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Abundance and Dynamics of Centric Diatom *Coscinodiscus* and Pennate Diatom *Pluerosigma* in Atlantic Ocean (Nigeria), Gulf of Guinea

***[1]OMORUYI, OA; [2]KADIRI, MO**

**[1]Department of Botany, Faculty of Life Sciences, Ambrose Alli University, Ekpoma, Nigeria*
[2]Department of Plant Biology and Biotechnology, University of Benin, Benin City, Nigeria:

**Corresponding Author Email: osasere.omoruyi@aauekpoma.edu.ng*
**ORCID: https://orcid.org/0000-0003-4505-9551*
**Tel: +2348055656885*

Co-Author Email: mokadiri@uniben.edu

ABSTRACT: Diatoms which are classified into centric diatoms and pPennate diatoms play vital role in themarine food chain. Hence, the objective of this paper is to evaluate the abundance, distribution, dynamics and occurrence of *Coscinodiscus* and *Pluerosigma* in Atlantic Ocean from Bight of Benin to Bight of Bonny in Nigeria. This study considered the abundance, dynamics and environmental factors influencing the distribution of centric and pennate diatoms in the Atlantic Ocean, Gulf of Guinea (Nigerian). Water samples for diatom analysis and physico-chemical analysis were collected along transect of the Atlantic Ocean (Nigerian) from Twenty (30) oceanic water stations in ten (10) locations from the eight (8) Nigerian coastal states. Eight taxa each of centric and pennate diatoms were found in the Atlantic Ocean. *Coscinodiscus radiatus* was the most widely distributed and abundant among centric diatom *Coscinodiscus* while *Pleurosigma enlongatum* was the most widely distributed species for the pennate diatom *Pleurosigma*. *Coscinodiscus maginatus* was least in distribution and abundant for the centric diatom *Coscinodiscus* while *Pleurosigma formosum* and *Pleurosigma P. formosum* v. *longissimum* were least occurring among the pennate diatom *Pleurosigma*. Ondo oceanic water was richest in the diversity of *Coscinodiscus* in Gulf of Guinea while Bayelsa oceanic water was richest in the diversity of *Pleurosigma* in Gulf of Guinea. Result revealed significant difference in the abundance of centric and pennate diatoms in the Atlantic Ocean. Temperature, pH, total dissolved solids, salinity, alkalinity, total hardness calcium, chloride silicate, sulphate and rainfall were environmental factors controlling the distribution and abundant of pennate and centric diatoms.

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Diatoms are microscopic eukaryotic algae with siliceous and opaline cell walls. They form an important part of plankton at the base of food chain. Diatoms are abundant and cosmopolitan (in distribution) in aquatic habitats. They play crucial role in the oceans where they fix large amounts of carbon dioxide, produce oxygen and synthesize carbohydrates that serve as a chief source of zooplankton food in the marine food chain. Diatoms are classified into two biological orders, the Centrales and the Pennales, correspondingly are called Centric diatoms and Pennate diatoms. Centric diatoms have discoid or cylindrical cells having radial symmetry in face or "valve" view (Graham and Lee 2000). A valve is the top or bottom of the silica frustule. The centric diatom (Order: Centrales) have valves with a concentric or radiating sculpture around a point or points, central or lateral without raphe or pseudoraphe. In contrast, valves of pennate diatom (referring to "feathery" patterns of ornamentation on the frustule) diatoms

**Corresponding Author Email: osasere.omoruyi@aauekpoma.edu.ng*
**ORCID: https://orcid.org/0000-0003-4505-9551*
**Tel: +2348055656885*

have more or less bilateral symmetry (Pal and Choudhury, 2014). The genus *Coscinodiscus* is a centric diatom and contain species with cells with circular valve face outline and members of the Order Centrales Class Coscinodiscophyceae. Pennate diatoms (Order: Pennales) have elongated valves and are bilaterally symmetrical. Pennate diatoms are generally outlined boat shaped or rod shaped, sometimes oval, cuneate, crescent shaped or sigmoid and their markings are generally pinnate or transverse (Pal and Choudhury (2014)). Pennate diatoms either have true raphe, or hyaline median line (pseudoraphe), or raphe obscured by lateral wings or keel (cryptoraphe) and lack processes (Pal and Choudhury, 2014).

Pleurosigma has raphe on a keel or wing that usually lies in the midline of the valve. Cells usually twisted about the apical axis (Pal and Choudhury, 2014). Diatoms have been examined as part of phytoplankton flora (study) in Nigeria (Kadiri, 2006 a,b) and species of the genera *Coscinodiscus* and *Pleurosigma* have been passively mentioned in these studies. No study has specifically examined the dynamics of *Coscinodiscus* and *Pleurosigma* nor categorically compared the abundance, distribution and occurrence of centric and pennate diatoms in the entire stretch of the Atlantic Ocean, Gulf of Guinea, from the Bight of Bonny to the Bight of Benin in Nigeria. Hence, the objective of this paper is to evaluate the abundance, distribution, dynamics and occurrence of Coscinodiscus and Pluerosigma in Atlantic Ocean (Nigeria), Gulf of Guinea.

MATERIALS AND METHODS

Description of the Study Area: Atlantic Ocean is one of the largest oceans in the world. It is located between Africa and Europe to the east and the Americas to the west. The Atlantic Ocean covers a total area of about 106,460,000 square kilometers, it is the second biggest ocean of the world with approximately 20% of the Earth's surface and about 29 % of its water surface area. Gulf of Guinea is the northeastern most part of the tropical Atlantic Ocean between Cape Lopez in Gabon, north and west to Cape Palmas in Liberia. The intersection of the Equator and Prime Meridian (zero degrees latitude and longitude) is in the gulf (World Resources, 1990). The Nigerian coast extends from the Bakassi Peninsula in Cross River State to Badagry in Lagos State. The Atlantic Ocean in Nigeria extends from Lagos in South-West, in the Bight of Benin to Cross River in the South-South in the Bight of Bonny, traversing eight states, which are Cross River, Akwa Ibom, Bayelsa, Delta, Ondo, Ogun, and Lagos state. Nigerian coast covers a length of 1000km (Egboge *et al*., 1994; Kadiri, 2002). Thirty stations were sampled on the Atlantic Ocean from ten locations in the eight coastal states of Nigeria (Fig.1). Each coastal state was assigned an oceanic water location except Lagos state which had three oceanic water locations (namely; Lekki, Bar Beach and Badagry). The sampled locations were grouped into two zones; South-South and South-West. Cross River, Akwa Ibom, Bayelsa and Delta were the South-South oceanic water zones in the Bight of Bonny while Ondo, Ogun, and Lekki, Bar Beach and Badagry were the South-West oceanic water zones in the Bight of Benin.

