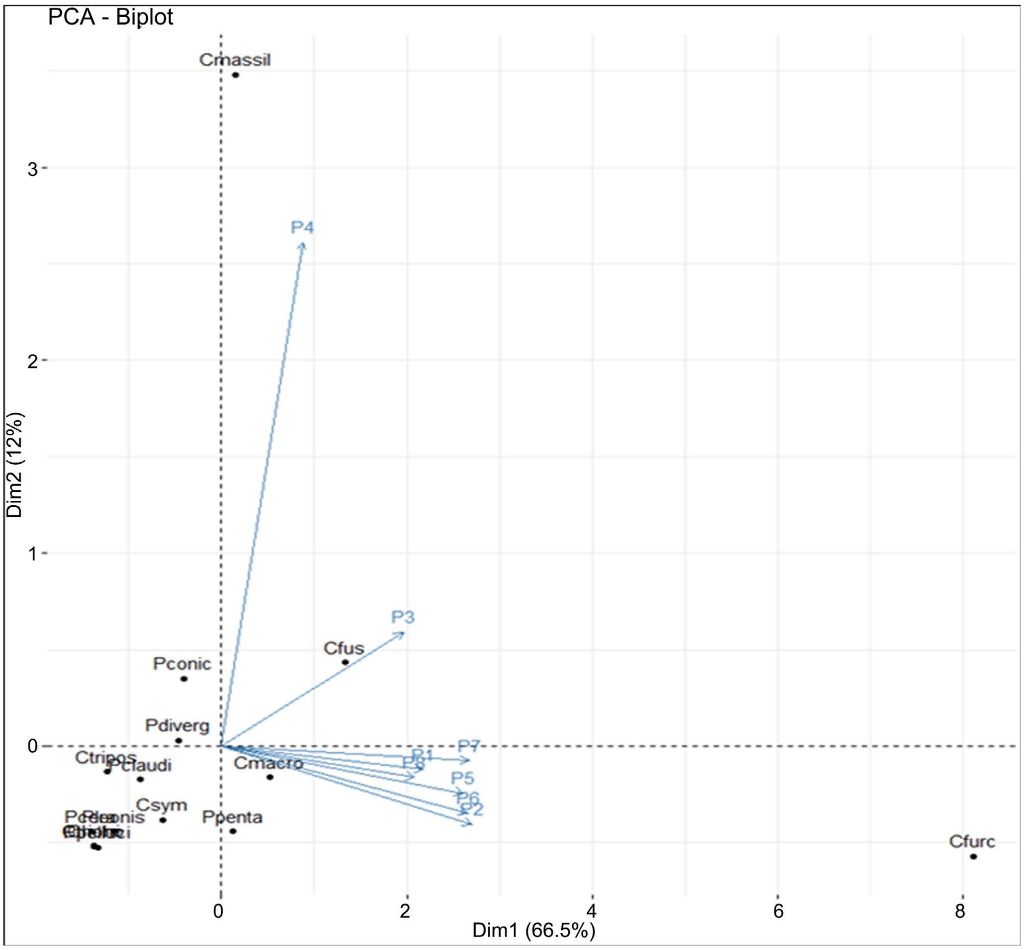


Figure 10. Graphical representation of inventoried taxa and sampling points. **Legend:** *C. horri*: *Ceratium horridum*; *C. macro*: *Ceratium macroceros*; *C. fus*: *Ceratium fusus*; *C. sym*: *Ceratium symmetricum*; *C. tricho*: *Ceratium trichoceros*; *C. furc*: *Ceratium furca*; *C. tripos*: *Ceratium tripos*; *C. massil*: *Ceratium massiliens*; *P. leonis*: *Protoperidinium leonis*; *P. pelluci*: *Protoperidinium pellucidum*; *P. curt*: *Protoperidinium curtipe*; *P. conic*: *Protoperidinium conicum*; *P. penta*: *Protoperidinium pentogonum*; *P. claudi*: *Protoperidinium claudicans*; *P. diverg*: *Protoperidinium divergens*; *P. cera*: *Protoperidinium cerasus*.

