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Modelling Environmental Factors on Bloom Forming *Cyclotella* species (Stephanodiscaceae Glezer & Makarova (1986) in the Central Bonny Estuary, Rivers State, Nigeria

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Abstract:

This study was carried out to examine modelling the effects of environmental gradients on bloom-forming *Cyclotella* species. Plankton samples were collected with a 20 µm mesh plankton net. The physicochemical characteristics were determined in situ, and the nutrients were analyzed in the laboratory using the APHA 2012. The highest mean cell density of 355.43±49.55 Cells L^{-1} was recorded in station 4, and the lowest of 63.33±17.02 Cells L^{-1} in station 2 for *C. antiqua*. In contrast, 360.81±70.05 Cells L^{-1} was recorded in station 3, with the lowest of 204.67±61.67 Cells L^{-1} in station 2 for *C. meneghiniana* spp. respectively. Principal component analysis revealed that TDS, DO, PO_4, NO_3 and NO_2.

In contrast, a positive relationship, while pH and salinity had a negative relationship with *C. antiqua*. Nitrite, TDS, and DO show a positive relationship, while salinity, phosphate, temperature, and pH negatively correlated with *C. meneghiniana* across stations. TDS, DO, and NO_2 were the most used forecast predictors for *Cyclotella* spp., which were positively correlated. The observed data were compared with the simulated result. *Cyclotella antiqua* and *meneghiniana* increased with a rise in TDS and NO_2 as the forecast predictors to ascertain its effect on the predicted species. The increasing human-induced anthropogenic pressure is primarily influencing the eutrophication of water. With an increase in nutrients (TDS and NO_2), that species may form a bloom. There is a need for best management practices to address nutrient discharge in the central Bonny estuary.

Keywords: *Cyclotella* species, algal species, forecast, correlation, environmental gradient, Bonny estuary

1. Introduction

Phytoplankton is an incredibly complex, polyphyletic group of organisms that can exhibit various morphological, physiological, and behavioral characteristics (1). Phytoplankton

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biomass, primary production, and community composition are all highly dynamic at the land-sea interface, where human actions and climate variability intersect to drive complex patterns of change over time (2). Recent research has identified processes that cause blooms at the land-sea interface, such as nutrient inputs from river inflow (3,4). Phytoplankton blooms have ecological and biogeochemical significance because much of the annual primary production in estuarine-coastal ecosystems occurs during these events when photosynthesis exceeds system respiration (5). Cyanobacteria are common members of phytoplankton communities in any aquatic environment, and some of them can form persistent blooms. These blooms have been associated with anthropogenic eutrophication (6).

In estuarine systems, algal communities are highly variable and affected by numerous environmental and ecological factors, including water temperature, salinity, light intensity, nutrient availability, inter-and intra-specific competition among the algae, and predation (7). *Cylotella* is a genus of diatoms (Kützing) Brébisson, (often found in oligotrophic environments , both marine and freshwater. It is in the family Stephanodiscaceae and the order Thalassiosirales (8). The most commonly found species in marine environments are *C. caspia*, *C. litoralis*, *C. meneghiniana*, *C. striata*, and *C. stylorwn* (9). Recently, (10) separated all species with a concentrically undulating, areolate central area and complex marginal striae, placing them in the newly erected genus *Punticulata Håkansson.* There have been nearly 100 different species of the genus described and taxonomically accepted. (11). The taxonomy of *Cyclotella* is tough to unravel due to the considerable morphological differences among species (12,13). The centric diatom *Cyclotella* is a species-rich, complex genus characterized by (14). Hakansson (2002) (10) summarised the modern-day concept of the genus *Cyclotella* (Ku¨tzing) Bre´bisson (Stephanodiscaceae, Bacillariophyta) as a large, complex mixture of centric diatoms, categorized by a marginal alveolate-striated area, a central area devoid of striae, and a ring of fultoportulae (strutted processes) interrupted by a single rimoportula (labiate process) on the valve mantle. The author also presented an excellent review of the complex nomenclatural issues involved in the generic typification of *Cyclotella*, which led to the conservation of the generic name, *Cyclotella* (Ku¨tzing) Bre´bisson.

A long-term diatom dataset (1982–2006) analysis showed that diatom communities have been dominated by *Cyclotella* taxa since 2000, with these taxa increasing during periods of stronger thermal stratification and low nitrogen to-phosphorus ratios (15). *C. meneghiniana* is one of the most extensively studied diatoms (16,17,18,19,20), and is also featured as the single most common diatom species in the review by (21) of global diatom diversity. In recent years centric diatoms of estuaries have begun to receive more attention, especially the genus *Cyclotella* (Kützing) Brébisson (22,12,23,24,25).

Widespread increases in the relative abundances of the planktonic diatom *Cyclotella* sensu lato have been documented in many paleolimnological records of arctic (26), subarctic (27), alpine (28), sub-alpine (15) and temperate lakes (29) over recent centuries. Some studies have modeled different dimensions of primary production, such as diversity or algal growth time (30). A recent attempt has been made by (31) to predict phytoplankton blooms using machine learning algorithms. When a model fails to fit well, it can be easily assessed as poor. The trials of designing an effective and dependable prediction method, such as a description of the real blooming cell concentrations and the use of describing variables that could be time-consuming and resource-consuming at each run of the model bloom dynamics studies (32), can be focused on the lack of adequate predictive models for bloom forming algae used in the management per spective. Several environmental factors (both physical and chemical), including nutrient availa bility and temperature changes, are described as important drivers for bloom-forming algal species (Stephanodiscaceae) abundance. This study was carried out to model the effect of some of these environmental factors on bloom forming *Cyclotella* species in the central Bonny estuary.

2. Materials and Methods

2.1 Study area

The Bonny estuary is one of the numerous low-land coastal waters of the Niger Delta Complex. It is located between 4° 25 " and 4° 50 " N latitude and 7° 0 " and 7°15 " E longitude in River State, Nigeria (Figure1). It is mainly brackish with very little freshwater discharge, mostly from the New Calabar River system. It consists of a main river channel and many associated creeks and creek-lets. The Bonny estuary is a major shipping route for crude oil and other cargoes. It leads to the Port Harcourt quays, Federal Ocean Terminal, Onne, and the Port Harcourt Refinery terminal jetty, Okrika. The Bonny estuary (maximum width of 2 km and a maximum depth of approximately 15 m near the mouth) has the largest tidal volume of all the river systems in the Niger Delta, and it is mostly affected by tidal movement. The salinity fluctuates with the season, and the tidal regime is influenced by the Atlantic Ocean (33).

2.2 Sampling Stations

Four sampling stations were established through a preliminary reconnaissance survey of the estuary course at 500 m intervals using *ArcGIS* Version 10.0. (34): The sampling stations were established based on, the area's ecological settings, vegetation, and human activities. The stations were:

Station 1: This station is located at longitude 4°75.61E and latitude 7°02. 54N.Nembe waterfront has a jetty. Nembe waterside experiences the activities of persons patronizing the Creek Road market close to this ferry port. Station 2: This station is located at longitude 4°73.29E and latitude 7°01.11N, situated in the Isaka community, commonly called the Isaka open river area. This is where a river empties into the estuary. The Nypa palm dominated the vegetation.

Station 3: This station is located at longitude 4°74.93E and latitude 7°02.77N, at the back of the Ibeto cement factory, where waste from the industrial activities of the factory is discharged into the estuary.

Station 4: This station is located at longitude 4°77.25E and latitude 7°00.85 N. This is the Nigerian Port Authority Jetty (NPA) dockyard. The area receives refinery effluent through the dug-in passage, as shown in (Figure 1).