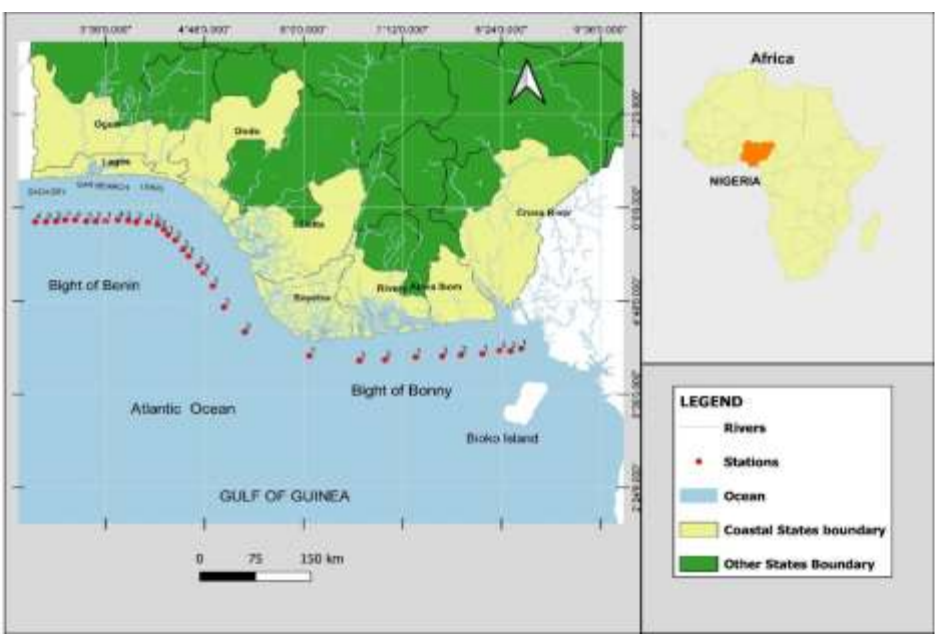


Fig.1: Map of study area

The Nigerian coastal area is a tropical rain forest with a hot wet equatorial climate type, characterized by a unique climate with almost uniform temperature with minimal variation all through the year. Its rainfall pattern is characterized by double rainfall peak in July and September. The climate has eight months of rainfall or wet season and four months of dry season although there is no month without rain. The driest months are in January and February at the beginning of the year. The wettest months are in June, July with a break in August and the heavy rains resume in September to October before the dry season set in, in November. Within the two seasons there are four distinguishable periods classified into: the Dry-wet period (a transitional period from the dry season to wet season); the Wet period (a period of frequent and high amount of precipitation); the Wet-dry period (a transitional period from the wet season to the dry season); and the Dry period (period of no rain fall). The Wet-dry period is characterized by decrease in the frequency and amount of precipitation (as compared to the preceding Wet period) and gradual transition into the dry period while the Dry-wet period is the characterized by a period of increase in the amount and frequency of precipitation as compared to what was experienced in the preceding dry period. The Wet period is the peak period of rainfall as a contrast to the Dry season with little or no rainfall.

Sampling: Periodic (dry-wet, wet, wet-dry and dry periods) planktonic diatom samples were collected over the period of March 2014 – January 2015. Integrated Quantitative water samples were collected at each station with the aid of a Lund Tube into a 1L phytoplankton sample container for diatom analysis. Each phytoplanktonic diatom sample were preserved with Lugols iodine and 10% formalin. Centric and pennate diatoms were identified to species level, using taxonomic literature and taxonomic identification keys. Centric and pennate diatom enumeration and estimation of cell concentrations was carried out according to the method of Lackey (1938) (Lackey's drop method) with the aid of compound microscope pre-calibrated with a stage and ocular micrometer.
Statistical analysis were employed to evaluate the dynamics of centric and pennate diatom species. Canonical Correspondence Analysis (CCA) was applied to evaluate the relationship between environmental variables and the abundance of centric and pennate diatoms. Bray–Curtis coefficient, and hierarchical clustering was used to determine similarity. PERMANOVA was used to detect significant differences in diatom community structure between zones, location, seasons, periods and diatom groups.

RESULTS AND DISCUSSION

Spatial Distribution Of Species In The Atlantic Ocean, Gulf Of Guinean (Nigeria)Coscinodiscus Spp.: The spatial variation of total *Coscinodiscus* genus is shown in figure 2a and 2b. Spatially, Ondo oceanic water (152.7 x10^3 cell L^{-1}) recorded the highest *Coscinodiscus* spp. abundance while Delta oceanic water (17.3x 10^3 cell L^{-1}) had the least abundance for *Coscinodiscus* spp in the Gulf of Guinea. Bayelsa oceanic water had the highest abundance (121.3 x 10^3 cell L^{-1}) among the South-South coastal oceanic water. Although Ondo oceanic water in the South-West (Bight of Benin) recorded the highest cell count for *Cosinodicus* spp in the Gulf of Guinea (Nigeria), yet abundance of *Coscinodiscus* spp. observed in Bayelsa oceanic water in the South-South (Bight of Bonny) was higher than those observed in the South-West oceanic water locations of Lekki (104 x 10^3 cell L^{-1}), Bar Beach (42.3 x 10^3 cell L^{-1}) and Badagry (71.5 x 10^3 cells L^{-1}) except for Ogun which was slightly (a little) higher (126.7 x 10^3 cell L^{-1}).

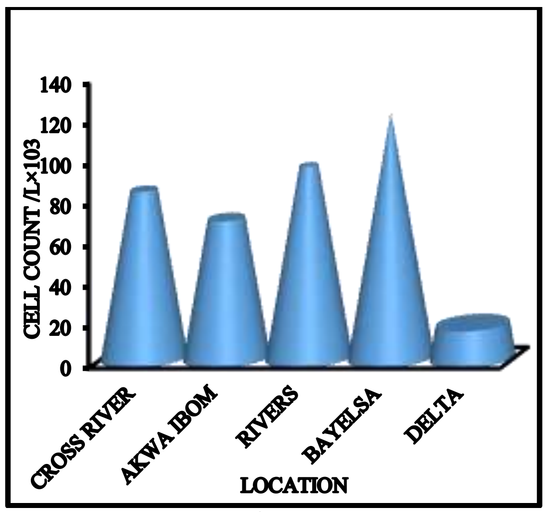


Fig.2a: Spatial cell density of *Coscinodiscus* spp in the South-South Zone of the Atlantic Ocean (Nigeria)

The spatial distribution of various *Coscinodiscus* species in the Atlantic Ocean is shown is figure 3a and 3b *C. radiatus* Ehrenberg was the most widely distributed species of *Coscinodiscus* in the Atlantic Ocean Gulf of Guinea (Nigeria). It was present in all oceanic location and recorded the highest biomass among other species found in all the locations expect in Ondo where *C. radiatus* (10 x 10^3 cell L^{-1}), was slightly less in biomass to *C. centralis* (12 x 10^3 cell L^{-1}). *C. concinnus* and *C. lineatus* Ehrenberg where at pal in distribution. Both species were the second most widely distributed species of the genus *Coscinodiscus*. *C. lineatus* was present in most locations sampled except in Cross River, Delta and Ogun locations. Both species were present in 7 locations and absent in 3 (three) locations. *C. concinnus* was not recorded in Bayelsa and Delta location in the South-South and Lekki location in the South-West. *C. lineatus* was mostly a South-West oceanic water species in the Gulf of Guinea. *C. concinnus* and *C. lineatus* was the second most widely distributed *Coscinodiscus* species after *C. radiatus* in the South-South oceanic water zone Gulf of Guinea (Nigeria). *C. centralis* was fairly distributed in South-South oceanic water, present in two locations (Cross River and Bayelsa), but the most widely distributed species after *C. radiatus* in the South-West. *C. centralis* was present in all location sampled in the South-West except in Bar Beach oceanic water. *C. centralis* was most abundant among other species in Ondo oceanic water.

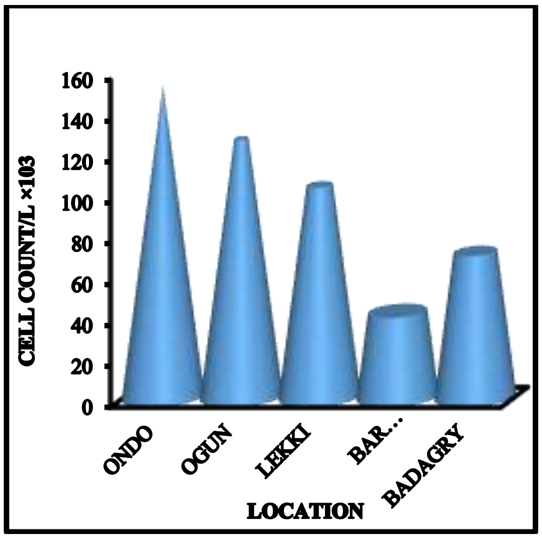


Fig.2: Spatial cell density of *Coscinodiscus* spp in the South-West Zone of the Atlantic Ocean (Nigeria)

C. marginatus was the most poorly distributed in the South-West oceanic water. It was present in just Ondo oceanic water and absent in other locations in other South-West, while it was recorded in Rivers and Bayelsa oceanic water in the South-South. *C. granii* and *C. wailesii* were barely distributed in the South-South oceanic waters. *C. granii* and *C. wailesii* were observed in one oceanic location each in the South-South, Bayelsa and Rivers respectively. Both species were fairly distributed in South-West. *C. ganii* was present in three (3) locations (Ondo, Ogun and Lekki oceanic waters) while *C. wailesii* was observed at two (2) locations (Ondo and Ogun oceanic waters). *C. oculus-iridis* (Ehrenberg) Ehrenberg was the least distributed in the Atlantic Ocean, Gulf of Guinea (Nigeria). It was found in three (3) South-West locations (Ondo, Bar Beach and Badagry oceanic water) while totally absent in the South-South oceanic water location Gulf of Guinea. Rivers and Bayelsa oceanic waters were most rich in *Coscinodiscus* spp in South-South coastal waters while Ondo oceanic water and to a lesser extent Ogun and Badagry oceanic waters were most rich in *Coscinodiscus* spp in the South-West. Rivers State oceanic water recorded five (5) species: *C. concinnus*, *C. lineatus*, *C. marginatus*, *C. radiatus*, *C. wailesii*. Bayelsa oceanic water recorded five (5) species: *C. centralis*, *C. granni*, *C. radiatus*, *C. marginatus*. Ondo oceanic water recorded 8 (eight) species: *C. centralis, C. concinnus, C. granni*, *C. lineatus*, *C. oculus-iridis*, *C. marginatus*, *C. radiatus* and *C. wailesii*. Ogun oceanic water recorded five (5) species: C. centralis, *C. concinnus*, *C. granni*, *C. radiatus*, *C. wailesii* and Badagry oceanic water had five (5) species: *C. centralis*, *C. concinnus*, *C. lineatus*, *C. oculus-iridis* and *C. radiatus*.

