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Interaction of Some Environmental Gradients with Bloom Forming *Coscinodiscus* Species (Kützing, 1844) in the Upper reaches of Bonny Estuary Rivers State, Niger Delta

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ABSRTACT: This study was carried out from December 2021 to November 2022 to examine the interaction of environmental factors with bloom-forming *Coscinodiscus* species. Plankton samples were collected with a 20 µm mesh plankton net. The nutrients were analysed in the laboratory using the APHA 2012 Method, while physico-chemical characteristics were determined in situ. Three species were recovered *C. concinnus, granni, and radiatus C. Concinnus* recorded the highest mean density values in stations 1 and 2. *C. granni* recorded the lowest density values in stations 2 and 3, while *C radiatus* recorded the highest density value in station 2 and the lowest in station 1. The three species decreased across seasons (from dry to wet). Interaction between principal component analysis, environmental parameters, and *Coscinodiscus* spp. across stations indicates that temperature. and nitrate showed a strong positive correlation with *C. granni* species, while *C. concinus* showed a strong positive correlation with salinity. Conductivity, pH, and nitrate. Phosphate and nitrite showed a strong positive correlation with C. radiatus. These environmental parameters (temp.NO3, salinity, pH, TDS, and DO) greatly influence the distribution and abundance of the Coscinodiscus spp. and were the most used predictors in the forecast of *Coscinodiscus* spp., which were positively correlated. The regression coefficient, R2 = 0.878, in the model for *Coscinodiscus concinus* species accounted for 87% of the significant predictors and therefore confirmed the predictive power of this ARIMA model for predicting bloom forming *C. concinus* species, while the remaining species could not be accounted for. Human activities are having an increasing influence on the marine environment, especially the eutrophication of water. With an increase in the environmental gradients, there is a possibility of the species forming a bloom. There is the need for best management practices to address nutrient discharge in the Bonny Estuary.

KEYWORDS: Abundance, Bonny Estuary, *Coscinodiscus*, Diversity, Harmful algal species.

INTRODUCTION

Coscinodiscus is a genus of centric diatoms found in most areas of water. The free-living organisms, which are especially abundant in coastal regions, are an important food source for microcrustaceans and other aquatic life forms. Some Coscinodiscus species are considered cosmopolitan, while others have only been found in southern cold- or warm-water areas. (Hasle and Syvertsen, 1997) Some species, according to recent literature, have been involved in harmful effects that have caused significant damage to aquaculture and commercial fishery areas. (Takano, 1980; Nagai and Manabe, 1993). The genus is abundant in the Mexican, Argentine, and Antarctic seas. According to Van Landingham (1968), approximately 400 *Cosinodiscus* species names are properly published with priority.

Coscinodiscus (Coscinodiscophyceae, Bacillariophyta) is a species-rich genus with 174 taxonomically accepted species, among which 49 species have been identified in various coastal regions in China (Huang, et al.,2021). Some *Coscinodiscus* species can form red tides that may cause serious damage to aquaculture through competitive utilization of nutrients or by causing extensive clogging of fishing nets and other equipment (Tetsuya et al.,2000; Nishikawa et al.,2010) and can cause hypoxia and bring substantial losses to fishery by generating a large amount of sediments (Laing and Gollasch, 2022). As some Coscinodiscus species cannot tolerate cold temperature, their distribution indicates warming ocean temperatures and have been used to track global warming. Against this background, this study was carried out to investigate the interaction between environmental gradients and bloom forming Coscinodiscus species in the upper reaches of the Bonny Estuary in the Niger Delta.

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MATERIALS AND METHODS

Study area

The Bonny estuary is one of the Niger Delta Complex's multiple low-land coastal waters. It is situated in River State, Nigeria, between 4° 25" and 4° 50" N latitude and 7° 0" and 7°15" E longitude. (Figure1). It is mostly saline, with only a small amount of freshwater discharged from the New Calabar River system. It is made up of a major river channel and numerous associated creeks and creeklets. The Bonny Estuary is an important transportation path for crude oil and other cargoes, connecting the Port Harcourt quays, the Federal Ocean Terminal, Onne, and the Port Harcourt Refinery terminal jetty, Okrika. Among the river systems in the Niger Delta, the Bonny estuary (with a maximum width of 2 km and a maximum depth of roughly 15 m near the mouth) has the greatest tidal volume and is most significantly impacted by tidal movement. Seasonal changes in salinity and the Atlantic Ocean's impact on the tidal regime (Dangana, 1985).

