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Influence of Environmental Variables on the Abundance and Distribution of Phytoplankton: A case Study of Lekki Lagoon, Sub-Saharan Africa

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ABSTRACT

The distribution and abundance of biota in an aquatic environment is generally influenced by environmental parameters. This study was carried out to assess the relationship between environmental parameters and phytoplankton distribution in Lekki lagoon, Sub-Saharan Africa. Phytoplankton and environmental data were obtained from nine stations in three replicates each from January to December, 2016. The relationship between phytoplankton and environmental data was assessed through multivariate analysis using PRIMER v_6 Software. A total of thirty-seven (37) species from six (6) divisions were recorded which included Chlorophyta, Bacillariophyta, Cyanophyta, Charophyta, Ochrophyta and Euglenophyta. Chlorophyta appeared to be the most diverse division with 14 species, while Ochrophyta was represented by a single species. The highest number of individuals (25809 ind/ml) and species (21) was observed in Station 3, while Stations 8 and 1 ranked least in terms of number of individuals (10038 ind/ml) and species (14) respectively. The nine stations formed two non-significantly ($p>0.05$) different clusters based on the phytoplankton community and were strongly correlated with transparency, nitrate and total suspended solids combined. The model that best explained the pattern of distribution of phytoplankton among the stations included depth, conductivity, dissolved oxygen, biological oxygen demand, total dissolved solids and total suspended solids. The findings showed that distribution of phytoplankton is influenced by a complex of environmental parameters especially those related to light and nutrient availability.

INTRODUCTION

Lagoons have been reported to be one of the features dominating the stretches of the coast of West Africa (Adesalu and Nwankwo, 2012) and represent about 15% of the world coastal zone (Solarin, 1998). These habitats have high fish productivity (Bruno *et al.*, 2013) and play an important role in biological and reproductive cycles of many marine species (Franco *et al.*, 2006). The biota in lagoon usually comprises plankton, nekton and benthos (Onyema, 2013) with phytoplankton being a very important component on which the entire array of life depends (Abdul *et al*., 2015).

Phytoplankton are free- floating unicellular and colonial organisms that form a crucial part of an aquatic ecosystem as they are the primary producers through which energy is transferred to higher organisms in the food chain (Saifullah *et al*., 2014; Sharma *et al*., 2015; Tilahun and Ayalew, 2015). They inhabit the upper part of the water column down to the limit of light penetration known as the euphotic zone. Phytoplankton biomass and productivity play a vital role in regulating the population and diversity of organisms in the higher trophic levels (Kathiresan, 2000; Gnanamorthy *et al*., 2013). Also information on the primary productivity is a very important tool for forecasting the fishery potential of a water body (Rajkumar *et al*., 2009).

Environmental parameters are the major determinants that control the dynamics in the abundance, diversity and distribution of phytoplankton in any aquatic ecosystem (Hulyal and Kaliwal, 2009). Changes in environmental parameters may have adverse effects on the production and physiological properties of the biological components in an aquatic ecosystem thereby reducing the ability of such organisms to compete with other populations within the environment (Dushyant and Singh, 2013). Due to their sensitivity to changes in the environment, phytoplanktons are often used as important indicators of water quality in ecological studies (Brettum and Andersen, 2005).

Various studies have been carried out on phytoplankton and environmental parameters of Lagoons in Sub-Sahara, Africa (Onyema, 2009; Onyema and Nwankwo, 2009; Adesalu, 2012; Adesalu and Nwankwo, 2012) where univariate analyses were mostly used. However, Lekki lagoon has not been extensively studied on this area. This study therefore aims to investigate the relationship (complex) between phytoplankton distribution and environmental parameters in Lekki lagoon with a view of detecting the set of environmental parameters that best explain the distribution and abundance of phytoplankton in the Lagoon.

MATERIALS AND METHODS

Description of the Study Area

This study was carried out in Lekki lagoon which is located between Lagos State and Ogun State, Sub-Saharan Africa. The lagoon lies between 4° 00'to 4°15' E and between 6°25' to 6°37' N, with a surface area of about 247 km^2 and it is mostly shallow (less than 3.0 m deep) with a maximum depth of 6.4m (Emmanuel, 2010).