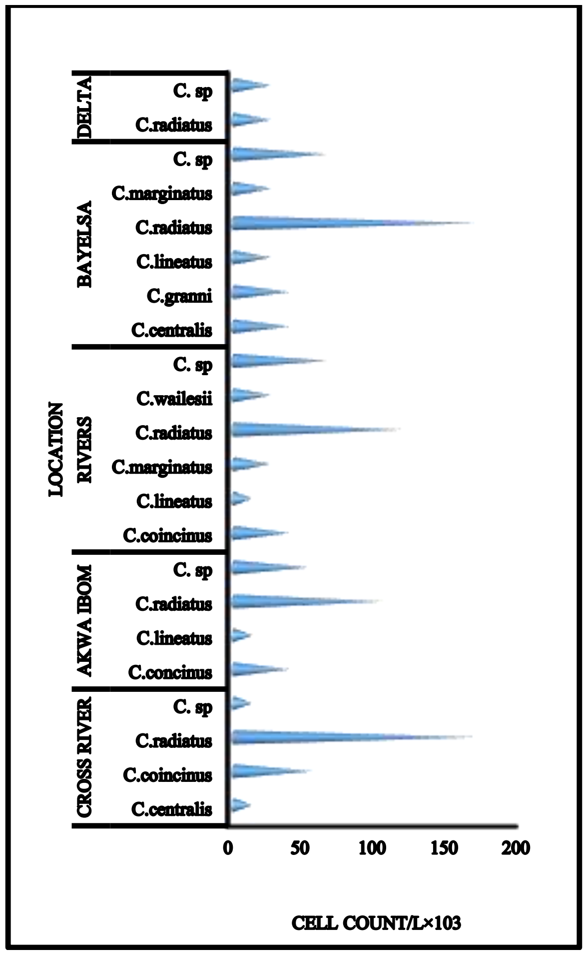


Fig. 3b: Spatial distribution of *Coscinodiscus* sp. South-South Zone of the Atlantic Ocean

Pleurosigma Spp: The spatial abundance of total *Pleurosigma* sp. in Gulf of Guinea (Nigeria) is shown in figure 4a and 4b. The South-West oceanic water had higher abundance of *Pleurosigma* spp. as compared to the South-South oceanic water. All values of *Pleurosigma* biomass recorded in the South-West oceanic locations were higher than values observed in the South-South locations, except for Lekki oceanic water (83.25×10^3 cell $L^{-1)}$ which was less than the value recorded in Rivers (177.667×10^3 cell L^{-1}) and Bayelsa (108.33×10^3 cell L^{-1}) oceanic waters. Rivers and Bayelsa recorded the highest and second highest *Pleurosigma* spp. abundance, respectively among the South-South oceanic waters. Bar Beach and Badagry record the highest and second highest *Pleurosigma* spp. abundance, respectively among the South-West oceanic waters.

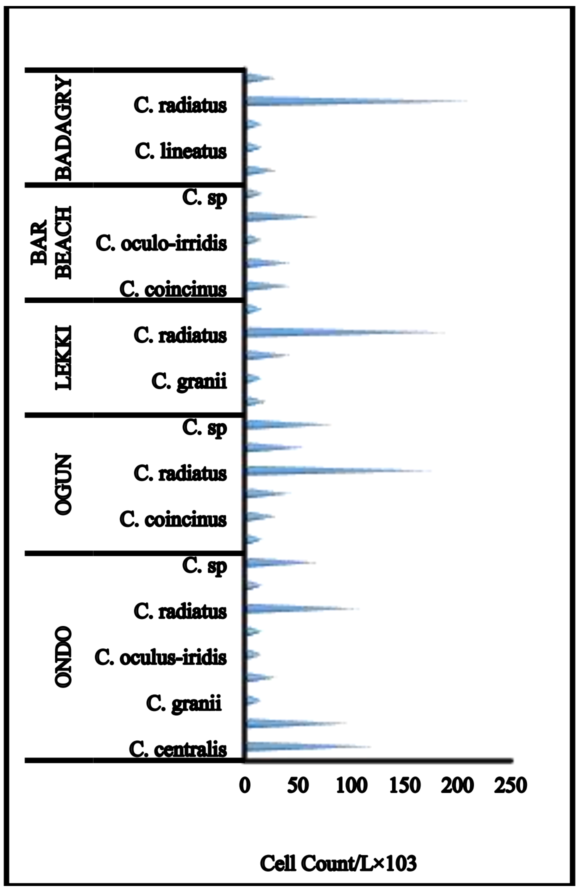


Fig. 3b: Spatial distribution of *Coscinodiscus* sp. South-West Zone of the Atlantic Ocean

Spatial Distribution of Pleurosigma Sp. in Nigeria Coastal Waters: The spatial distribution of various *Pleurosigma* spp. in Nigerian coastal waters is shown in figure 5. *Pleurosigma elongatum* was most widely distributed in the Gulf of Guinea (Nigeria). *P. elongatum* accounted for the most abundant species of the genus *Pleurosigma* in the Atlantic Ocean. It accounted for the highest density among the species of *Pleurosigma* in Cross River, Akwa Ibom, Rivers, Ondo, Ogun and Badagry oceanic waters while in Lekki and Bar Beach oceanic waters, it recorded the second highest species in cell density among the *Pleurosigma* species. *P. delicatulum* W.Smith was found in two locations: Lekki oceanic water in the South-West and Bayelsa oceanic water in the South-South. *P. delicatulum* accounted for the most abundant species in Lekki oceanic water, where as it was the least abundant species in Bayelsa oceanic water.

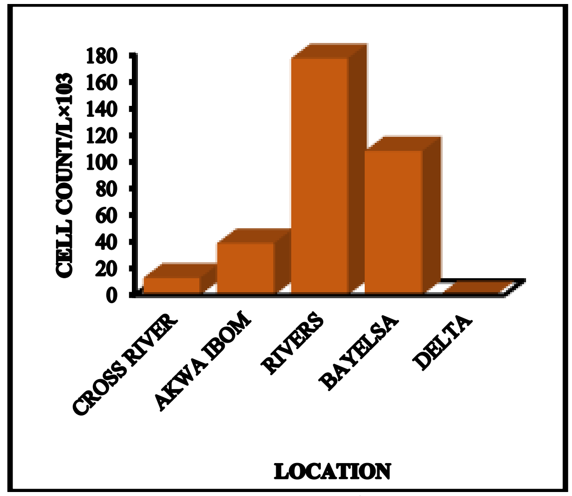


Fig.4a: Spatial abundance/cell density of *Pleurosigma* spp in the South-South Zone of the Atlantic Ocean (Nigeria)

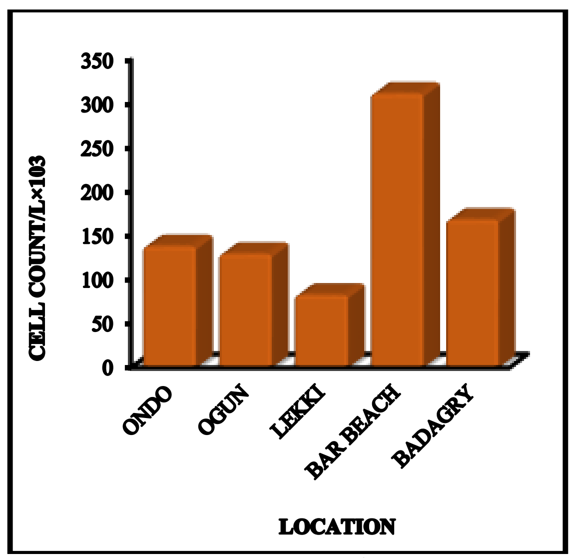


Fig. 4b: Spatial abundance/cell density of *Pleurosigma* spp in the South-West Zone of the Atlantic Ocean (Nigeria)

The spatial distribution of *P. decorum* W. Smith was similar to *P. delicatulum*, it was observed in two locations in the Gulf of Guinea, one location each in the Bight Bonny (South-South) and Bight of Benin (South-West). It was recorded in Bayelsa oceanic water in the South-South where it accounted for the most abundant species and in Badagry oceanic water in the southwest and accounted for second most abundant *Pleurosigma* sp. *P. formosum* W. Smith *and. P. formosum* v. *longissimum* Grunow were least distributed in the Gulf of Guinea (Nigeria) recorded in only outhwest oceanic water and in one location each; Badagry and Bar Beach respectively.