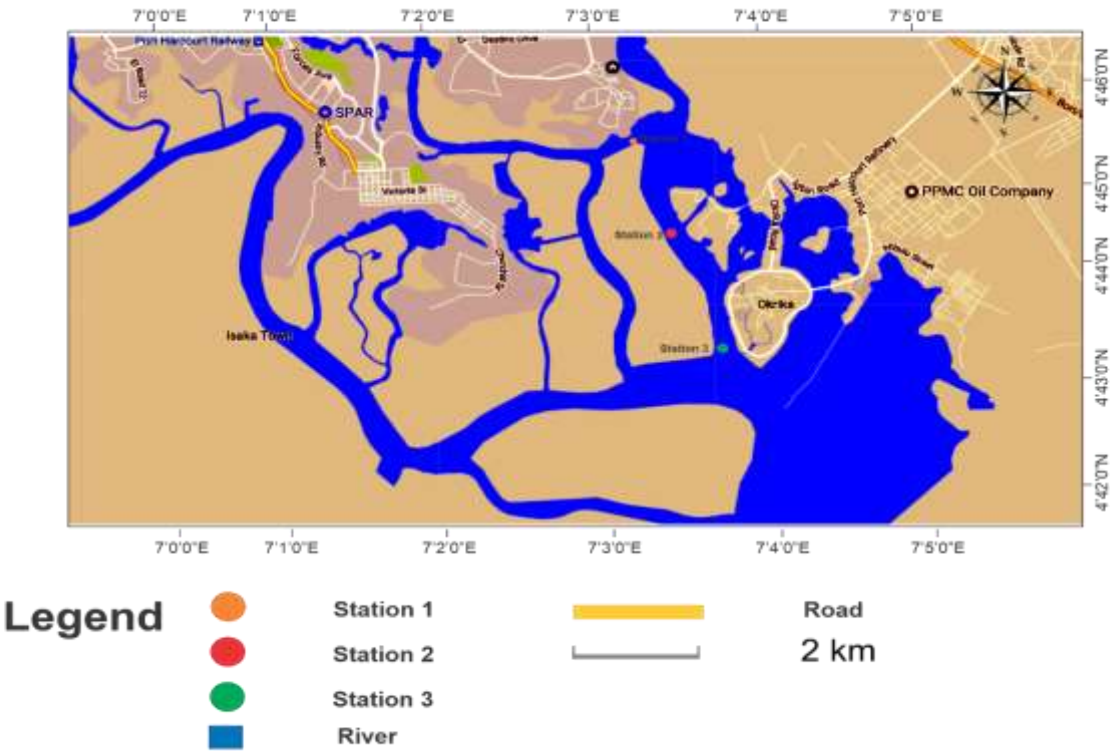

Figure 1: Map of the study area

Sampling Stations

Using ArcGIS Version 10.0, three sampling sites were set up at intervals of 500 m during a reconnaissance preliminary survey of the estuary path. (Redlands.2010): The sampling locations were chosen based on the local ecology, flora, and human activity. The stations chosen include Station 1: (Abuloma jetty), Station 2 (Kalio Ama) and Station 3 (Ogoloma).

Collection and assessment of Water Samples for Nutrient Analyses

Temperature (^{O}C), salinity (ppt), pH, dissolved oxygen (DO) (mg/l), and total dissolved solids (TDS) (mg/l) were the physico-chemical parameters that were measured in-situ at each sampling site using a Horiba water checker (Model: Extech D0700). Nutrient samples from the surface water (PO4, NO3, and NO2) were taken at neap tide at a depth of 5 centimetres in a plastic container that had already been cleaned. After being collected in triplicate, each sample was brought to the lab to be analysed for nutrients using the APHA 4500 Method. (2012).