It is fed by River Oni in the North-eastern part and Rivers Oshun and Saga in the North-western part (Kuton *et al.*, 2014). It opens into the Atlantic Ocean via the Lagos lagoon and Lagos harbour.

Sampling of Phytoplankton and Environmental Variables

The study area was stratified into nine (9) sampling Stations: 1- The brushpark area-Iwopin (4°17' E, 6°56' N), 2- Area where River Oni influxes the lagoon (4°14' E, 6°56' N), 3- The centre of the lagoon (4°16' E, 6°55' N), 4- Area where River Mosafejo influxes the lagoon (4°20 'E, 6° 56' N), 5- Imeki (4° 15' E, 6°49'N), 6- Mouth of River Osun (4°06' E, 6°12' N), 7- Emina (4°08' E, 6°54' IN), 8- Ebute Lekki (4°07' E, 6°46' N), 9- Yuboye (4°14' E, 6° 57 'N) and sampling was carried out randomly within the stations in three replicates per station on a monthly basis, each from January to December, 2016. Plankton samples were obtained in 150ml labeled plastic bottles using plankton net of 55µm mesh size that was slowly hauled horizontally at about 30 cm depth against the water current in each sampling station for 5 minutes. Samples were then preserved in 4% formalin as described by Ogbuagu and Ayoade (2012) and

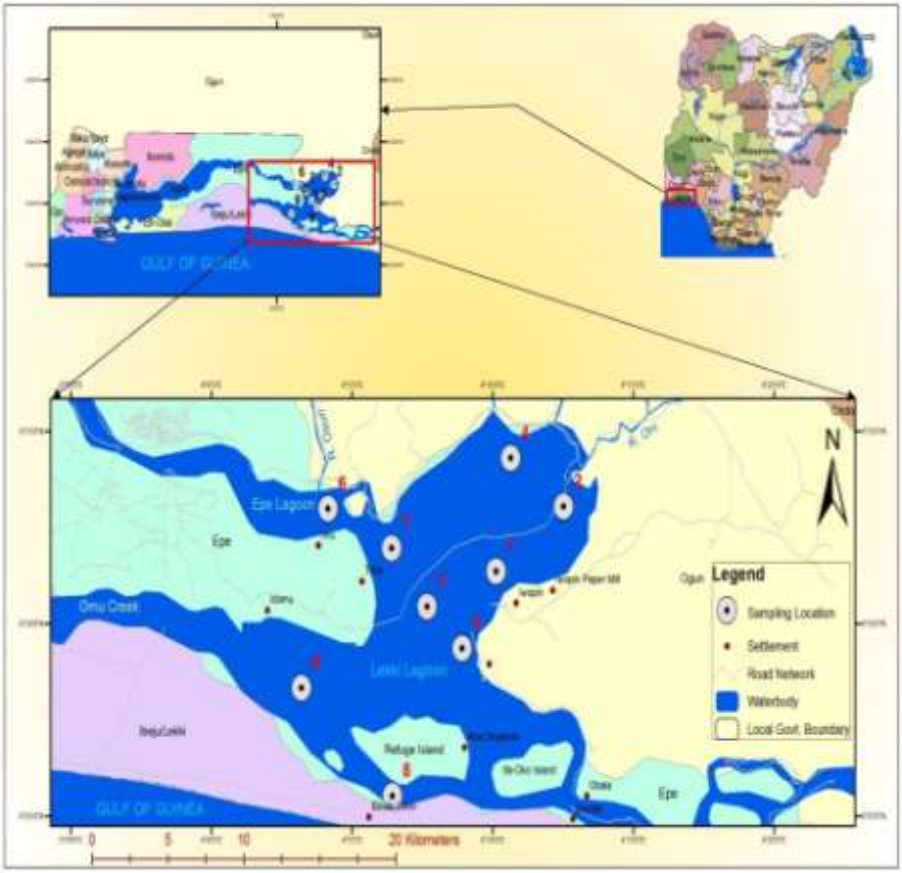
Sharma *et al*. (2015). Samples were obtained during daylight between 11am and 2pm so as to minimize variations as a result of the diurnal migration of plankton (Adesalu, 2012).

Identification of Phytoplankton

Samples containing phytoplankton were allowed to settle down on getting to the laboratory and the supernatant was decanted to have about 10ml concentrates for each sample. About five drops of each concentrated sample were examined under a binocular microscope at different magnifications (X100 and X400) and identified usingstandard guides (Jeje and Fer-nando, 1986; APHA, 1998; Krammer and Bertalot, 2000). Phytoplankton was recorded in individual/millilitre (ind/ml).