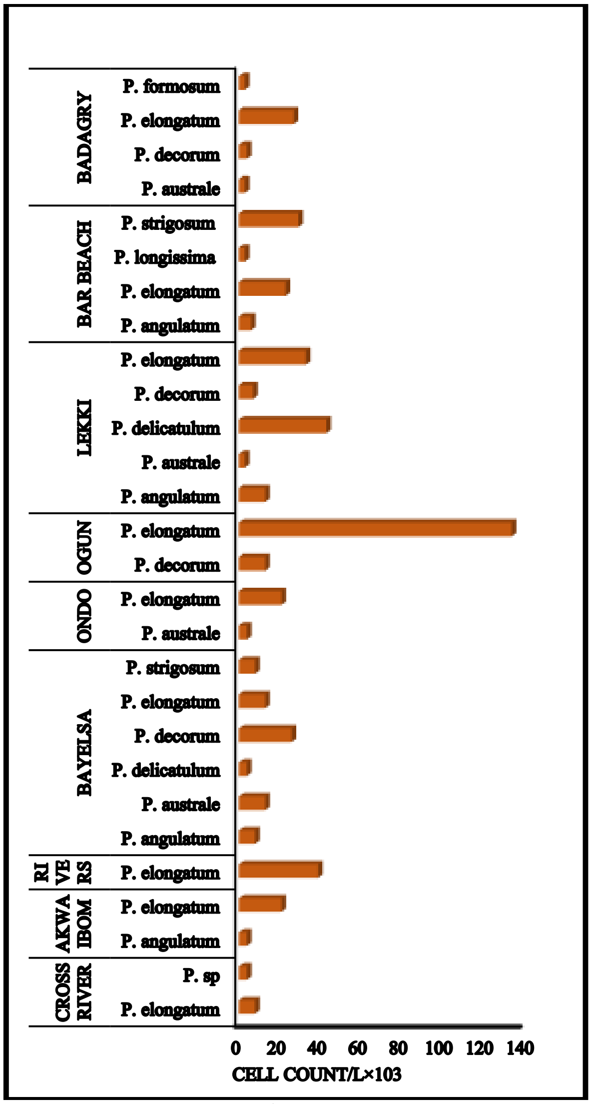


Fig.5: Spatial distribution of *Pleurosigma* spp. in the Atlantic Ocean

P. australe Grunow and *P. angulatum* (J.T. Quekett) W. Smith were observed in four (4) oceanic locations each; Bayelsa, Ondo, Lekki and Badagry oceanic water for *P. australe* and Akwa Ibom, Rivers, Lekki and Bar Beach oceanic water for *P. angulatum*. *P. strigosum* W.Smith was in two oceanic locations in Atlantic Ocean, Bayelsa in South-South and Bar Beach in South-West coastal waters Gulf of Guinea.

Bayelsa (in South-South) and Lekki (in South-West) both recorded the highest number of *Pleurosigma* species in their various zone while Bayelsa oceanic water (six species; *P. angulatum, P. australe, P. delicatulum, P. decorum, P. elongatum and P. strigosum*) accounted for the oceanic location with the highest number of *Pleurosigma* species in the Gulf of Guinea. Bar Beach and Badagry recorded four (4) species each of the genus *Pleurosigma*, while Cross River, AKwa Ibom, Rivers, Ondo and Ogun were at pal (two (2) species each) in the number of *Pleurosigma* spp. present and also accounted for the least number of *Pleurosigma* spp. present. The South-West zone recorded had the highest number of *Pleurosigma* spp. (eight (8) species) in the Gulf of Guinea while South-South zone (seven (7) species) was one species less in number of *Pleurosigma* spp. recorded.

Seasonal Abundance Distribution of Species in the Atlantic Ocean, Gulf of Guinea (Nigeria): Coscinodiscus Spp: Seasonal variation of total cell density of *Coscinodiscus* genus in the Atlantic Ocean is represented in Figs 6a and 6b. Dry-wet period was most favourable for *Coscinodiscus* spp. abundance in the oceanic waters of Lekki, and Ondo in the South-West, and Akwa Ibom (34.7 x10^3 cell L^{-1}) in the South- South. Dry season was the most favourable for *Coscinodiscus* spp. abundance in the oceanic waters of Rivers (39.0 x 10^3 cells L^{-1}), Bayelsa, (47.7 x 10^3 cell L^{-1}), Delta (8.7 x 10^3 cell L^{-1}) (South-South), Bar Beach (16.3 x 10^3 cells L^{-1}) and Badagry (35.8x 10^3 cells L^{-1}). The wet-dry period generally represented a less favourable period for *Coscinodiscus* spp. abundance in the Atlantic Ocean especially in the South-West locations. In general the dry season (dry-wet and dry periods) represented the season for highest *Coscinodiscus* spp. abundance in the Atlantic Ocean Gulf of Guinea.

*Seasonality of Coscinodiscus Spp. in the Atlantic Ocean***:** The seasonal variation of *Coscinodiscus* sp. in the Atlantic Ocean is as shown in figure 7a and b. *C. concinnus* and *C. radiatus* were present in all the period in the Gulf of Guinea. *C. radiatus* was the most abundant species in all the seasons in the Gulf of Guinea. It recorded the highest cell density in all the periods except the dry wet period in the South-West where *C. Centralis* was slightly higher. The dry period and to a lesser extent the wet period was most favourable for *C. radiatus* abundance in the South-South. The cell density in the dry period (86.7×10^3 cell/l) almost equal cell densities of the other periods put together (4.333 ×10^3 cells /l, 43.333 ×10^3 cells/l, and 21.767 ×10^3 cell/l for dry-wet, wet and wet-dry periods). An interchange of this phenomenon was observed in South-West. The wet period and to a lesser extent the dry period was most favourable for the abundance of *C. radiatus* in the South-West. Seasonally *C. concinnus* was second in line of most abundant among the species studied in the Gulf of Guinea. (after *C. radiatus*). It was the second most abundant *Concinodiscus* species in all the periods except in the wet period in the South-South when this position was taken by *C. marginatus*.

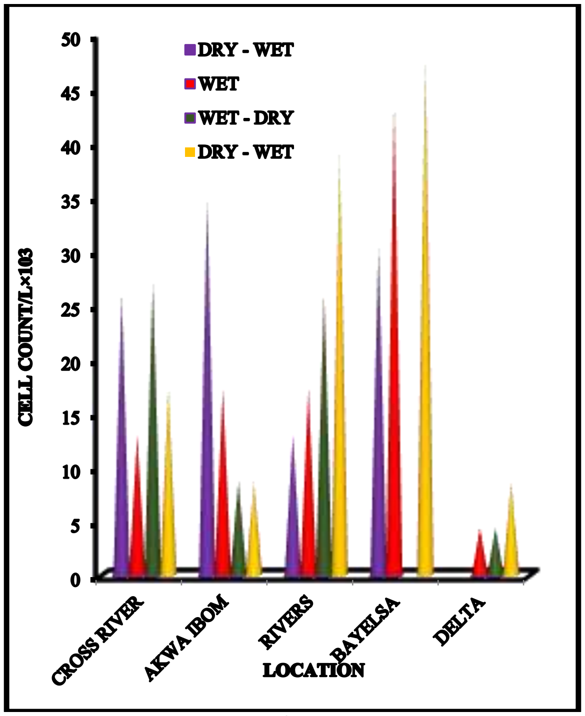


Fig.6a: Seasonal cell density of *Coscinodiscus* spp in the South-South Zone of the Atlantic Ocean (Nigeria)