The slight decrease in salinity observed at P4 compared to the other points could be the result of an influence of the fresh waters of the Lobé. Overall, according to a report by MINEPN [35], the increase in salinity in some places may be due to a low supply of fresh water (for example in the Kribi region compared with that of Limbé close to Wouri Estuary). However, it has been reported that the low salinity of the water such as that recorded during the long rainy season favors the proliferation of dinoflagellates especially the benthic species [36].

The Suspended Solids were generally low in the different points ranging from 4.69 to 8.46 mg/l with an average of 06.36 ± 1.43 mg/L. The averages observed were generally lower than those of the Suspended Solids obtained upstream of a coastal river, the Kienké in Kribi [37]. The low Suspended Solids are linked to the phenomenon of clogging and sedimentation in the marine environment.

Nitrites, nitrates and orthophosphates recorded during this work, they were higher than those recorded in 2006 by Krakstad *et al.* [33] in a study that covered 07 months with a monthly measurement frequency (<0.003; 0; 0.5 mg/L for nitrites, nitrates and orthophosphates respectively). The increase of nitrates (1.52 ± 0.44) and orthophosphates (1.84 ± 0.2) concentration recorded during this study could be come from mainly industrial, domestic, hotel, landing stages and fish markets. The high concentrations observed at P2, P5 and P8 would testify to the influence of the site activities on the enrichment of the environment with these nutrients. According to Carpenter [7] and Diaz *et al.* [8], the bioavailability of nutrients, mainly phosphorus and the different forms of nitrogen in excess concentrations could be the root cause of the algal bloom attributed to the eutrophication of water bodies.

The average temperature values of water, nitrates and orthophosphates compared to previous work showed an increase in temperature on the coast over the years and nutrient enrichment. Temperature and dissolved oxygen are the abiotic factors that have more positive and significant influence; negative and significant respectively on most of the species recorded.

4.2. Biological Variables

A total of 33 taxa including 15 belonging to the genera *Ceratium* and 18 to the genera *Protoperidinium*. This diversity is low compared to the results of the work of Lakkis [29] in Lebanese marine waters and the Levantine basin where 54 species of *Ceratium* and 32 species of *Protoperidinium* have been identified; Okolodkov [12] in the Sistema Arrecifal Veracruzano Park, in the southern Gulf of Mexico, which has recorded 33 species belonging to the genera *Ceratium*. Koéme [28] identified 21 species of *Ceratium* and 04 species of *Protoperidinium* in the Grand-Lahou lagoon complex in Côte d'Ivoire. This difference of diversity observed could be related to the duration of each study, the specific characteristics and the climatic conditions prevailing in the study areas. The spatio-temporal variation in the context of this work could also be justified by the specific characteristics of each sampling point, the climatic conditions specific to each season and the geographical distribution of species.

Amongst all the species recorded, *Ceratium furca* was the only regular species. A similar finding was made by Lakkis [29] in Lebanese waters. This species as well as *Ceratium fusus* and *Ceratium tripos* although generally incidental and rare in the context of this work have been recognized by several works as a harmful species. Indeed, according to Schmidt and Schaechter [38], the species belonging to this genus *Ceratium*, specifically *Ceratium tripos*, *Ceratium furca*, and *Ceratium fusus* were able to produce the largest flowers of dinoflagellates due to their large size which takes into account that a limited number of cells have a significant impact. The red-brown flowers of these species such as *Ceratium furca* have been known to damage fish gills and to create anoxic conditions by depleting dissolved oxygen from the environment, which can suffocate various animals in the area [39].

As a whole, the highest presence of rare taxa shows of a permanent renewal of taxa belonging to the genera researched which could be very sensitive to the variations of environment conditions. The specific composition and the dynamics of the populations algales during this study would be influenced by innumerable physico-chemical factors and by the biological interactions like chattering by the zooplancton and the competition inter and intraspecific.

The spatial and seasonal distribution of species in the section studied showed overall dominance of the genera *Protoperidinium*. The number of species identified for this genera was greater than the number for *Ceratium*. Some species of this genera may survive for a longer period of time, for example, *Protoperidinium depressum* may survive up to 71 days in states of starvation or low food availability [40]. Smaller to larger diatoms and dinoflagellates are the primary food source for *Protoperidinium*, and their proliferation can cause a red tide of *Protoperidinium* [41].