Analysis of Environmental Parameters

Electrical conductivity, pH, depth, transparency and surface water temperature were determined *in-situ.* Surface water temperature, pH and electrical conductivity were determined using a pH-EC meter (Model: HANNA HI 98129), depth was determined using a graduated pole, while transparency was measured with a secchi-disc,salinity, alkalinity, phosphate, sulphate, nitrate, dissolved oxygen, biological oxygen demand, total suspended solids and total dissolved solids were determined in the laboratory following standard procedures (APHA, 2005).



Key: 1=Brushpark, 2=River Oni, 3= Open water, 4= River Mosafejo, 5= Imeki, 6= River Osun, 7=Emina, 8=EbuteLekki, 9=Yuboye.

Fig. 1: Map of Lekki lagoon showing the sampling stations.

Data analyses

Data collected during the study were subjected to descriptive, inferential and multivariate analysis using Paleontological statistics (PAST) and PRIMER version 7.0. The biota and water quality parameters data were pre-treated before carrying out

the multivariate analysis as suggested by Clarke and Gorley, (2015). The biota abundance data were pretreated by standardization (to show relative composition) and square-root transformed in order to avoid the analysis to be dominated by certain species and to ensure that the analysis was community-based rather than just being about a few numerically abundant species. Pretreatment of environmental parameters data was achieved through normalization and logarithmic transformation (where strong skewness was observed on carrying out Draftsman plot). Normalisation was done by subtracting the mean (across all samples) from each entry of a single variable and dividing by the standard deviation of that variable. This was done in order to set the variables on a common scale since variables such as environmental parameters are known not to have a comparable scale of measurement. The basic multivariate analyses performed included Resemblance Matrices calculation (by Bray-Curtis Similarity for biota and Euclidean distance for water quality parameters), Cluster analysis (by hierarchical agglomerative clustering), Similarity Profile (SIMPROF) test, non-metric Multidimensional Scaling (nMDS), Principal Component Analysis (PCA), Similarity Percentage (SIMPER), Permutation-based Multivariate Analysis of variance (PERMANOVA) and Community structure.

RESULTS

Distribution and relative abundance of phytoplankton

Table 1 shows the spatial distribution and relative abundance of phytoplankton in Lekki lagoon during the study. A total of thirty-seven (37) species from six (6) divisions were recorded. In terms of number of species recorded per division, Chlorophyta had the highest number (14) of species, followed by Bacillariophyta (11), while Ochrophyta had the least (1) number of species. *Ankistrodesmus* sp. was the most predominant species in Stations 1 and 4 (40.27% and 28.56% respectively).

Table 1: Spatial distribution and relative abundance of phytoplankton in Lekki lagoon (nos/ml)