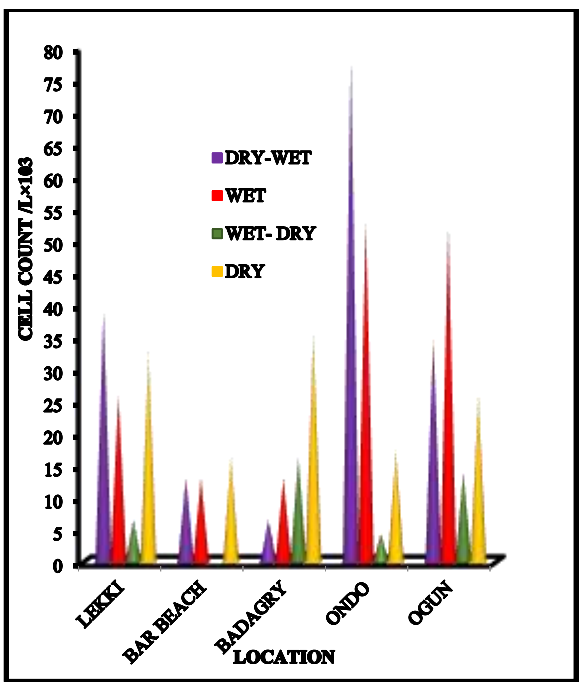


Fig. 6b: Seasonal cell density of *Coscinodiscus* spp in the South-West Zone of the Atlantic Ocean (Nigeria)

The dry-wet period was most favourable for abundance of *C. concinnus* in the Gulf of Guinea and to lesser extent the wet- dry and wet period in the South-South and South-West respectively. *C. granni* and *C. marginatus* were observed in both zones of the Atlantic Ocean (Nigeria) during the dry-wet and wet periods. The wet period was most favourable for the abundance of *C. granni* and *C. marginatus* in the South-West and South-South respectively.

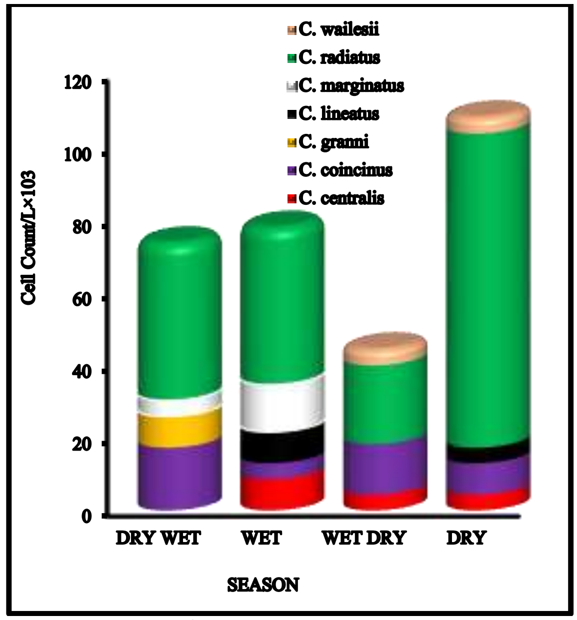


Fig.7a: Seasonality of *Coscinodiscus* spp. in the South-South Zone of the Atlantic Ocean

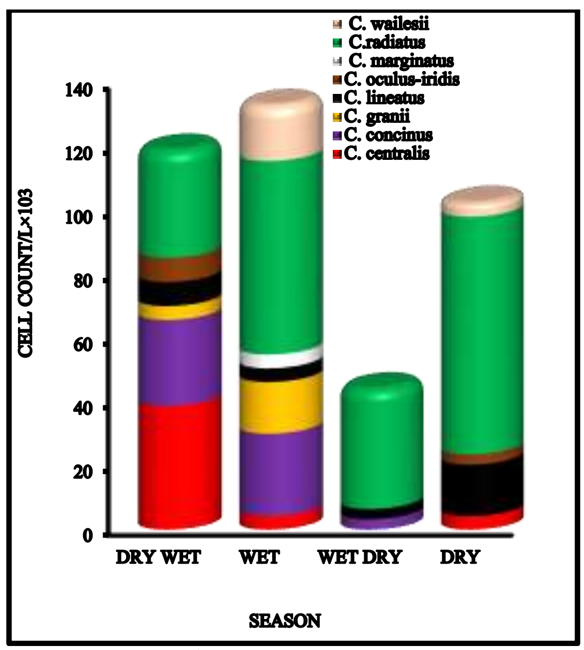


Fig.7b: Seasonality of *Coscinodiscus* spp. in the South-West Zone of the Atlantic Ocean

C. centralis was present in all the periods in the Atlantic Ocean (Nigeria) although it was absent in one

period each in each zones. It was absent absent in dry-wet period in the South-South and wet-dry period in the South-West. The dry-wet period was most favourable for *C. centralis* in the South-West while the wet season was most favorable in the South-South. *C. lineatus* was found in all the periods in the South-West while it was present in two periods (wet and dry periods) in the South-South. The dry periods was most favourable for its abundance in the South-West while the wet period was most favourable for it abundance in the South-South. *C. wallesii* was present in three periods (wet, wet-dry and dry periods) and absent in the dry wet period in the Atlantic Ocean. It was present in both zones in the dry period and absent in the wet and wet-dry period in South-South and South-West zones respectively. Wet period was most favourable for the abundance of *C. wallesii* in the South-West.
Dry season (dry-wet and dry periods) was the season for *C. oculus-iridis* in the Atlantic Ocean. The dry wet period was most favourable for it abundance. The cell density of *C. oculus-iridis* in the dry- wet period (7.583×10^3 cell/l), doubled the cell density in the dry period (3.25×10^3 cell/l). The wet period was the most favourable for *Conscinodiscus spp*. diversity in the South-West while this same phenomenon was observed in the dry period in the South-South.

Periodic Abundance Of Pleurosigma Spp. In Atlantic Ocean, Nigeria: The seasonal cell total cell density of *Pleurosigma* genus in the Atlantic Ocean (Nigeria) is shown in Figure 8a and 8b. *Pleurosigma* spp was most abundant in the dry season (dry-wet and dry periods) in the Atlantic Ocean (Nigeria). Lekki, BarBeach and Badagry recorded highest *Pleurosigma* spp abundance in the dry period. Akwa Ibom, Rivers, Bayelsa and Ogun recorded highest *Pleurosigma* spp abundance in the dry-wet period. *Pleurosigma* spp abundance was generally low in the Atlantic Ocean. Specifically wet-dry period recorded the least *Pleurosigma* spp abundance for Akwa Ibom, Rivers, Ondo and Ogun while wet period recorded least *Pleurosigma* spp abundance for Cross River, Lekki and Badagry. The zero value for cell density and abundance was recorded in Cross River during dry-wet and dry period, Ondo and Ogun during the dry period, Delta in all periods. The presence of the genus *Pleurosigma* was recorded in all periods in Akwa Ibom, River, Lekki, BarBeach and Badagry Atlantic oceanic water.

Seasonality of Pleurosigma Spp. in Atlantic Ocean: Figure 9a and b shows the seasonality of different *Pleurosigma* spp. in the Atlantic Ocean P. *enlongatum* showed similar pattern of seasonality in both South-South and South-West zones of the Gulf of Guinea. It recorded it highest abundance of cell density in the dry-wet period in both zones and it least abundance in wet dry period in both zone. *P. enlogatum* showed similar pattern of seasonality in both South-South and South-West zones. It recorded it highest and least cell densities in the dry-wet period and wet-dry period respectively in both zones. *P. angulatum* was present in all the periods (in three periods; dry-wet, wet-dry and dry period) in the South-South and absent during wet period. It was present in the wet and dry periods and absent in the transitional periods in South-West.