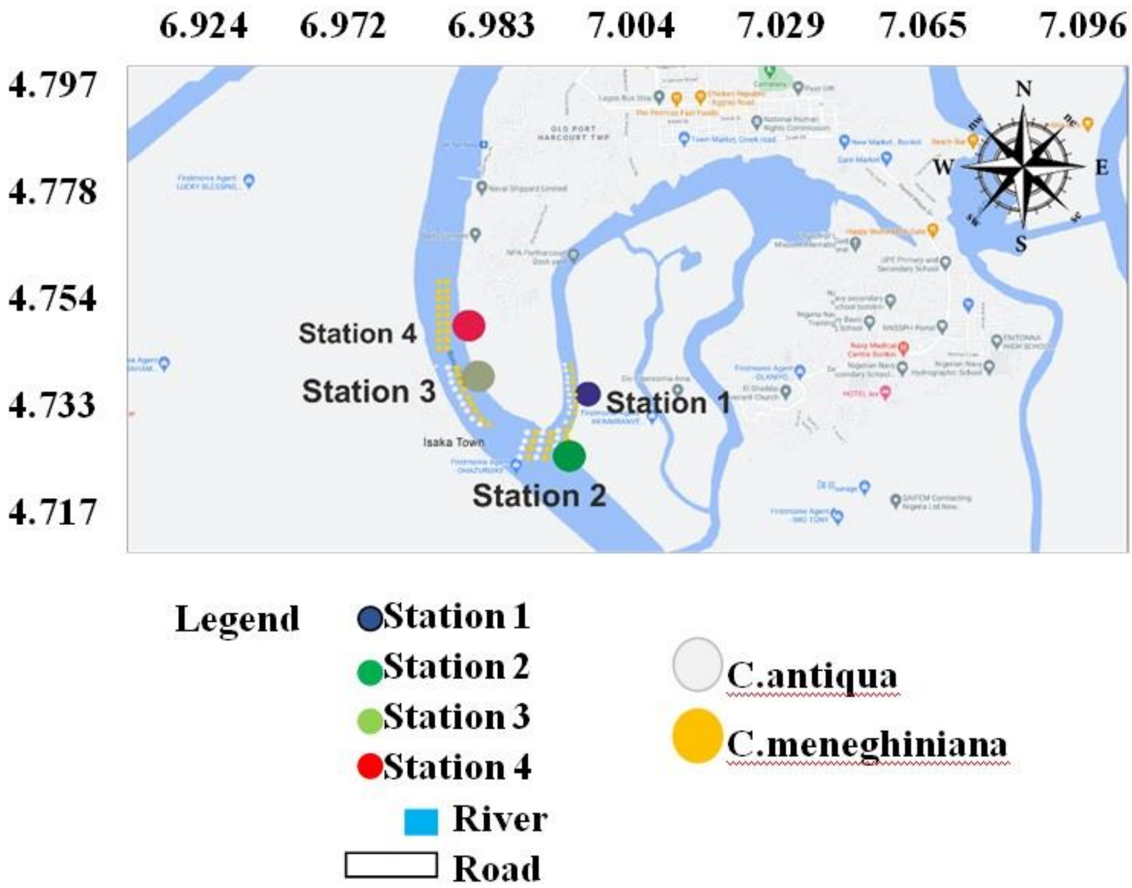

Figure (1): Map of the study area showing different sampling stations and spatial distribution of *Cyclotella* spp.

2.3 Collection and assessment of Water Samples for Nutrient Analyses

Physico-chemical parameters were: temperature (^{O}C), salinity (ppt), pH, dissolved oxygen (DO) (mg/l), and total dissolved solids (TDS) (mg/l) were measured in-situ with a Horiba water checker (Model: Extech D0700) at each sampling location The surface water samples for nutrients (PO_4, NO_3, and NO_2) were collected at neap tide at a depth of 5 cm with a pre-cleaned plastic container. All the samples were collected in triplicate and taken to the laboratory for nutrient analysis using the (35).

2.4 Collection of Water samples and Algae

Water samples for quantitative analysis of algae were collected monthly from four sampling stations from November 2019 to December 2020 (12 months) using a 20-liter bucket five times into a 20µm mesh size plankton net in a vertical position. Net catches were transferred into a 250 ml plastic container and preserved with a 4% buffered solution, which was concentrated to 10 ml in the laboratory.

2.5 Enumeration of *Cyclotella* bloom-forming Algal species.

Cyclotella species of microalgae were enumerated using the Lackey Drop Micro-transect Counting Method (35). The sample was mixed well before sub-sampling a drip of 0.05 ml onto a glass slide in triplicate with a cover slip. In a given volume, both the processed volume and the number of observed microalgae were known; their abundance was counted with a low power objective with an inverted microscope (Leica DMIL). Microphotographs of the bloom-forming algal *Cyclotella* species were taken by camera fixed to the microscope. (36) and (37) were employed to identify the algae.

Individuals per ml were calculated;

$$\text{(Number (No.) Individuals)} / \text{(ml)} = \frac{(C \times TA)}{(A \times S \times V)}$$

Where,

C = number of organisms counted; TA = area of the cover slip, mm^2; A = area of one strip, mm2; S = number of strips counted, and V = volume of sample under the cover slip, ml

Results were converted and expressed as Number (No.) of Cells per liter (Cells L^{-1}).

2.6 Statistical Analysis

Statistical analysis was done using the Statistical Package for Social Science (SPSS) 16.0 windows. (38). One-way Analyses of variance (ANOVA) were employed for the statistical interpretation of data to compare the means. At the same time, Post hoc - Duncan's test was used to determine significant differences across the station in the study. Spatial variation of the various environmental parameters and harmful algal species across the season was done using Student's T-test. Principal component analysis (PCA) was used to analyze the relationship between *Cyclotella* species and significant environmental factors using PAST software (39).

2.6.1 A predictive model for Bloom forming Algal species.

To develop a model for predicting the trend of bloom-forming algal species in the estuary, we used the Autoregressive Integrated Moving-Average Model (ARIMA MODEL) (p, d, q). ARIMA Modelling was developed using SPSS Expert Modeler (v18.1.1) software. The model consists of three parts: an autoregressive (AR) part, a moving average (MA) part, and an integrated (I) part. The development of ARIMA models is based on the methodology quantified in the classic work (40). The autoregressive integrated moving average (ARIMA) model is obtained as a combination of the autoregressive (AR) and moving average (MA) and integrated (I) models. Consider a stochastic process Xt specified as-

$$X_t - \alpha_1 X_{t-1} - \alpha_2 X_{t-2} - ... - \alpha_p X_{t-p} = \varepsilon_t + \beta_1 \varepsilon_{t-1} + \beta_2 \varepsilon_{t-2} + ... + \beta_q \varepsilon_{t-q}$$

$$X_t = \alpha_1 X_{t-1} + \ldots + \alpha_p X_{t-p} + \varepsilon_t + \beta_1 \varepsilon_{t-1} + \beta_q \varepsilon_{t-q}$$

where p (the number of autoregressive) and q (the number of moving average terms) (41).

2.6.2 Statistical Tests for Model Performance

In this study, two tests were used to evaluate the model performance: the coefficient of correlation (r^2) and the Bayesian information criterion (BIC). The R-square (R^2) indicates how well the model fits the data (R-square close to 1.0 indicates that the model accounted for nearly the predictability with the variables identified in the model). The Bayesian information criterion also indicate how well the model fits the data. The use of the regression technique and Bayesian information criterion allows the sensitivity ranking to be determined based on the relative magnitude of the regression coefficient (40,42).

3. Results

(Table 1) shows the mean value of the environmental parameters of the Central Bonny estuary. There is a significant difference in pH, DO, PO_4, NO_3, and NO_2, while temp, salinity, and TDS were not significantly differed across the stations. (Table 2) shows the seasonal variation of the environmental parameters. pH, DO, salinity, and TDS were found to have decreased from the dry to the wet season while temperature values increased from dry to wet. The values of nutrients (PO_4 and NO_3) reduced from dry to wet, while NO_2 increased from dry to wet. All environmental parameters (temp. DO, salinity, TDS, nitrate, and nitrite) showed spatial and temporal variations from dry to wet season except pH and phosphate ($p<0.01$).