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Collection of Water samples and Algae

Using a 20-litre bucket five times into a plankton net with a 20 µm mesh size and held vertically, water samples were taken monthly from four sampling sites between December 2021 and November 2022 (12 months) for the quantitative analysis of algae. Net catches were put into a plastic receptacle with a capacity of 250 ml, preserved with a buffered solution of 4%, and then concentrated to a volume of 10 ml in the laboratory.

Enumeration of *Coscinodiscus* bloom forming Algal species.

Using the Lackey Drop Micro-transect Counting Method, the *Coscinodiscus* species of microalgae were counted. (APHA, 1998). Before subsampling a drip of 0.05 ml onto a glass slide in duplicate with a cover-slip, the sample was thoroughly mixed. Both the processed volume and the count of visible microalgae in a particular volume were known; their abundance was determined using an inverted microscope and a low power objective. (Leica DMIL). The bloom forming *Coscinodiscus* algal species were microphotographed using a camera that was attached to the microscope. To identify the species, Hallegraeff et al. (1995) and Tomas (1997) were employed.

Individuals per ml was calculated;

(Number (No.) Individuals) ⁄ (ml= (C x TA) / (A x S x 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 litre (Cells L^{-1}).

Statistical Analysis

The Statistical Package for Social Science (SPSS) 16.0 windows were used for the statistical study. (SPSS In,.2007). For the statistical analysis of the data, one-way analyses of variance (ANOVA) were used to compare the means, and post hoc Duncan's test was used to establish whether there were significant differences between the study stations. The Student's T-test was used to analyse the spatial variation of the different environmental parameters and the bloom forming *Coscinodiscus* algal species throughout the season. Using PAST software, correlation analysis was used to examine the relationship between *Coscinodiscus* species and important environmental variables. (Leps and Similauer, 2003).

Predictive model for Bloom forming Algal species

To develop a model for predicting the trend of *Coscinodiscus* harmful 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 of Box and Jenkins (1976). 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-

Xt - α1Xt-1 - α2Xt-2 - ... - αpXt-p = εt + β1εt-1 + β2εt-2 + ... + βqεt-q

Xt = α1Xt-1 + … + αpXt-p + εt + β1εt-1 + βq εt-q

where p (the number of autoregressive) and q (the number of moving average terms) (Asteriou and Hall 2011).

Statistical Tests for Model Performance

The Bayesian information criterion and the coefficient of correlation (r^2) were used in this research to assess the model performance. (BIC). R-square (R^2) is a measurement of how well a model matches 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 degree to which the model matches the data was also determined using the Bayesian information criterion. Based on the relative magnitude of the regression coefficient, the sensitivity ranking can be determined by applying the regression method and the Bayesian information criterion. (Box and Jenkins, 1976; Salas et al., 1999).

RESULTS AND DISCUSSION

(Table 1) shows the mean value of the environmental parameters in the upper reaches of the Bonny estuary. There is a significant a difference in pH, turbidity, PO_4 and NO_3 while temp, DO, salinity and TDS were not significantly different across the stations. (Figure 2) showed the mean density values per litre of *Coscinodiscus* species, *C concinnus* recorded the highest mean density values

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in station 1 and 2. *C granni* recorded the lowest density values in station 2 and 3, while *C radiatus* recorded the highest density value in station 2 and lowest in station 1 respectively.

Table 1: Physico chemical and nutrient parameters of the Upper reaches of Bonny Estuary

Parameters	1	2	3	sig
pH	7.17 ± 0.12[a]	7.37 ± 0.09[ab]	7.47 ± 0.05[b]	0.065
Temp. (^{O}C)	28.20 ± 1.02[a]	27.88 ± 1.12[a]	28.21 ± 1.07[a]	0.967
DO. (mgL^{-1})	6.00 ± 0.74[a]	5.70 ± 0.71[a]	4.87 ± 0.53[a]	0.647
Salinity (ppt)	5.52 ± 1.66[a]	2.90 ± 1.27[a]	3.96 ± 4.53[a]	0.267
BOD. (mgL^{-1})	2.64 ± 0.14[a]	2.84 ± 0.32[a]	2.93 ± 0.21[a]	0.364
Turbidity (NTU)	4.78 ± 0.19[a]	5.18 ± 0.11[a]	6.90 ± 0.18[b]	0.002
TDS (mgL^{-1})	23.05 ± 3.54[a]	18.31 ± 4.71[a]	16.90 ± 0.17[a]	0.867
PO_4 (mgL^{-1})	2.09 ± 0.47[a]	1.79 ± 0.52[a]	1.94 ± 0.45[a]	0.010
NO_3 (mgL^{-1})	0.69 ± 0.04[a]	4.86 ± 1.95[b]	0.42 ± 0.04[a]	0.007