Unlike the diversity that was dominated by the genera *Protoperidinium*, the densities were dominated by the species belonging to the genera *Ceratium* at all collection points and in all seasons. This dominance in terms of density could be explained according to Dodge and Marshal [13] who emphasizes that genera *Ceratium* is an omnipresent kind of dinoflagellates to theca, slow growing, found during all seasons and contributes significantly to the annual primary production in the world's oceans. In particular, this density dominated by the species *Ceratium furca* and *Ceratium fusus*. On the coast of Kribi, the appearance of a bloom of one of these two species could be predicted during the short and long rainy season at points P2, P5, P6 and P7. They have more preferences according to the Factor Analysis of the Correspondences at points P2 and P6. Their strong presence could be justified by the fact that *Ceratium furca* is a species commonly found in coastal waters and whose ecological impact caused by flowers has intensified in recent years [42] while *Ceratium fusus* is classified as a cosmopolitan species found in an ambient temperature between 2˚C and 29.5˚C [13]. The positive and significant correlation recorded testifies to the importance of temperature for the development of this species.

Despite their low density observed during this study, some species belonging to the genera *Protopéridinium* should be monitored. *Protoperidinium divergens*, *Protoperidinium steinii*, *Protoperidinium crassipes* identified during this work have been recognized as harmful by several works. Positive and significant correlations between *Protoperidinium divergens*, temperature and orthophosphates; Negative and significant between *Protoperidinium divergens* and dissolved oxygen observed show that an increase in temperature, an enrichment in orthophosphate and a decrease in dissolved oxygen, could cause the efflorescence of this species in the coast of Kribi. The temperature seems to be favorable for the flower of this genera, as reported by Raji and Padmavati [18] during the flower of *Protoperidinium divergens* in the Andaman compartment region. In addition, phosphorus is an essential nutrient that causes eutrophication leading to lush algae growth when their concentrations exceed certain limits [43] [44]. Overall, the majority of *Protoperidinium* species appear to be diatom grazers, some may use, or even require dinoflagellate prey for their proliferation while others may feed on prey larger than themselves [44].

In reference to similar studies carried out in the world [18] [39] [42] [45], this work has allowed to count in the study area 06 species of the studied genera which could cause in time phenomena such as the appearence of algal blooms and fish poisoning never experienced in the Cameroonian coast. These are *Ceratium furca*, *Ceratium fusus*, *Ceratium tripos*, *Protoperidinium divergens*, *Protoperidinium steinii*, *Protoperidinium crassipes*.

5. Conclusions

Which involved inventorying taxa belonging to the genera *Ceratium* and *Protoperidinium* and the abiotic factors associated with them, that spatial and temporal distribution of the number of species beliongong to the genera *Proteridinium* is higher than those belonging to the genera *Ceratium*. There was a marked increase in the density of the species belonging to the genera *Ceratum* precisely *Ceratium furca*, *Ceratium fusus*, *Ceratium macroceros*, *Ceratium massiliens*. Variations in spatial diversities and densities have generally changed very little with the level of anthropization of the coast. However, the identified pest species were more present in terms of occurrence and density on the section from P5 to P8, *i.e.* the area where offshore and deep-water ports are found. Seasonally, the densities of the different species were higher during the long dry season, the short and the long rainy season. These were more specifically *Ceratium furca*, *Ceratium fusus*, *Ceratium macroceros*, *Ceratium massiliens*, *Protoperidinium claudicans*, *Protoperidinium conicum*, *Protoperidinium divergens*, *Protoperidinium pentagonum* and *Protoperidinium biconicum*.

In view of these results, an efflorescence of the identified harmful species could be predicted at points P2, P5, P6, P7 during the short and long rainy season for *Ceratium furca*; P5 and P8 during the long rainy season for *Ceratium fusus*; P4, P5, P7 during the long rainy season for *Protoperidinium divergens*.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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