Table (1): Environmental Parameters of the Central Bonny Estuary across Stations

Stations	1	2	3	4	Sig. (p-value)
pH	6.85±0.09[a]	7.26±0.05[ab]	7.32±0.04[c]	7.35±0.05[c]	0.000**
Temp. (^{O}C)	29.97±0.71[a]	28.97±0.56[a]	28.98±0.50[a]	28.96±0.54[a]	0.822
DO. (mg/l)	4.97±0.34[b]	4.46±0.28[ab]	3.89±0.16[a]	4.32±0.20[ab]	0.040**
Salinity(ppt)	15.09±1.42[a]	19.40±2.40[a]	18.24±2.21[a]	17.80±1.59[a]	0.524
TDS (mg/l)	19.57±2.24[a]	18.34±2.24[a]	17.16±2.43[a]	16.87±2.22[a]	0.458
PO_4 (mg/l)	3.14±0.21[a]	3.70±0.25[a]	9.48±1.05[c]	5.40±0.67[b]	0.000**
NO_3 (mg/l)	0.72±0.07[b]	0.53±0.04[a]	0.71±0.06[b]	0.49±0.08[a]	0.014**
NO_2 (mg/l)	0.003±0.001[a]	0.005±0.001[a]	0.007±0.000[b]	0.004±0.001[a]	0.000**

*Superscripts of the same alphabet are not significantly different across the column (P>0.05)

**Superscripts of different alphabets are significantly different (P<0.05)

** Significant at p<0.01

Table (2): Seasonal Variation of the Environmental Parameters of the Central Bonny Estuary

Parameters	Dry	Wet	Sig. (p-value)
pH	7.39±0.03	7.08±0.03	0.62
Temp. (^{O}C)	28.32±0.39	29.85±0.25	0.00**
DO. (mg/l)	5.10±0.20	3.97±0.77	0.00**
Salinity (ppt)	24.10±1.24	13.20±0.33	0.00**
TDS (mg/l)	19.20±1.60	17.20±0.85	0.00**
PO_4 (mg/l)	4.68±0.548	5.26±0.32	0.11

NO_3 (mg/l)	1.12±0.33	0.73±0.03	0.00**
NO_2 (mg/l)	0.0044±0.003	0.0047±0.002	0.02**

** Significant at $p<0.01$

(Figure 2) showed the range of the mean cell density per liter of *Cyclotella antiqua* and *Cyclotella meneghiniana* species in the estuary. (Figure 3) showed the seasonal density cellsL^{-1} of *Cyclotella* spp., *C.antiqua,* and *C meneghiniana*, both species increasing across seasons (dry to wet), respectively. (Figure 4) showed that *Cyclotella* spp. occupy 6% of the abundance of the harmful algal species of 94% in the estuary.

The Principal Component Analysis between environmental parameters and *Cyclotella* spp. in station 1 is shown in (Figure 5). (DO, temp., and TDS) were positively correlated, while pH and salinity were negatively correlated with *Cyclotella* spp. Similarly, NO_3 and NO_2 were positively correlated, while PO_4 was negatively correlated with *Cyclotella* Spp. At station 2, pH, salinity, andPO_4 were negatively correlated, while DO, temperature, TDS NO_3, and NO_2 were positively correlated with *Cyclotella* spp. (Figure 6).

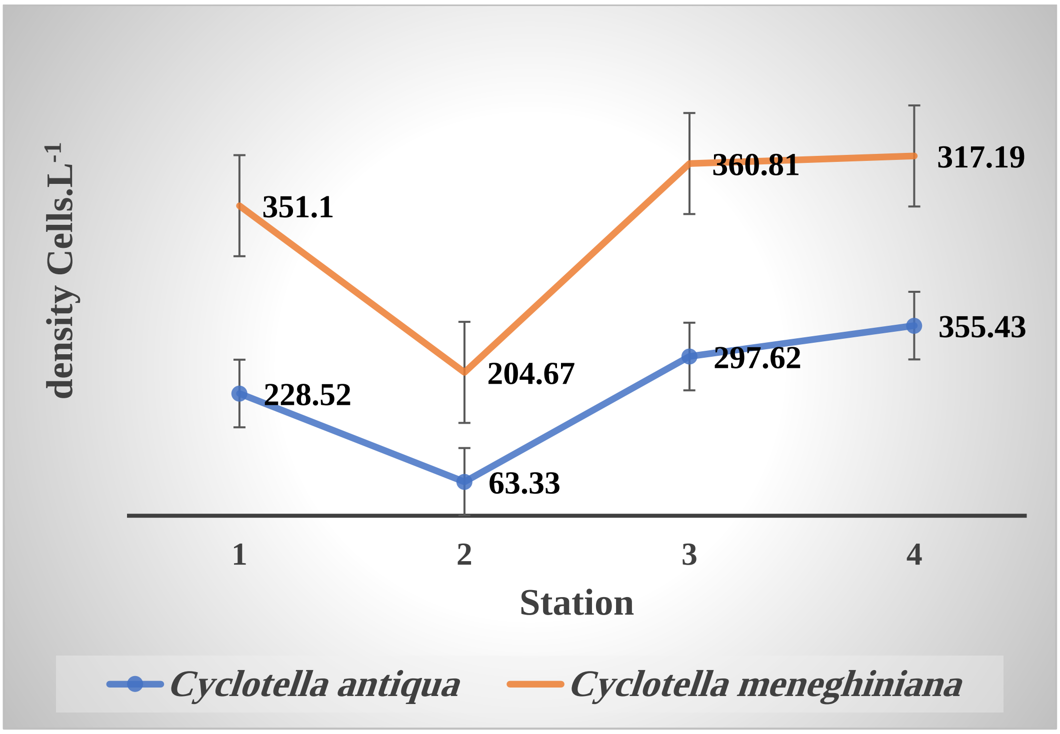

Figure (2): Mean Cell Density/Litre of *Cyclotella* spp. in the Central Bonny Estuary

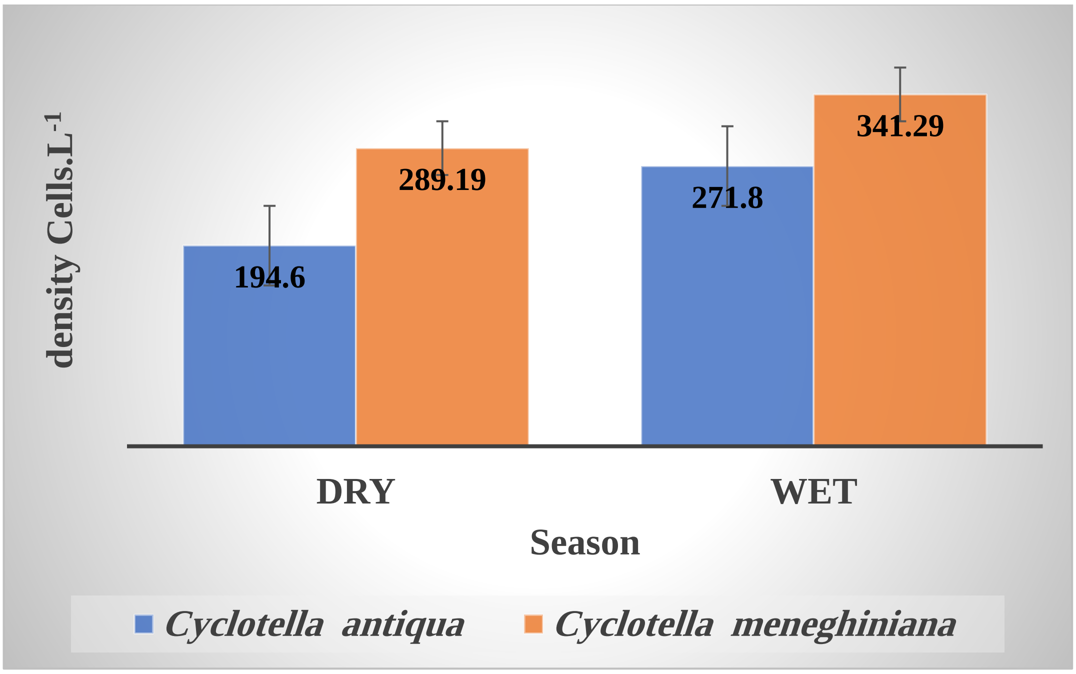

Figure (3): Mean Cell Density/Litre of *Cyclotella* spp. Across season in the Central Bonny Estuary