*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)

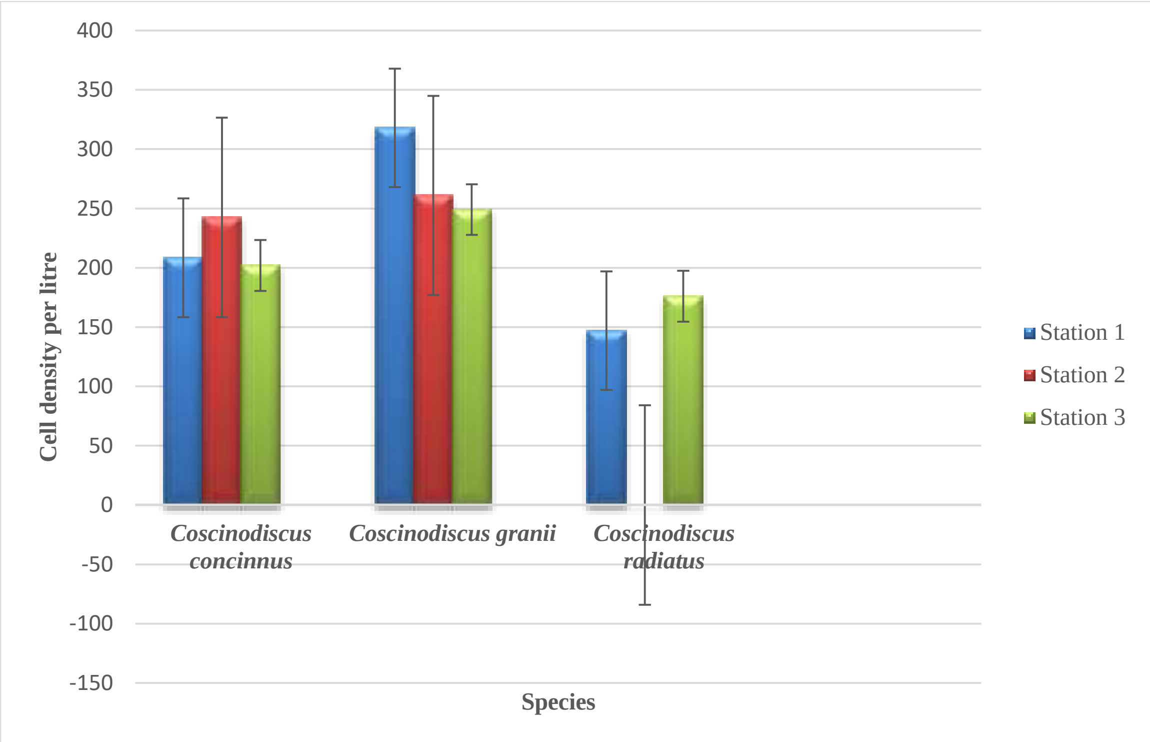

Figure 2: Mean Density per Litre of Harmful *Coscinodiscus* Algal Species Across Stations in Upper reaches of Bonny Estuary

Figure 3 showed the seasonal density cellsL^{-1} of *Coscinodiscus* spp., the three species *C. concinus. C. granni* and *C radiatus* decreased *across* seasons (dry to wet) respectively.
The Principal Component Analysis between environmental parameters and *Coscinodiscus* spp as shown across stations in figure 4 below revealed that temp., and nitrate showed a strong positive correlation with *C. granni* species, while *C. concinus* showed a strong positive correlation with salinity, pH and nitrate. Phosphate and nitrite showed a strong positive correlation with *C. radiatus*. Plates I-III Below showed the family and species of microphotographed bloom forming *Coscinodiscus*