			STATIONS								
CLASS	ORDER	SPECIES	1	2	3	4	5	6	7	8	9	TOTAL
CHLOROPHYTA	a. Sphaeropeales	*Ankistrodesmus sp*	800(40.27)	1743(14.02)	3759(15.22)	6783(28.56)	3213(15.76)	147(1.41)	2289(10.61)	-	1386(11.17)	37521
		Selenastrum sp	-	-	-	42(0.18)	42(0.21)	-	-	-	315(2.54)	399
		Kirchneriella sp.	-	840(6.76)	-	-	-	-	-	-	-	840
	b. Chlamydomonadales	*Eudorina sp.*	-	63(0.51)	-	504(2.12)	735(3.61)	-	714(3.31)	147(1.46)	735(5.92)	2898
		Characium sp.	-	651(5.24)	210(0.85)	-	63(0.31)	1638(15.73)	1512(7.01)	-	357(2.88)	4431
		Botryococcus sp.	1743(8.77)	378(3.04)	2982(12.08)	420(1.77)	3024(14.83)	105(1.01)	189(0.88)	21(0.21)	693(5.58)	9555
	c. Chlorococcales	*Hydrodictyon sp.*	-	315(2.53)	-	210(0.88)	-	-	-	210(2.08)	147(1.18)	882
		Crucigenia sp.	-	588(4.73)	1617(6.55)	-	-	294(2.82)	3906(18.11)	-	105(0.85)	6510
	d. Oedogoniales	*Bulbochaete sp.*		882(7.10)	-	3234(13.62)	294(1.44)	-	1848(8.57)	714(7.08)	3234(26.1)	10206
	e. Microsporales	*Microspora sp.*	-	399(3.21)	21(0.09)	1029(4.33)	-	21(0.20)	-	-	-	1470
	f. Ulotrichales	*Ulothrix sp.*	273(1.37)	-	1029(4.17)	-	273(1.34)	105(1.01)	-	-	-	1680
	g. Oocystales	*Protococcus sp.*	-	2604(20.95)	1722(6.97)	2100(8.84)	2226(10.93)	3381(32.46)	2394(11.10)	3087(30.63)	819(6.60)	18333
	h. Tetrasporales	*Tetraspora sp.*	-	777(6.25)	2499(10.12)	168(0.71)	-	945(8.27)	1680(7.79)	147(1.46)	588(4.74)	6720
	i. Chorellales	*Chorella sp.*	-	-	1113(4.51)	-	-	462(4.44)	-	-	-	1575
BACILLARIOPHYTA	a. Tabellariales	*Diatoma sp.*	651(3.28)	-	105(0.43)	-	168(0.82)	-	-	-	-	924
		Tabellaria sp.	-	126(1.01)	525(2.13)	-	1995(9.78)	63(0.61)	-	-	21(0.17)	2730
	b. Naviculales	*Navicula sp.*	1470(7.40)	-	735(2.98)	-	672(3.30)	-	-	735(7.28)	378(3.05)	3990
		Pinnularia sp.	84(0.42)	-	105(0.43)	-	294(1.44)	-	294(1.36)	-	-	777
		Gyrosigma sp.	1764(8.88)	-	105(0.43)	420(1.77)	1470(7.21)	-	-	399(3.96)	-	4158
	c. Thalassiophysales	*Amphora sp.*	-	588(4.73)	252(1.02)	-	-	-	-	-	-	840
	d. Thalassionemales	*Cyclonella sp.*	1092(5.50)	-	-	1365(5.75)	105(0.52)	84(0.81)	567(2.62)	399(3.96)	63(0.51)	3675
	e. Cymbellales	*Cymbella sp.*	-	189(1.52)	-	-	-	-	504(2.34)	-	-	693
	f. Rhopalodiales	*Epithemia sp.*	-	273(2.20)	-	-	-	42(0.40)	-	609(6.04)	-	924
	g. Eunotiales	*Eunotia sp.*	357(1.80)	-	-	210(0.09)	210(1.03)	231(2.22)	-	-	-	819
	h. Fragilariales	*Fragilaria sp.*	1155(5.81)	-	420(1.70)	210(0.88)	-	-	-	-	357(2.88)	2142
CYANOPHYTA	a. Chroococcales	*Merocystis sp.*	-	42(0.38)	567(2.30)	-	-	-	-	-	-	609
	b. Oscillatoriales	*Oscillatoria sp.*	-	-	84(0.34)	168(0.71)	-	-	294(1.36)	-	-	546
		Phormidium sp.	210(1.06)	1176(9.46)	5103(20.66)	2709(11.41)	3780(18.54)	714(6.86)	1974(9.15)	1827(18.13)	126(1.02)	17619
	c. Spirulinales	*Spirulina sp.*	1071(5.39)	-	-	1344(5.66)	126(0.62)	21(0.20)	483(2.24)	42(0.42)	-	3087
CHAROPHYTA	a. Desmidiales	*Cosmarium sp.*	443(2.22)	-	-	-	357(1.75)	357(3.43)	-	840(8.33)	-	1995
		Closterium sp.	1134(5.71)	357(2.87)	1743(7.06)	315(1.33)	1344(6.59)	147(1.41)	-	693(6.88)	-	5733
	b. Zygnematales	*Netrium sp.*	-	-	-	273(1.15)	-	336(3.23)	-	-	-	609
		Spirogyra sp.	-	-	-	-	-	-	63(0.29)	-	84(0.68)	147
OCHROPHYTA	a. Mischococcales	*Ophiocytium sp.*	-	420(3.38)	-	21(0.09)	-	-	21(0.10)	-	-	462
EUGLENOPHYTA	a. Euglenales	*Euglena sp.*	-	21(0.17)	-	2205(9.28)	-	609(5.85)	2835(13.15)	210(2.08)	-	5880
		Phacus sp.	-	-	-	210(0.88)	-	798(7.66)	-	-	84(0.68)	1092
	a. Dinoflagellata	*Ceratium sp.*	420(2.11)	-	-	-	-	-	-	-	2919(23.5)	3339
TOTAL			19866	12432	24696	23753	20391	10416	21567	10099	12411	1855630