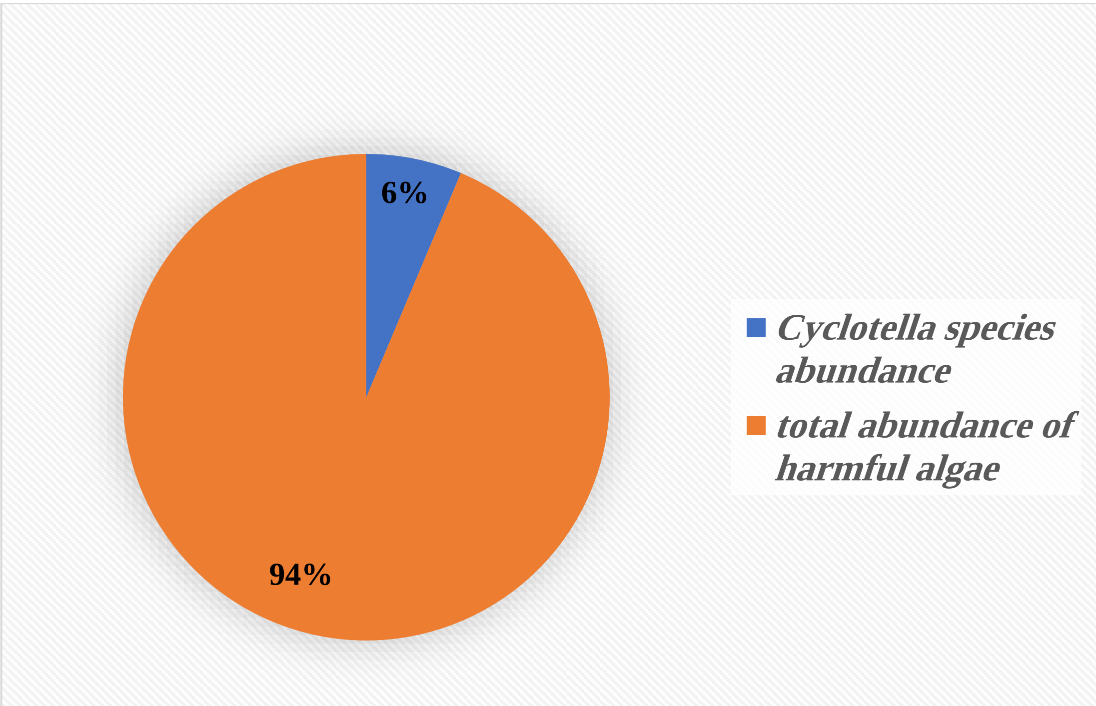

Figure (4): Relative abundance/ percentage composition of *Cyclotella* spp. in the Central Bonny Estuary

(Figure 7) showed station 3 was pH, dissolved oxygen, temperature salinity, phosphate, and nitrite correlated negatively with *Cyclotella* spp., while total dissolved solids and nitrate correlated positively with *Cyclotella* spp. In station 4, as shown in (Figure 8). *Cyclotella* spp.

Correlated negatively with pH, Salinity, and phosphate, while total dissolved solids, nitrate, and nitrite correlated positively with all *Cyclotella* spp. Dissolved oxygen was positively correlated with *Cyclotella antiqua* spp. and negatively correlated with *Cyclotella meneghiniana* spp. (Figure 9) showed the observed and forecast for *Cyclotella antiqua* species with a very strong model fit (R^2) value of 0.844 and a BIC value of 8.97. Significant predictors were TDS, DO, and NO_2, which is significant at 0.002. The species forecast steadily increased across the months compared to the observed values. (Figure 10) showed the observed and forecast for *Cyclotella meneghiniana* spp. With a mildly strong model fit (R^2) value of 0.766 and a BIC of 9.77. Significant predictors were TDS and NO_2 which were significant at 0.206. The species forecast increased across the predicted months. (Figure 11) showed the observed and forecasted total biomass with a strong model fit (R^2) value of 0.839 and a BIC value of 10.44. TDS and NO_2 were significant predictors, with a significance level of 0.298. The total biomass forecast also increased across the predicted months.

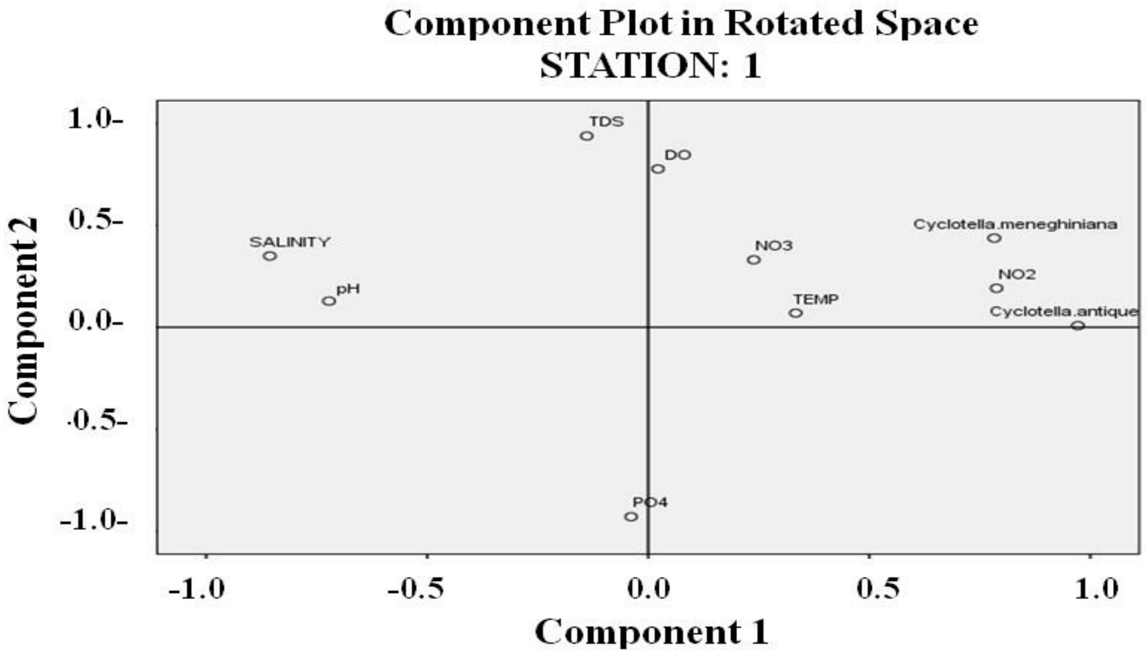

Figure (5): PCA Analysis of *Cyclotella* spp. with environmental parameters of station 1 in the Central Bonny Estuary