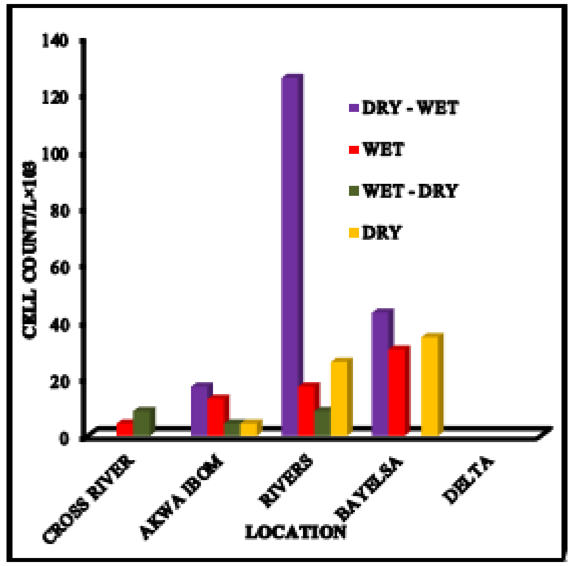


Fig.8a: Seasonal cell density of *Pleurosigma* spp in the South-South Zone of the Atlantic Ocean (Nigeria)

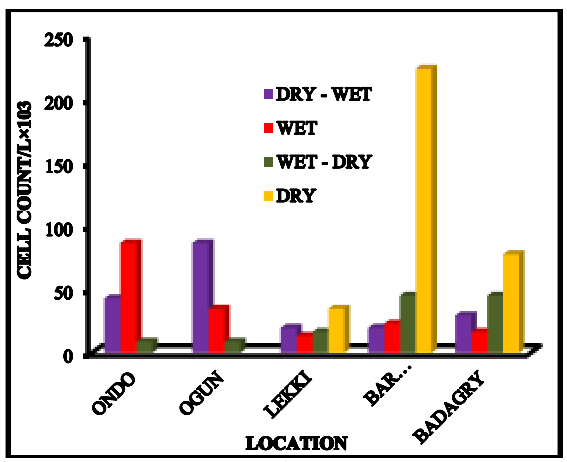


Fig.8b: Seasonal cell density of *Pleurosigma* spp in the South-West Zone of the Atlantic Ocean (Nigeria)

Pleurosigma australe only occurred in the dry-wet period in the South-South, while it occurred in the wet and dry period in the South-West. For *P. decorum* was present in three periods (dry-wet, wet-dry and dry periods) in the South-South zone, while it was present in two periods (dry-wet and wet periods) and absent in the wet-dry and dry periods. The transitional periods, dry-wet period (South-South) and wet-dry period

(South-West) were most favourable for the abundance of *P. decorum* in the Atlantic Ocean. *P. decorum* was most abundant in the wet-dry period and to a lesser extent in the dry-wet period in the South-South zone while it was most abundant in the dry-wet period in the South-West. *P. delicatulum* showed different seasonality in the South-South and South-West zones.

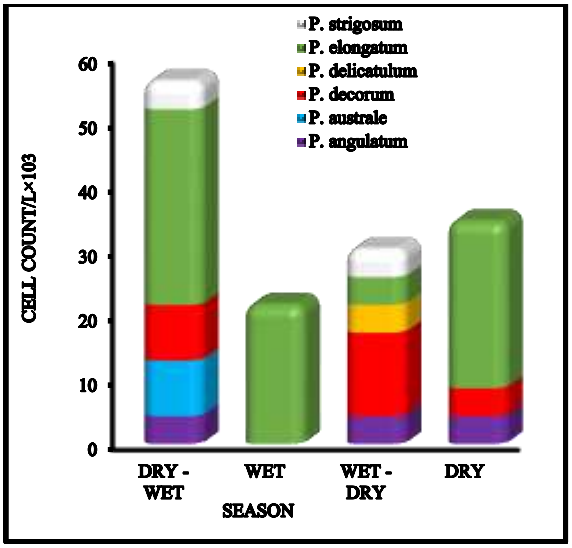


Fig.9a: Seasonality of *Pleurosigma* spp. in the South-South Zone of the Atlantic Ocean

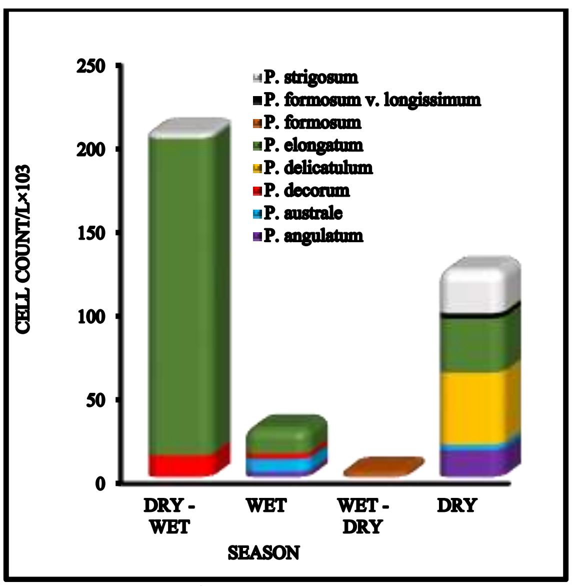


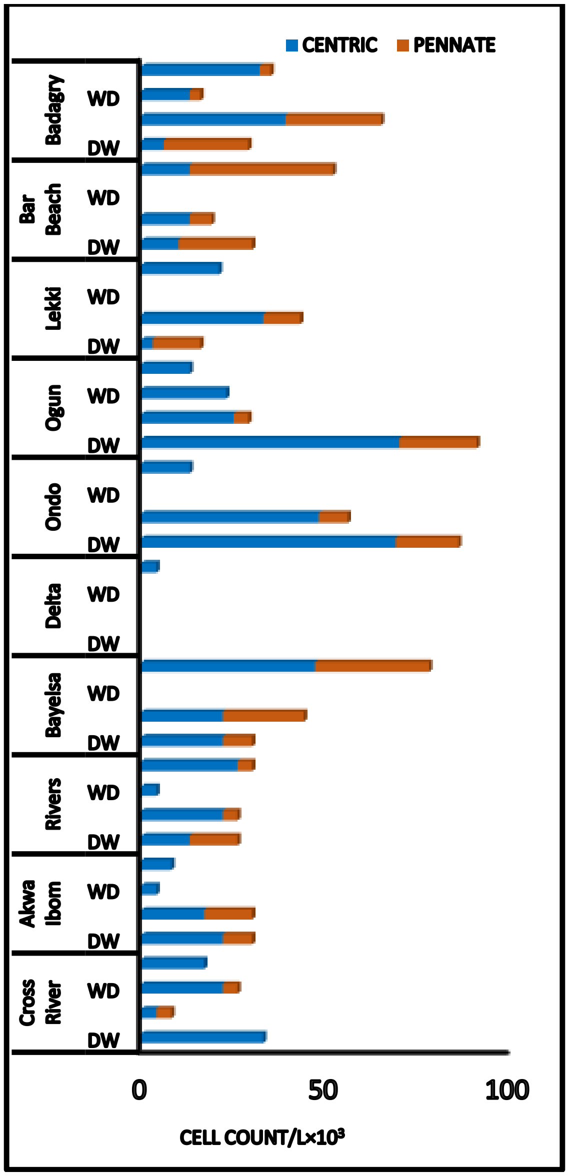
Fig. 9b: Seasonality of *Pleurosigma* spp. in the South-West Zone of the Atlantic Ocean

It was present in a period each in both zones. It was observed in the wet-dry period in the South-South and in the dry period in the South-West, whereas *P. formosum* was totally absent in all the periods in the South-South but was the sole representative species of the pennate diatom *Pleurosigma* during the wet-dry season in South-West zone. *Pleurosigma formosum* v. *longissimum* was only present in the Atlantic Ocean (Nigeria) in the dry period. *Pleurosigma strigosum* was observed in three seasons (dry-wet, wet-dry and dry periods) in the Atlantic Ocean, It was present in two seasons each in both zones of the Gulf of Guinea. It was present in the transitional periods (dry-wet and wet-dry periods) in the South-South while it occurred in the dry season (dry-wet and dry periods) in the South-West. Generally, Dry-wet period was the most favourable period for the abundance of *Pleurosigma* spp. In the Atlantic Ocean. The transitional periods recorded the highest number of *Pleurosigma* spp. with five species each, present at a time for the South-South zone while the dry period (five species) and to a lesser extent wet period recorded this scenario for the South-West. Wet period and the wet dry period were the periods with the least cell density and *Pleurosigma* species richness in the South and South-West respectively.

Comparison Of The Periodic Abundance Of Centric And Pennate Diatoms In The Atlantic Ocean: Figure 10 shows the cell density of centric and pennate diatoms in the Atlantic Ocean. The cell density of the centric diatom *Coscinodiscus* in the Atlantic Ocean was consistently higher than that of pennate diatom *Pleurosigma* in the entire stretch of the Gulf of Guinea (from the Bight of Benin to the Bight of Bonny).