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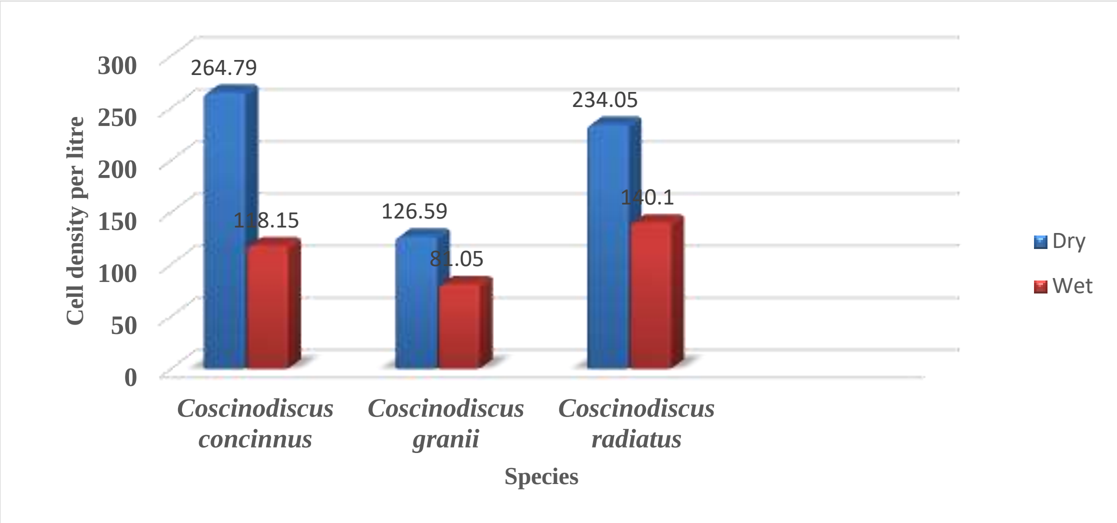

Figure 3: Mean Density per Litre of Harmful *Coscinodiscus* Algal Species Across Season in the upper reaches of Bonny Estuary

Plate 1
Family: Coscinodiscaceae
Species: Coscinodiscus concinnus
Magnification X40

Plate I1
Family: Coscinodiscaceae
species: Coscinodiscus granni

Plate III
Family: Coscinodiscaceae
Species: Coscinodiscus radiatus

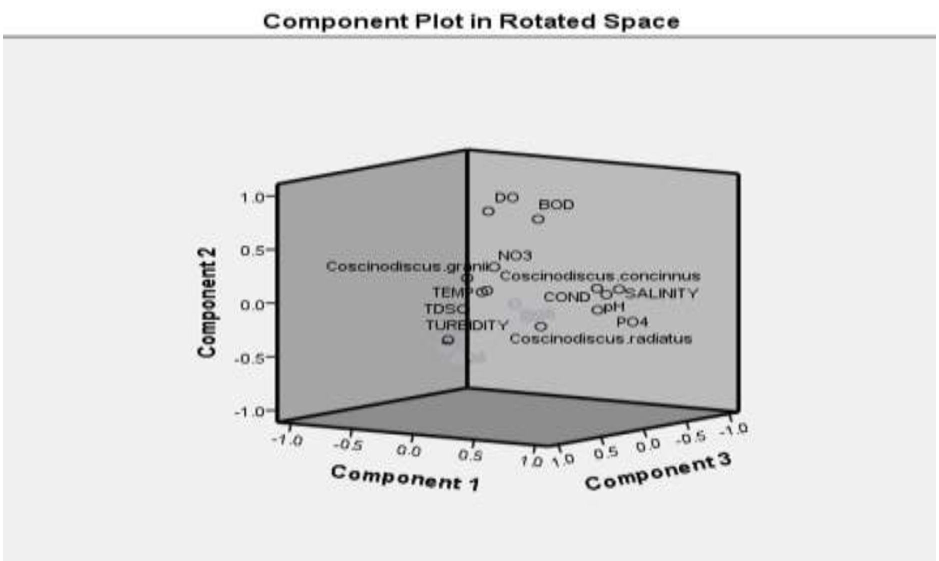

Figure 4: PCA Analysis of Harmful *Coscinodiscus* Algal Species with environmental parameters of the upper reaches of Bonny Estuary