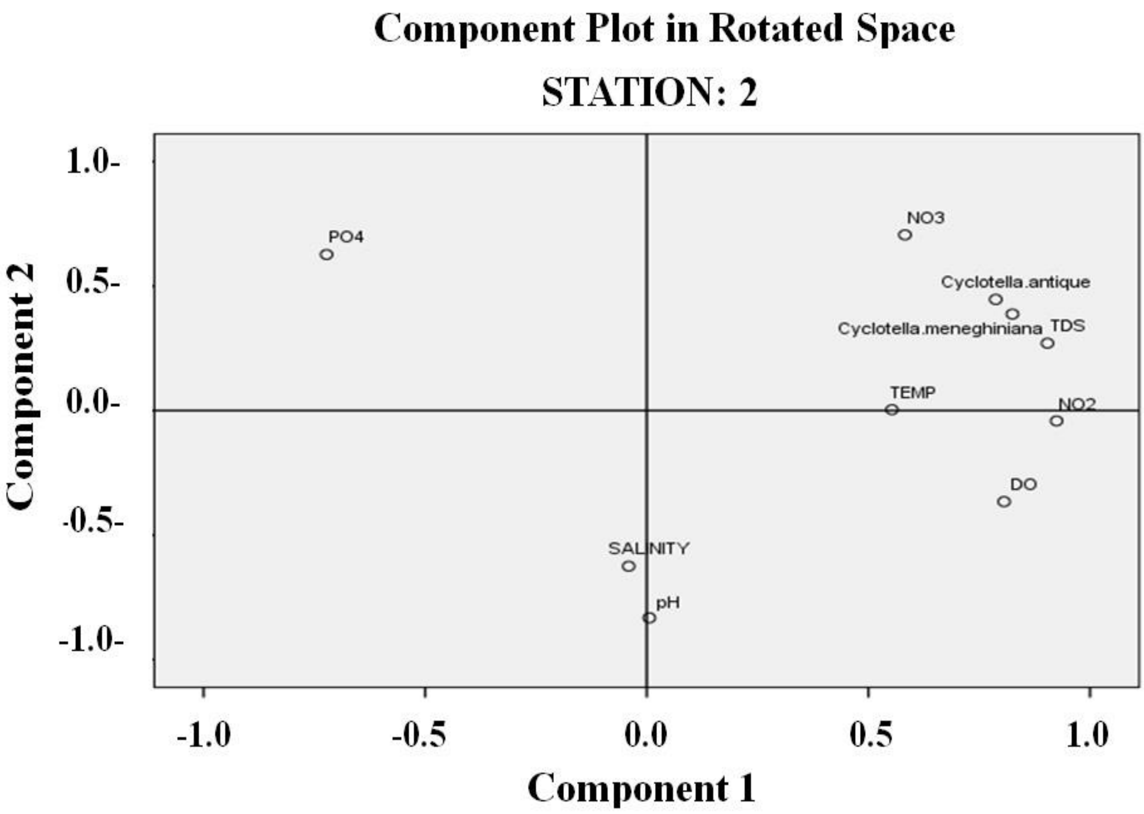

Figure (6): PCA Analysis of *Cyclotella* spp. with environmental parameters of station 2 in the Central Bonny Estuary

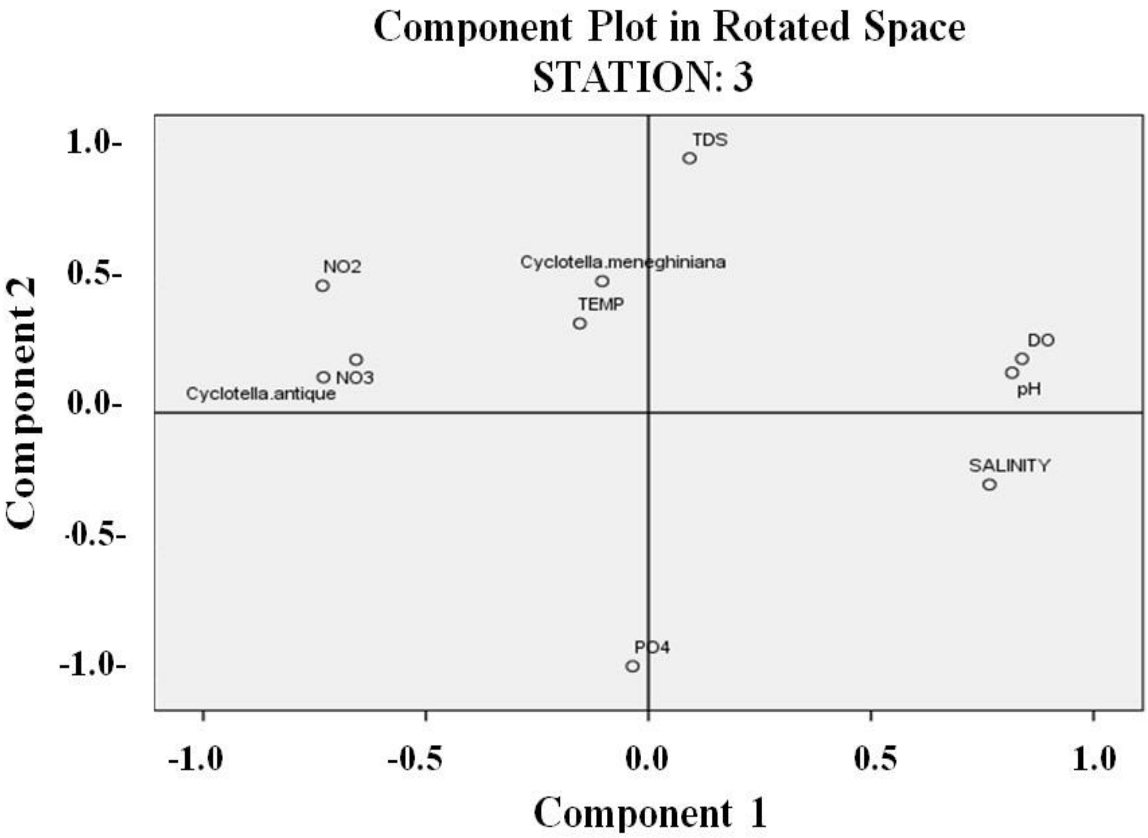

Figure (7): PCA Analysis of *Cyclotella* spp. with environmental parameters of station 3 in the Central Bonny Estuary

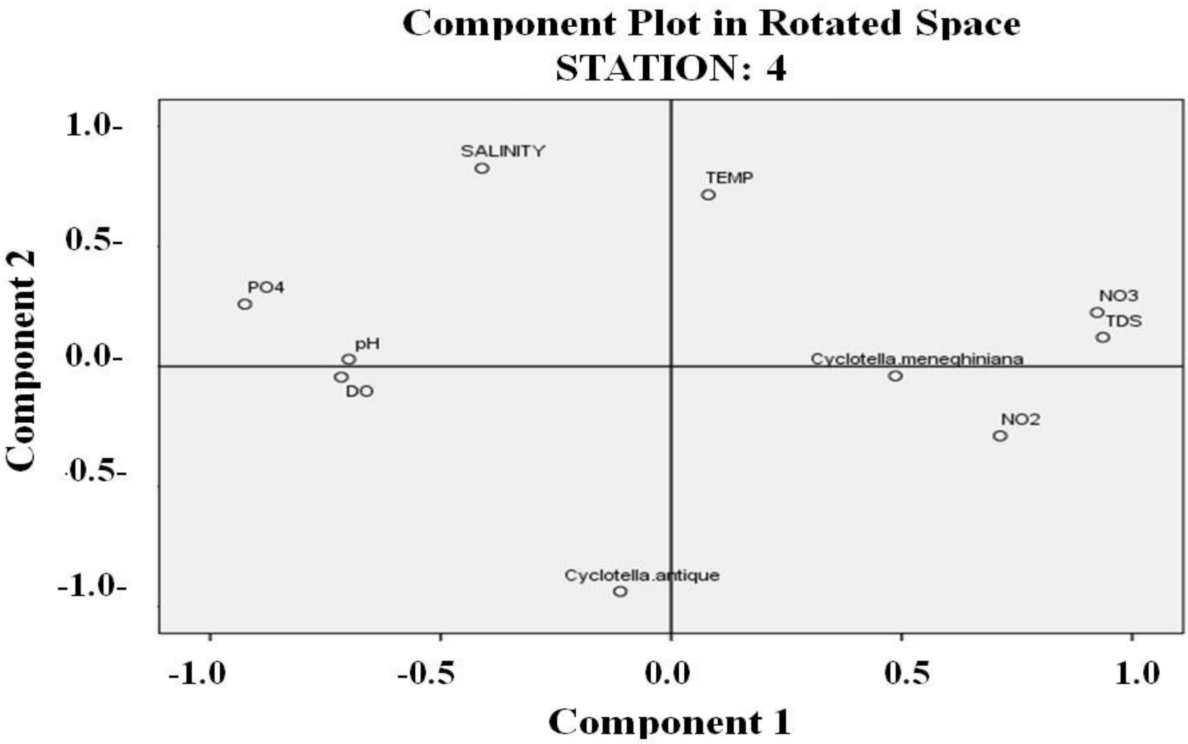

Figure (8): PCA Analysis of *Cyclotella* spp. with environmental parameters of station 4 in the Central Bonny Estuary