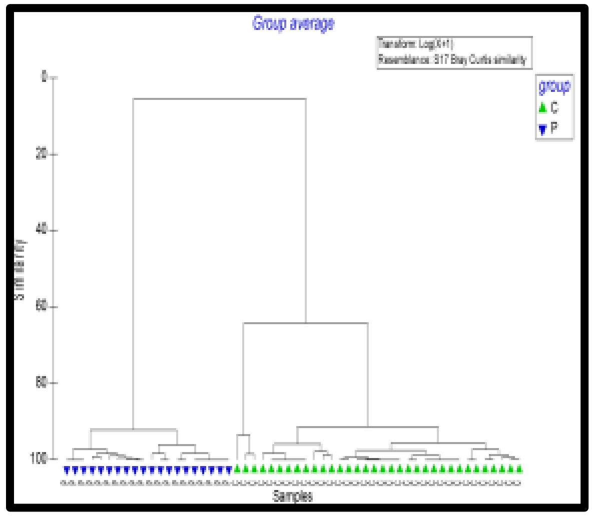
Multivariate and similarity Analysis: Bray Curtis Dendogram of Similarity of diatom group in Atlantic Oceanic as shown in figure 11 reveals two major cluster of pennate diatom and centric diatom. PERMANOVA result (table 1) detected a significant difference between the abundance of the centric and pennate diatom in the Atlantic Ocean but no significant difference in diatom community structure between zones, location, seasons and periods.

The result of canonical correlation analysis conducted to explore the relationship between environmental variables and the density of various species is shown in figure 12a and 12b. Result of Canonical Correspondence Analysis (CCA) in the South-South, (figure 12a) revealed that Fe, NO3 SiO3 and alkalinity had direct effect on *P. australe*, *P. decorum*, *C. centralis* and *C. marginatus*. Total hardness, Mg, TDS, salinity, humidity chloride had positive relation with *C. lineatus* and *P. elongatum*. Rainfall and pH strongly affected *C. concinnus*. *wailesii* and *P. angulatum*. DO and elevation had direct effect on *C. radiatus*, *P. delicatulum* and *P. strigosum*. CCA analysis, in the South-West (figure 12b), Turbidity, Po4, NO3, SO4, SiO3, DO, was positively associated with *C. marginatus*, *C. concinnus*, *C. lineatus* and *P. strigosum*. Humidity, Mg, total hardness and rainfall had a direct effect on *C. oculus-iridis*, *C. centralis* and *P. elongatum*. Colour had possible effect on *C. granii*, *C. wailesii*, *P. decorum* and *P. angulatum*. Calcium, Chloride, Alkalinity, EC, Salinity and TDS had positive effect on *P. australe*, *C. radiatus*, and *P. delicatulum*.



DW=Dry-Wet; W=Wet; WD=Wet dry; D= Dry
Fig.10: Periodic Abundance of Centric and Pennate Diatoms in the Atlantic Ocean.

The distribution of *Coscinodiscus* spp in this study in the Atlantic Ocean, Gulf of Guinea, compares with similar ecosystems around the world. Of the eight (8) species of *Coscinodiscus* (*C. centralis*, *C. concinnus*, *C. granii*, *C. lineatus*, *C. marginatus*, *C. oculus-iridis*, *C. radiatus*, and *C. wailesii*) recorded five (5) (*C. concinnus*, *C. granii*, *C. radiatus*, and *C. wailesii*) were also recorded in the in the North Sea around Helgoland and Sylt, (Hopperant, 2009). In Ogun State oceanic water, the four species (*C. concinnus*, *C. granii*, *C. radiatus*, and *C. wailesii*) was similar to the observation in the Northern European Sea, (Kraberg *et al*., 2010). In Kuwaiti waters, only six (6) species (*C. centralis*, *C. granii*, *C. marginatus*, *C. oculus-iridis*, *C. radiatus*, and *C. wailesii*) were found (Manal *et al*., 2009).



C = Centric diatom, P = Pennate diatom
Fig.11: Bray Curtis Dendogram of Similarity of diatom groups in Atlantic Oceanic

Table 1: PERMANOVA result of centric and pennate diatom community structure

Factors	SS	MS	Pseudo-F	P(perm)
Zone	1376,2	1376,2	0.40483	0.822
Location	25747	2860,8	0.82783	0.697
Station	951,39	951,39	0.27927	0.91
Group	90869	90869	48.949	**0.001**
Period	11920	3973,4	1.1923	0.288

The wide distribution of *C. centralis*, also earlier observed in coastal waters of Nigeria (Kadiri 2011) attests to its description as a widely-spread oceanic plankton species. It is common in the North Atlantic, and in the North Sea (Hendey, 1964), in Kuwait's waters (Manal *et al*., 2009).

The observation of *C. concinnus* in South-South oceanic waters is concordant with the observation of Kadiri (2006) in Eastern Niger Delta area of Nigeria, Kraberg *et al*. (2010) in the Northern European Sea and Hoppenrath *et al*. (2009) in Helgoland and Sytl. In their study in the Atlantic Ocean, (Beaugrand *et al*, 2019) noted and described *C. concinnus*, along with some other phytoplankton (*Leptocylindrus danicus*, *Skeletonema costatum*, the dinoflagellates *Ceratium longipes*, *C. macroceros*, *C. tripos*) as cold-temperate neretic species, and *C. wailesii* as Cold-Temperate

Shallow Neritic. The rare distribution in the South-South oceanic waters and fair distribution in South-West coastal of *C. granii* contradicts its often observed cosmopolitan nature observed in Northern European Sea (Kraberg *et al* 2010) and in Helgoland (Hoppenrath *et al*., 2009) but congruous with its distribution in north-western European coasts, North Sea, Norwegian and Danish Seas, Irish Sea, English Channel (Hendey, 1964) and in Kuwait's waters (Manal *et al*., 2009).

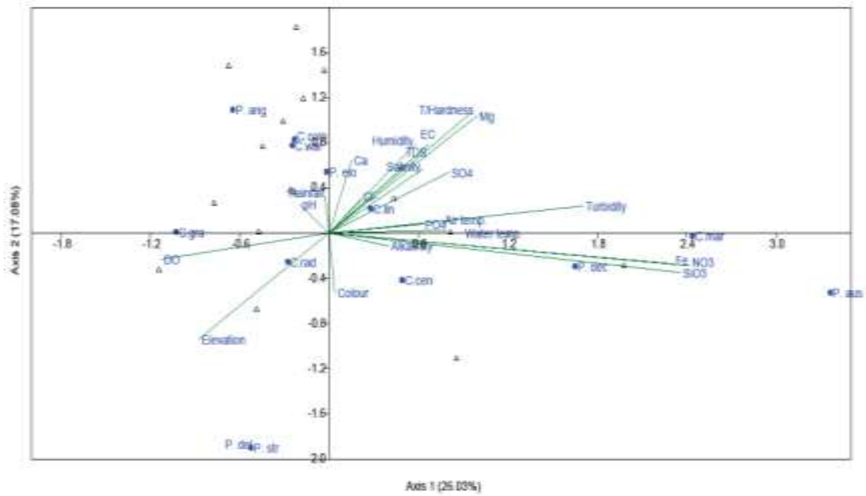


Fig.12a: Canonical Correspondence Analysis (CCA) of the correlation between diatom species and environmental variables in the South-South Zone

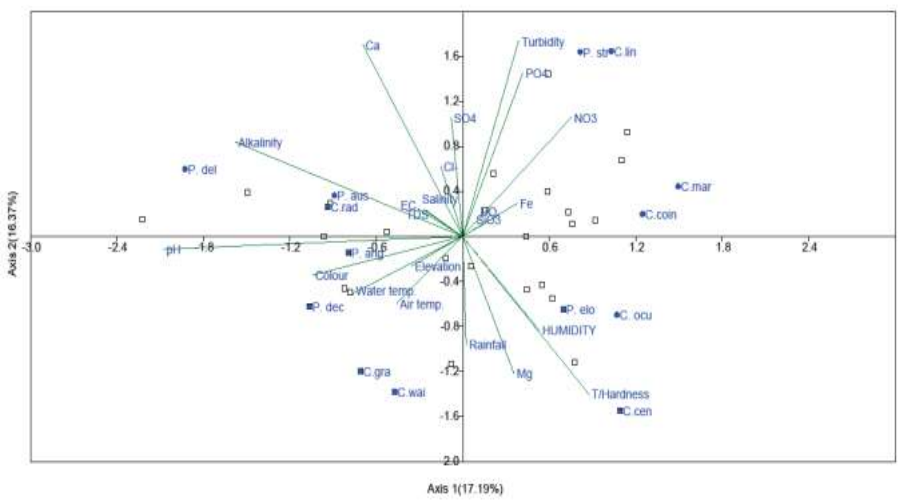


Fig.12b: Canonical Correspondence Analysis (CCA) of the correlation between diatom species and environmental variables in the South-West Zone

The abundance and cosmopolitan nature of *C. radiatus* in the Atlantic Ocean Gulf of Guinea (Nigeria) coincides with what was observed in in Northern European Sea (Kraberg, 2010), Helgoland and Sylt. (Hoppenrath *et al*., 2009), in all North European coasts, North Sea, and English Channel (Hendey, 1964) and in Kuwait's waters (Manal *et al*., 2009). It is also generally regarded as having ubiquitous distribution. In Eastern Niger Delta area of Nigeria however, *C. radiatus* was registered as a sporadic species (Kadiri 2006).