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Figure 5 showed the observed and forecast for *Coscinodiscus concinus* species with a very strong model fit (R^2) value of 0.878 and a BIC value of 9.25. Significant predictors were temp., BOD salinity and TDS, which is significant at 0.975. The species forecast steadily increased across the months as compared with the observed values. Figure 6 showed the observed and forecast for *Coscinodiscus granii* species. with a weak model fit (R^2) value of 0.357 and a BIC of 9.74. Significant predictors were DO and salinity and were not significant at 0.000. The species forecast barely increase across the predicted months.

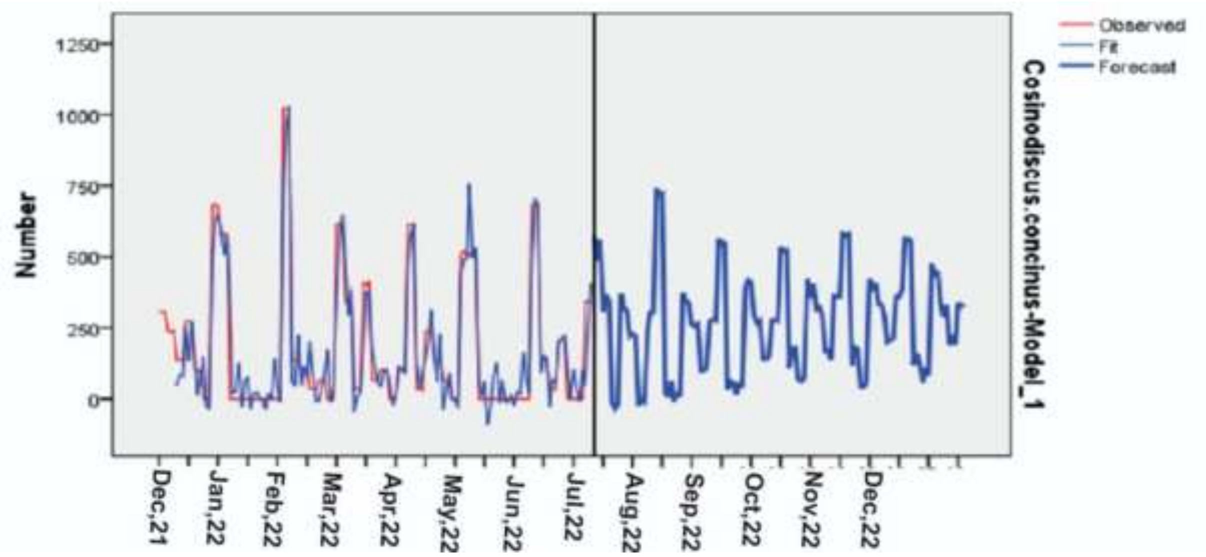

Figure 5: Observed, Fit and Forecast of *Cosinodiscus concinus spp*

Model Description

Model Type: ARIMA (0,0,2)

Model	BIC	Number of Predictors	Model Fit statistics	Ljung-Box Q (18)			Number of Outliers
			R-squared	Statistics	DF	Sig.	
Cosinodiscus. concinus- Model_1	9.25	4 Temp.,BOD, Salinity,TDS	0.878	6.932	16	0.975	0