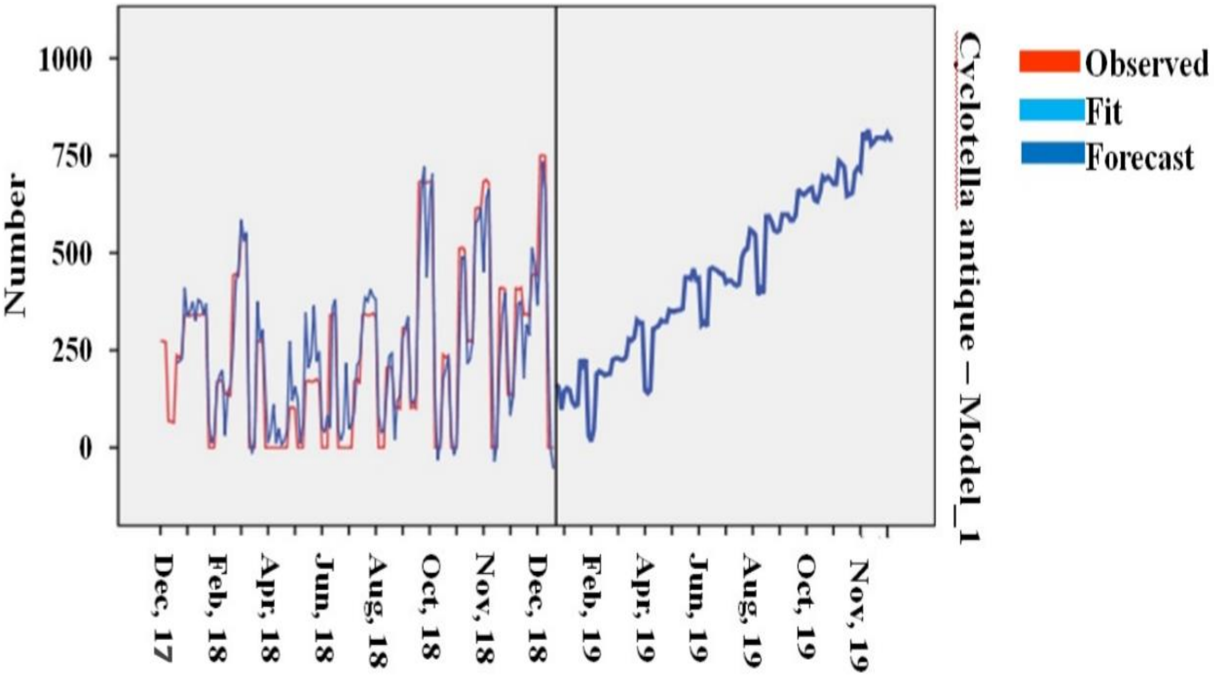

Figure (9): Observed, fit, and forecast species of *Cyclotella antiqua*

Table (3): Model description of *Cyclotella antiqua*

Model	BIC	Number of Predictors	Model Fit statistics	Ljung-Box Q(18)			Number of Outliers
			R-squared	Statistics	DF	Sig.	
Cyclotella.antiqua Model_1	8.97	3 TDS,DO,NO_2	0.844	37.982	16	0.002	0

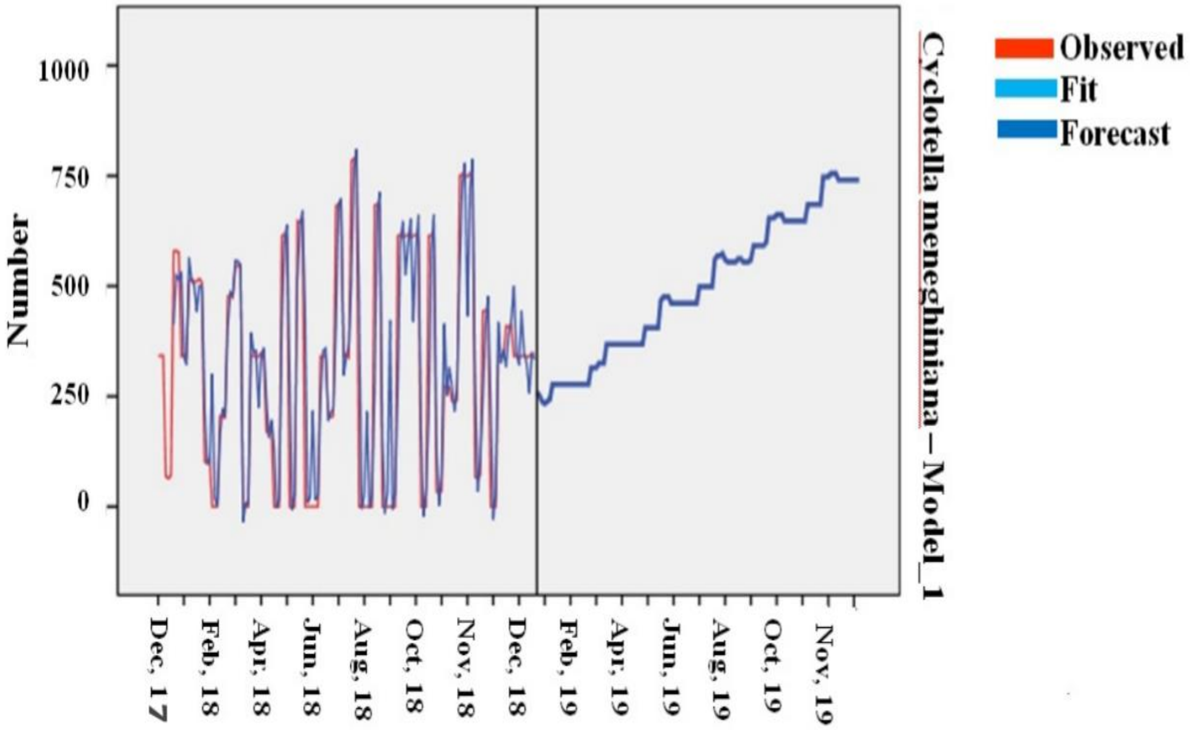

Figure (10): Observed, fit, and forecast species of *Cyclotella meneghiniana*

Table (4): Model description of *Cyclotella meneghiniana*

Model	BIC	Number of Predictors	Model Fit statistics	Ljung-Box Q(18)			Number of Outliers
			R-squared	Statistics	DF	Sig.	
Cyclotella. meneghiniana- Model_1	9.77	2 TDS, NO_2	0.766	20.323	16	0.206	0

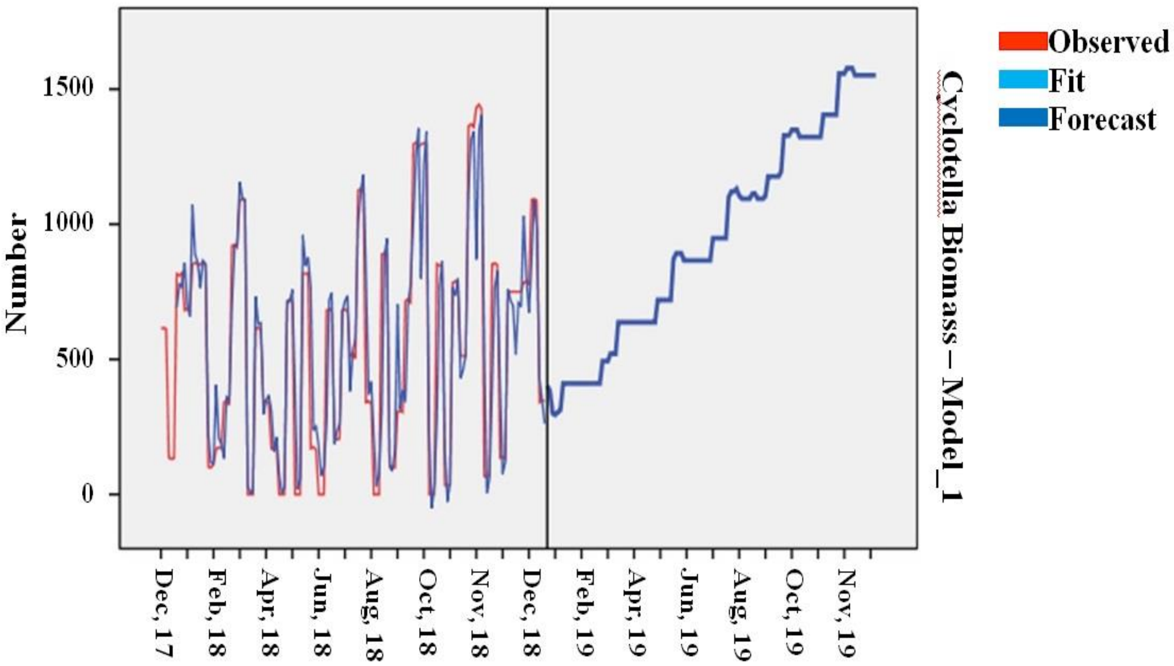

Figure (11): Observed, fit, and forecast species of *Cyclotella* total biomass

Table (5): Model description of *Cyclotella* total biomass

Model	BIC	Number of Predictors	Model Fit Statistics	Ljung-Box Q(18)			Number of Outliers
			R-squared	Statistics	DF	Sig.	
Total.Biomas-Model_1	8.39	2 TDS, NO_2	0.839	18.446	16	0.298	0