In their decadal consideration of phytoplankton, *C. radiatus*, *C. eccentricus*, and *C. lineatus* were persistent, occurring throughout the period of three decades (Biswas *et al.*, 2010). On the basis of a 30-year collected plankton samples, *C. radiatus, C. centralis, C. concinnus, C. granii* and *C. asteromphalus* were noted as regular members of the plankton flora of the Oslofjord (Norway) and the Skagerrak (North Atlantic), *C. granii* and *C. asteromphalus* were less common in number and occurrence than the others (Hasle and Lange, 2011).

On the other hand, *C. wailesii* was fairly distributed, and is different from the finding in Northern European Sea and in the western Baltic Sea, Helgoland and at Sylt but is in conformity the finding of Hasle and Syvertsen, (1997) in North Atlantic water and Manal *et al*. (2009) in Kuwait's waters.

Coscinodiscus wailesii is a world-wide distributed species, known from all the ocean regions, reported in estuarine or neritic waters from temperate to tropical (Fernandes *et al.*, 2001). The blooms of *C. wailesii* seem to be more frequent in cold coastal waters with frequent freshwater inputs, forming a common blooming species in China, Japan and European Seas (Manabe and Ishio 1991; Gomez and Soussi, 2010). According to the latter authors, *C. wailesii* requires high nutrient inputs (silicate) and water column mixing to proliferate. Gómez and Sami Souissi (2010) described *C. wailesii* as one the most common examples of non-indigenous phytoplankton species in the European Seas, preferentially occurring in winter and early spring, with a maximum in April 2001 (720 cells L^{-1}). This coincided with exceptionally high precipitation rates, river discharges and a cold winter (negative phase of the North Atlantic Oscillation) (Gomez and Soussi, 2010). A high phytoplankton bloom of *C. wailesii* associated with extensive mucus provoked the clogging of fishing nets in the southern English Channel (Gomez and Soussi, 2010). The blooms of *C. wailesii* and *Thalassiosira punctigera* in 1977-79 according to these authors coincided with the arrival of the 'Great Salinity Anomaly' into the English Channel and increased river discharges (Gomez and Soussi, 2010).

Although *C. wailesii* was in earlier years described as a common example of non-indigenous phytoplankton species in the European Seas, its world-wide distribution now contradicts this fact. This erroneous claim may have been due to wrong taxonomic identification as *C. concinnus or C. nobilis.*

Tanimura *et al*. (2017) recognized C. wailesii discerned by non-metric multidimensional scaling in northwest Pacifi¬c Ocean and stated that this species require high nutrient-inputs and water column mixing to grow (Nishikawa and Yamaguchi 2008; Tanimura *et al*. (2017). Their blooms occur more often in coastal waters with frequent freshwater inputs (Gómez and Souissi 2010).The influence of temperature observed in this study is also attested to by Tanimura *et al.* (2017) in Tsugaru Strait, Japan. The influence of temperature and salinity was indicated by Fernandes *et al.* (2001) in Brazil, noting that salinity is a principal environmental factor regulating the cell size restoration (by means of pseudoauxospore production) of *C. wailesii* cells. In this study, the distribution and occurrence of *C. oculus-iridis* and *C. marginatus* was poor contrary to their cosmopolitan distribution in North Atlantic water and the frequent occurrence in the North Sea, and in Kuwait's waters (Manal *et al*., 2009) and earlier finding by Kadiri (2006) stipulating the cosmopolitan distribution of *C. marginatus* in the Eastern Niger Delta area of Nigeria.

The distribution of *Pleurosigma* was also varied. Kraberg (2009) describes *Pleurosigma* as an occasionally found genus in coastal water phytoplankton in North European Sea, though it has been regarded as widespread in distribution in Atlantic Ocean waters (Kadiri, 2006, Manal *et al*., 2009). Specifically, *P. elongatum* was described as marine and brackish species common on North Sea coasts and in the English Channel, Spitzbergen, coasts of Norway, Baltic Sea (Hendey, 1964) and Kuwait's waters (Manal *et al*., 2009). *Pleurosigma formosum* was described as widely spread around all British coasts and on the coasts of all North Sea countries, occurring frequently in coasts all over the world, in water of high salinity. Similarly, *P. strigosum* was observed as marine, common on muddy shores and estuaries of the North Sea countries and English Channel, (Hendey, 1964) (Manal *et al*., 2009). In general, pennate diatoms tend to be more benthic than planktonic in nature (Cohn (2001; Wang *et. al.* 2019), lending credence to the prevalence and higher abundance of centric diatoms over pennate diatoms in this study. Cohn (2001), describe pennate diatoms as (motile) elongated forms that are usually sediment dwelling and centric diatoms as cylindrically symmetrical forms that are often planktonic and non-motile. These are supported by the finding of more pennate diatom other than centric diatoms in the various study of benthic diatoms by Prelle *et al.* (2019) ; Dalu *et al* 2016; An *et al.* 2017) and centric diatoms as most common in marine waters (Kociolek, 2015; Harwood and Nikolaev, 1995). The significant difference in the abundance of centric and pennate diatoms in the Atlantic Ocean is neither as a result of the different zones, location or stations studied nor as a result of seasonal or periodic variations. This means that there are other factors resulting in this significant difference between the abundance of both diatom groups. The commonality of species in the different parts of the world is ascribable to massive movements of species, via ship ballast waters, importation of sea foods, movement of currents between the different oceans of the world (Gomez and Soussi, 2010) and contamination from the introduction and cultivation of exotic commercial invertebrates (Fernandes *et al.*, 2001). The local plankton communities may be altered as well as their invasibility by exotic species from other regions (Streftaris *et al*., 2005, Gomez 2008). The introduction of exotic marine species portends grave ecological and economic risk for that region (Edwards *et al.*, 2001).

The population dynamics of these diatoms are also regulated by herbivory by zooplankton e.g. copepods (Tanimura *et al.*, 2017). The differential variation in the different diatom species affect the local aquatic trophic food chain. The abundance of diatoms can result in decreasing the population of other phytoplankton species or even mortality due to competition for nutrients; and oxygen depletion in the water column, from intense algal respiration and the incomplete diatom decomposition by bacteria near the sea bottom (Hasle and Fryxell 1995; Fernandes *et al.*, 2001). Generally phytoplankton (diatoms inclusive) dynamics drives ecosystem structure and function and are primarily affected by climate change and anthropogenic activities which impose stressors in coastal (aquatic) environments (Cloern 1996; Biswas *et al.*, 2010). The observation of influence of relevant environmental parameters on the species is corroborated by Schiebel *et al.* (2004) in Arabian Sea where it was pointed out that the number of diatoms was increased in waters with local temperature minimum and enhanced nutrient concentration (nitrate, phosphate, silicate). Additionally, crucial factors which determine which diatom species dominates or co-dominate an individual bloom are initial diatom population size, species-specific physiological traits and selective grazing pressure (Assmy *et al*., 2007; Boyd, 2013).

Conclusion: Marked variations were observed in the occurrence and density of centric diatom *Coscinodiscus* and Pennate diatom *Pleurosigma* in the Atlantic Ocean. The difference resulting from most likely difference in structure and not as a result of the zones, location or stations studied nor as a result of seasonal or periodic variations. The examination of distribution and abundance of phytoplanktonic diatoms is important in the establishment of effective management strategy of their blooms in aquatic ecosystems and ultimately invasion limitations.

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