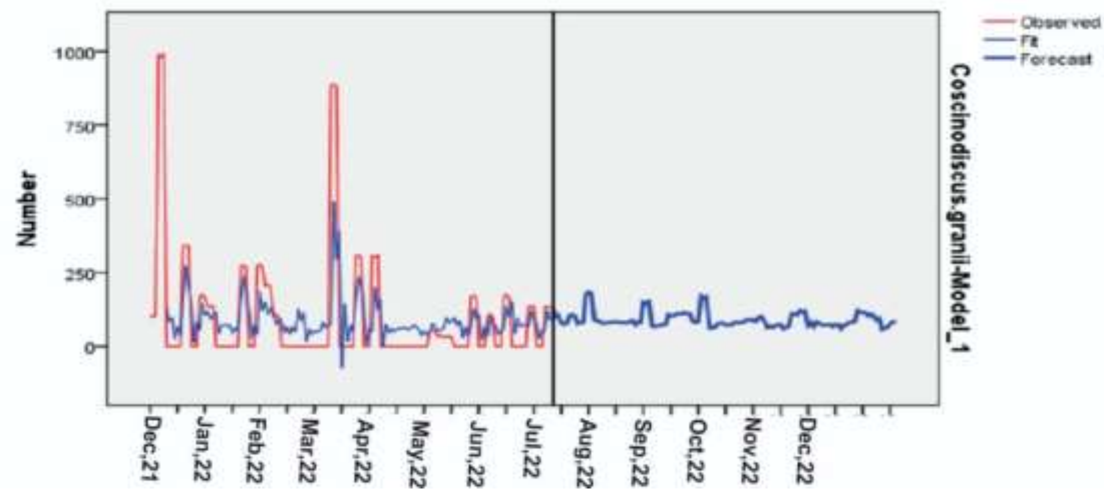

Figure 6: Observed, Fit and Forecast of *Coscinodiscus granii spp*

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Model Description

Model Type: ARIMA (0,0,1)

Model	BIC	Number of Predictors	Model Fit statistics	Ljung-Box Q (18)			Number of Outliers
			R-squared	Statistics	DF	Sig.	
Coscinodiscus.granii Model_1	9.74	2 DO, Salinity	0.357	55.366	17	0.000	0

DISCUSSION

The study's results revealed that there is a spatial variation in pH, turbidity, phosphate, and nitrate levels across the stations. The pH levels measured were within the suggested range for aquatic life and within World Health Organization limits. (WHO,2011). Temperature values observed were within the normal range for the Niger Delta area, which is consistent with the results of Vincent-Akpu and Nwachukwu (2016), who reported a temperature range of 27ºC to 30ºC in the Bonny Estuary. Salinity values varied subtly along the higher reaches of the Bonny estuary. This trend is ascribed to effluent water discharge from several industrial establishments engaged in bunkering activities, as well as domestic activities common along the estuary. A similar trend of TDS reported in this study was also reported by Chindah and Nduaguibe (2003) and Vincent-Akpu and Nwachukwu (2016), both in the Bonny estuary. The high surface runoff, overland flow, as well as the greater release of organic wastes into station 1 as compared to other stations in the upper reaches of the estuary, may be responsible for the high total dissolved solid concentration found at station 1. The measured phosphate levels in the upper portions of the estuary were marginally above the USGS. (2007)-recommended tolerable limit of 0.10 mg/L in flowing waters. In contrast to Ebere (2002), who measured (4.95-14.73 mg/l) at polluted sites in the upper Bonny estuary, Falomo (1998) reported a mean phosphate of 1.4 mg/L in Okrika Creek, central Bonny estuary. The range of nitrate recorded in this study was below the statutory limits of 20 mgL^{-1} given by the USEPA (2000). 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 both plants and micro-organisms (Glidewell, 1990).

The high density of *C concinnus* species in station 1, *C radiatus* in station 2, and *C granni* and low density of the species in station 2 and 3 may have been caused by the inflow of running water. Many marine systems experience alternating times of growth limitation involving a variety of nutrients due to variations in the yearly cycle of freshwater inflows mixing with the ocean. This in turn may result in a change in nutrient availability, which affects succession patterns and the frequency of the *Coscinodiscus* alga abundance. Pilkaityte and Razinkovas (2007). Diatoms called Coscinodiscus species are prevalent in epipelagic communities, and their abundance is dependent on environmental factors, which changes in response to shifting environmental conditions. (Mooser et al., 1996).

The station 3 turbidity values were higher, which is consistent with the low biomass of Coscinodiscus algae abundance. Low cell biomass in the estuarine system might be caused by high turbidity levels, which would cause varying photochemistry. (Pierce et al., 2004). Usup et al. (2002) found that the cell densities of harmful algal species that can form blooms that were observed in this research were insufficient ($<10^6$ $Cells.L^{-1}$), which is consistent with the density values of *Coscinodiscus* spp. in the study area. Contrary to the results of Ogamba et al. (2004), who claimed that in tropical areas, the dry and wet seasons showed distinct fluctuations, with algal abundance in the wet season in Niger Delta waters, the *Coscinodiscus* spp. decreased from the dry to wet season. They claimed that run-off from catchment areas along the estuary was likely to blame for the elevated turbidity during the rainy season.