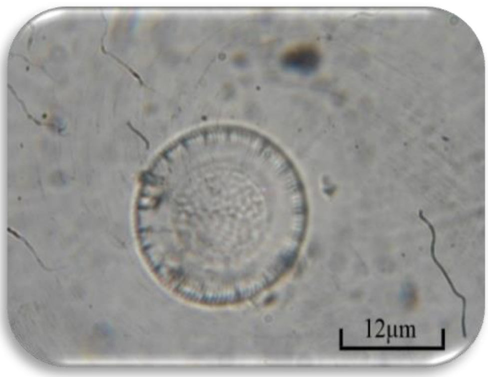

Plate 1: *Family: Stephanodiscacea*
Species: Cyclotella antiqua
Magnification:40X

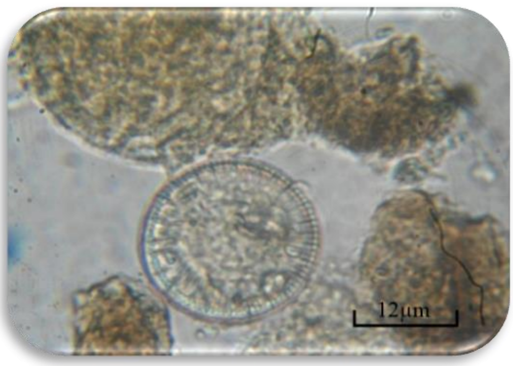

Plate 11*: Family: Stephanodiscacea*
Species: Cyclotella meneghiniana
Magnification: 40X

4. Discussion

The present study showed that there is no spatial variation in pH, dissolved oxygen, phosphate, and nitrate across the stations. The pH values recorded were within the recommended range for aquatic life and World Health Organisation limits (43). The seasonal difference in pH values witnessed is in line with the results of studies conducted by (44) in the Bonny Estuary, where pH values were documented with lower pH values in the rainy season. Temperature values recorded were within the normal range concerning the location in the Niger Delta region. Temperature values also increased from the dry to wet period, which agrees with the findings of (45) and (46), who reported a temperature range between 27ºC and 30ºC in the Bonny Estuary. Davies and Ugwumba (2013) (47) reported a less concentration of DO in the wet season as compared to the dry season in the upper Bonny estuary. They attributed it to the decreased photosynthetic events of algae, which agrees with the result of this research. Salinity values showed a subtle variation along the Bonny estuary. Higher salinity values were recorded throughout the dry season than in the wet season in the present study, which compared favourably with the report of (48) , in the estuary described higher salinity in the dry season than in the wet season. This trend is attributed to effluent water discharge from several industrial establishments carrying out bunkering and domestic activities that are prevalent along the estuary. A similar trend of TDS reported in this study was also reported by (49) and (45), both in the lower Bonny estuary. The high total dissolved solid concentration observed at station 1 may be ascribed to high surface runoff, overland flow, and the higher release of organic wastes into station 1 compared with other stations in the estuary. The observed phosphate concentrations in this estuary were higher than the tolerable limit of 0.10 mg/L in flowing waters as recommended by the (50). Falomo (1998) (51) reported a mean phosphate of 1.4 mg/L in Okrika Creek, central Bonny estuary, while (52) recorded (4.95-14.73 mg/l) at polluted sites in the upper Bonny estuary. A higher phosphate value was recorded in the wet season than in the dry season, which contrasts with the findings of (53), who reported higher phosphate in the dry season. However, natural inputs from organic matter decay might contribute to the high phosphate concentrations in the Bonny Estuary. The range of nitrate recorded in this study was below the statutory limits of 25–50 mgL^{-1} given by the (54) and 20 mgL^{-1} by the (55). Nitrate values decreased from the dry to the wet season, which agrees with the findings of (56), who recorded a higher nitrate value in the dry season than in the wet season. This might be attributed to high anthropogenic inputs into the estuary. The nitrite values were within the range of values expected for unpolluted water, which slightly increased from the dry to wet season. The findings were in line with (57) findings. Nitrate does not pose a health threat, but it is readily reduced to nitrite by the enzyme nitrate reductase, which is widely distributed and abundant in plants and micro-organisms (58).

The ratio of *Cyclotella* spp. concerning the total abundance of the harmful algal species recovered in the estuary revealed 6% of *Cyclotella* species to the total algal abundance. The highest mean value was 355.43±49.55 Cells.L^{-1} was recorded in station 4 (NPA Dockyard), and the lowest mean value of 63.33±17.02 Cells.L^{-1} at station 2 (Isaka open river) was recorded for *C antiqua* spp. At the same time, *Cyclotella meneghiniana* recorded the highest mean density of 360.81±70.05 Cells.L^{-1} in station 3 (Back of Ibeto cement), and lowest of 204.67±61.67 Cells.L^{-1} in station 2 (Isaka open river). The influx of running water may have contributed to the high density of species in stations 3 and 4 and low density of the species in station 2 (Open River) due to the influx of running water. In many marine systems, variations within an annual cycle of freshwater inflows, mixing with the ocean, will lead to alternating periods of growth limitation involving multiple nutrients. This can cause a shift in nutrient availabilities, influencing succession patterns in algal abundance. (59). *Cyclotella* species are diatoms that are common elements in epipelagic communities. It is recognized that diatoms' (*Cyclotella* spp.) abundance is sensitive to environmental variables and responds to changing environmental conditions (60). In the estuarine system, low cell biomass may be due to high turbidity levels, hence fluctuating photochemistry (61). This reason could be attributed to the low density of this species in station 2 (the open river.), The low cell biomass of this harmful algal species may have resulted from tidal movement. According to (62), cell densities of harmful algal species capable of forming blooms recorded in this study were not high enough ($<10^3$ Cells.L^{-1}) for toxic production species and ($<10^6$ Cells.L^{-1}) for non-toxic production species, which is in agreement with the density values of *Cyclotella* spp. in the study area. Consequently, the cell densities of *Cyclotella* spp. recovered in the estuary cannot be treated as blooms but have great tendencies towards possible bloom formation if the environmental factors are not properly checked. The *Cyclotella* spp. increased from the dry to the wet season, which agrees with the findings of (63), who stated that in tropical regions, the dry and wet seasons showed distinct fluctuations with *Cyclotella* algal abundance in the wet season in Niger Delta waters. They reported that harmful algal densities were among the reasons for higher turbidity in water bodies. High turbidity during the rainy season was probably attributed to run-off from catchment areas along the estuary.

Coastal waters are characterized by a high degree of spatial and temporal variability of environmental parameters. *Cyclotella* spp. from Karst waters are widely tolerant to various environmental parameters, such as adaptation to high water stability (64) and low light availability, allowing them to dominate in more mesotrophic water bodies (65). In this study, high pH in the dry season was closely associated. With the dominance of *Cyclotella* spp., which is normally generally found in nutrient -poor waters and-poor waters, this agrees with (66). One of the main factors believed to act on long-term algal dynamics is global warming, but its effects are not always as expected. For example, algal biomass has been shown to decrease with global warming. In other instances, its effects are counterbalanced by other processes, such as re-oligotrophication, resulting in resilient algal structures. (67).

Principal component analysis between environmental parameters and total biomass of *Cyclotella* spp. across stations revealed that TDS, DO, PO_4, NO_3, and NO_2 were positively correlated while salinity, temperature, and pH were negatively correlated with *Cyclotella* spp. This interaction indicates the preference of *Cyclotella* spp. for lower temperatures, which also confirms the negative correlation of its abundance with temperature. These environmental parameters (NO_3, NO_2, TDS) greatly influence the distribution and abundance of the *Cyclotella* spp. in the estuary regarding stations 3 and 4 as compared to stations 1 and 2. This shows that the species have a high affinity for these variables for their growth which is in line with the findings of (68). The authors reported that diatom cells are capable of fast growth due to rapid nitrogen uptake (especially NO_3). This implies that the efficiency with which nitrogen and phosphorus are converted into phytoplankton biomass and the potential for bloom development vary across sites.

Moreover, grand experiments of nutrient reduction have shown that this efficiency changes over time (69). According to the ecological preferences of *Cyclotella choctawhacheeana* in the Zrmanja Croatian estuary and other sites (70,71,22,24). It tolerates wide salinity ranges and succeeds in brackish environments and saline lakes. It is usually a constituent of eutrophic environments, even suggesting it as an indicator of anthropogenic influences (71). However, along the east Adriatic coast, *Cyclotella choctawhatcheeana* is a significant constituent of phytoplankton that prefers oligotrophic conditions. The genus *Cyclotella* has been used as a useful indicator and can also be used to indicate low-nutrient conditions in coastal environments. The species is also known to require significantly lower nutrients than other species of phytoplankton species (72). The low concentration of nutrients in the study area corroborates the findings of (73) who stated that the Zrmanja Croatian estuary has a relatively low concentration of nutrients and the abundance of *Cyclotella* spp. compared with other coastal environments along the eastern Adriatic, does not reach the values characteristic of a eutrophic environment.

It can be seen that the concentration of nutrients in surface seawater has been increasing for years, which was probably due to increased population, increased discharge of domestic sewage, and caused nitrogen and phosphorus pollution in seawater (74,75). The increased concentration of nutrients was likely to cause the proliferation of particular species.

Total dissolved solids, dissolved oxygen, and nitrite were the most used predictors in the forecast of *Cyclotella* spp. These parameters were positively correlated with bloom-forming *Cyclotella* spp. in the present study. Yan *et al*. (2004) (76) reported using regression models to study algae in Qiandaohu waters, with the seven environmental factors taken as independent variables and algae Chl *a* as the dependent variable. Total phosphate and pH were applied three times in the equations. Water temperature (T) was used twice, while dissolved oxygen and total nitrogen were applied only once. The findings also buttressed the earlier inferences that total phosphate rather than total nitrogen was more likely to be a limiting factor for algae growth in the lake. It was also concluded that SD, pH, and TP were the most correlated factors with Chlorophyll a - algae biomass concentration.

Variables used as drivers in the application of machine learning algorithms for predicting the abundance or presence/absence of harmful algal bloom-forming microalgae include both biotic and abiotic variables. Abiotic variables used so far include site, season, calendar day, distance from the coast, meteorological variables (air temperature, wind speed and direction, cloud cover), physical variables of seawater (temperature, salinity, conductivity, turbidity, oxygen saturation, pH, Secchi depth, photosynthetic radiation, remote sensing reflectance) and nutrients in both dissolved and particulate forms (77,78). The observed data of the total biomass (1233.77 Cells L^{-1}) was compared with the simulated forecast result (1687.12 Cells L^{-1}), revealing that the *Cylotella* spp. increased steadily across the predicted months. The forecast predictors were increased to ascertain the effect on the predicted *Cyclotella* spp. *C. antiqua* and *C. meneghiniana* increased with a rise in TDS and NO_2. According to (79), the variables used to model harmful algae in coastal areas of the eastern Mediterranean were: temperature (T), salinity (S), and nutrient concentrations (phosphates and silicates), often recognized as drivers of algal growth and increased primary productivity in coastal waters. Anderson *et al*., (2002) (80) reported that nutrients can stimulate or enhance the impact of harmful species in several ways at the simplest level, harmful algae may increase in abundance due to nutrient enrichment but remain in the same relative fraction of the total algal biomass. This is in line with the result of the forecast concerning the nutrient (nitrite).

The regression coefficient, $R^2 = 0.839$ in the total biomass of this model for *Cyclotella* spp. accounted for 84% of the significant predictors and therefore confirmed the predictive power of this proposed model for predicting the formation of harmful *Cyclotella* spp. algal blooms. (81), who applied the Artificial Neural Network (ANN) model to analyze the influence of environmental factors on variations of algal biomass in the Youngsan River Estuary, South Korea. It was revealed that the statistical validation of the model showed extremely low sum square error ($SSE \leq 0.0003$) and root mean square error ($RMSE \leq 0.0173$) values, with an $R^2 \geq 0.9952$. The accuracy of the model predictions was high, despite the considerable irregularity and wide range of algal variations in the estuary. Concerning algal biomass, the contribution of seasonal environmental factors such as water temperature and solar radiation was high. Anderson *et al*. (2010) (82) adopted a different mathematical framework – a logistic Generalized Linear Model (GLM) – to predict potentially harmful algal bloom species in the Chesapeake Bay as a function of time of year, location, temperature, salinity, light, nutrients, and freshwater discharge. The result also showed that anthropogenic, irregular, and transient freshwater inflow and seasonal environmental changes contributed to algal variations and that the scale of the influence varied according to algal abundance.

The Spatially Referenced Regressions on Watersheds (SPARROW) and Nutrient Export from Watersheds (NEWS), have been extensively used to model harmful algal species in the Gulf of Mexico (83, 84). Abdolreza *et al*. (2017) (85) reported using hydrodynamic modules in the MIKE 3-Flow Model, which simulated the hydrodynamics and quality of water as well as the distribution of chlorophyll-*a* in the coastal area of the Oman Sea in Iran. The results revealed a good correlation amongst the identified algal species responsible for algal blooms with nitrate, phosphate and chlorophyll-a content of coastal waters, and the simulation results were adequately consistent with the measured data on variations of chlorophyll-a, i.e., the cause of algal blooms. Yan *et al*., (2004) (76) indicated the static model could forecast the species' growth and propagation trend. (Aggregated Scale Morphological Interaction between Tidal inlets and the Adjacent coast) ASMITA MODEL was used to study the effects of dredging and dumping strategies in the Western Scheldt. An adapted version of the model was used to model the interaction with the outer delta, and further extensions of this concept were applied to the Humber estuary (86). The Harmful Algal Blooms Expert System (HABES) project used fuzzy logic models to predict conditions favoring blooms and harmful effects from seven species from various European waters in the Dutch coastal zone (87). The open-loop grid model was also used to model long-term estuarine morphological evolution in a hypothetical estuary of constant width with a 2-D depth-integrated Delft3D model as described by (88). The 2DH depth-averaged version of the open (TELEMAC-MASCARET system) modeling software was used to simulate the Minho estuary hydrodynamics, given its capacity to accurately simulate hydrodynamic behavior in the coastal, river, and estuarine systems (89). The forecast findings showed that the estuary's statistical model could forecast the possibility of the *Cyclotella* spp. forming a bloom as a result of their abundance and response to environmental gradients.

5. Conclusion

A variability of environmental parameters characterizes the Central Bonny estuary and is becoming more vulnerable to eutrophication (nutrient enrichment) due to urbanization, industrial waste, desalination plants, agricultural activities, and ballast water. This variation in the environmental factors affected *Cyclotella* spp. abundance in the estuary. Concerning the significance of the interaction between the variables, with an increase in the environmental parameters (DO, TDS, and NO_2), there is a possibility of these *Cyclotella* species forming blooms through the excessive supply of nutrients from domestic waste and runoff from the agricultural fields into the estuary. It can be concluded that if only one nutrient is substantially increased, the other nutrient will limit growth. The forecasts of the bloom-forming *Cyclotella* spp. using the ARIMA model shows that as the supply of nutrients in the estuary increase, the cumulative density of *Cyclotella* algal population also increases in the Central Bonny estuary. There is a need for best management practices to address nutrient discharge in the Bonny estuary.

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