This interaction between principal component analysis, environmental parameters and *Coscinodiscus* spp. across stations indicates the temp., and nitrate showed a strong positive correlation with *C. granni* species, while *C. concinus* showed a strong positive correlation with salinity. Conductivity, pH and nitrate. Phosphate and nitrite showed a strong positive correlation with *C. radiatus*. These environmental parameters (temp.NO_3, Salinity, pH) greatly influence the distribution and abundance of the *Coscinodiscus* spp in the upper reaches of the estuary. This shows that the species have a high affinity for these variables for their growth which is in line with the findings of Lomas and Glibert, (2000). Boalch (1971) considered that *C. concinuus* and *C. garnni* were grown in culture but *C. concinnus* is more sensitive to temperature and could not be grown at temperatures higher than 150^{O}C. Also, Sra (1996) observed that *C. granii* present across the Argentina sea and usually associated with low temperatures and salinities which is in agreement with the result of this study. Temperature is probably the most widely recognised physical factors affecting the dynamics of algal communities (Peperzak, 2003). Salinity is the main physical parameter that can be attributed to diatom community (Sridhar et al,2006).

It is evident that the concentration of nutrients in surface seawater has been rising over time, which was likely caused by an increase in human population and the discharge of household sewage, which contaminated the sea with nitrogen and phosphorus. (Jin,2012). The proliferation of specific species was probably brought on by the higher nutrient concentration.

Temperature, BOD, salinity, total dissolved solid, dissolved oxygen were the most used predictors in the forecast of *Coscinodiscus* spp and these parameters were positively correlated with bloom forming *Coscinodiscus* spp. in the present study. Yan et al., (2004) 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. The findings also buttressed that TDS, pH, and TP were the most correlated factors with the biomass concentration of Chl *a* algae.

Both biotic and abiotic variables are used as drivers in the implementation of machine learning algorithms for the prediction of the abundance, presence, or lack of harmful algal bloom-forming microalgae. (Hill et al., 2020). Temperature, salinity, and nutrient concentrations (silicates) were the variables used to model harmful algae in coastal areas of the eastern Mediterranean, according to Androniki et al. (2021), and are commonly recognised as drivers of algal growth and increased primary productivity in coastal waters.

The regression coefficient, $R^2 = 0.878$ in the model for *Coscinodiscus concinus* species accounted for 87% of the significant predictors and therefore confirms the predictive power of this proposed model for predicting the formation of bloom forming *Coscinodiscus concinus* species while the remaining species could not be accounted for. According to Park and Sin (2021), 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. Anderson et al. (2010) 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 as well as seasonal environmental changes contributed to algal variations and that the scale of the influence varied according to algal abundance. The findings of the forecast showed the statistical model of the estuary could forecast the possibility of the *Coscinodiscus concinus* species forming a bloom as a result of their abundance and response to environmental gradients.

CONCLUSION

The upper reaches of the Bonny Estuary are characterised by a variability of environmental parameters and are becoming more vulnerable to eutrophication (nutrient enrichment) due to urbanisation, industrial waste, desalination plants, agricultural activities, and ballast water. This variation in the environmental factors affected *Coscinodiscus* spp. abundance in the estuary. With reference to the significance of the interaction between the variables, with an increase in the environmental parameters (temp.NO_3, salinity, pH), there is a possibility of these *Coscinodiscus* spp., with particular reference to *C. concinus* species, forming blooms through excessive supply of nutrients from domestic waste and runoff from agricultural fields into the estuary. The forecasts of the bloom-forming *Coscinodiscus concinus* spp. using the ARIMA model show that as the supply of nutrients in the estuary increases, the cumulative density of the *Coscinodiscus* algal population also increases in the upper reaches of the Bonny estuary. There is a need for best management practises to address nutrient discharge in the Bonny Estuary.

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DECLARATION OF INTEREST

The authors declare that there is no conflict of interest.

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