*****Values in parenthesis are percentages of relative abundance (%) of phytoplankton species

Key: 1=Brushpark, 2=River Oni, 3= Open water, 4= River Mosafejo, 5= Imeki, 6= River Osun, 7=Emina, 8=Ebute Lekki, 9=Yuboye

The least abundant species in Station1 was *Pinnularia* (0.43%) and Station 2 was *Eunotia* sp. and *Ophiocytium* sp. (0.09% each). *Protococcus* sp. was predominant in Stations 2, 6 and 8 with relative abundance of 20.95%, 32.46% and 30.63% respectively while the least predominant species in Station 2 was *Euglena* sp.; Station 6 were *Spirulina* sp. and *Microspora* sp. (0.20% each), Station 8; *Spirulina* sp. (0.42%). Stations 3 and 5 were predominated by *Phormidium* sp. (20.66% and 18.54% respectively), while Stations 7 and 9 were predominated by *Crucigenia* sp. (18.11%) and *Bulbochaete* sp. (26.06%) respectively. Of all the species recorded, only *Botyrococcus* sp. and *Phormidium* species were distributed across all the Stations.

Environmental Parameters

The mean, standard error and analysis of variance of the environmental parameters of Lekki lagoon for all the nine sampling Stations during the study are presented in Table 2. The water temperature of the Lagoon ranged from 27.96 ± 2.96 $^{\circ}$C in Station 3, to 29.35 ± 1.57 $^{\circ}$C in Station 9. The highest mean Depth was recorded in Station 5 (5.24±1.09 m) followed by Station 8(4.13±0.60 m), while the lowest mean value was recorded in Station 4 (1.07±0.35 m). The highest mean pH value was recorded in Station 6 (7.59±0.79) while the lowest mean value was recorded in Station 2 (6.75±0.36).

Table 2: Analysis of variance of environmental parameters in Lekki lagoon

	STATIONS								
PARAMETERS	1	2	3	4	5	6	7	8	9
Temperature (°C)	28.74±1.81^{a}	28.78±2.79^{a}	27.96±2.96^{a}	28.50±2.45^{a}	28.98±2.23^{a}	28.68±2.83^{a}	28.21±2.61^{a}	28.80±2.02^{a}	29.35±1.57^{a}
pH (m)	7.31±0.58^{b}	6.75±0.36^{ab}	7.04±0.49^{ab}	7.14±0.56^{ab}	6.93±0.54^{ab}	7.59±0.79^{ab}	7.14±0.35^{ab}	7.18±0.54^{ab}	7.24±0.28^{a}
Depth (m)	1.42±0.75^{c}	2.18±0.52^{dc}	2.20±0.87^{cdc}	1.07±0.35^{cdc}	5.24±1.09^{cd}	1.57±0.89^{cd}	2.25±0.73^{c}	4.13±0.60^{b}	1.26±0.55^{a}
Transparency (µs/cm)	0.69±0.02^{c}	0.59±0.03^{bc}	0.55±0.08^{bc}	0.65±0.07^{ab}	0.59±0.01^{ab}	0.56±0.02^{ab}	0.67±0.01^{ab}	0.72±0.02^{ab}	0.42±0.03^{a}
EC	792.06±73.01^{b}	145.45±72.81^{b}	398.11±23.12^{ab}	225.28±155.28^{ab}	185.39±47.67^{ab}	238.71±60.79^{ab}	629.17±39.19^{ab}	309.61±71.98^{ab}	640.78±97.32^{a}
Sulphate (mg/l)	74.21±4.23^{a}	39.35±9.05^{a}	53.17±8.83^{a}	45.84±8.78^{a}	42.81±8.28^{a}	54.71±9.30^{a}	73.52±4.58^{a}	52.09±9.12^{a}	69.00±6.58^{a}
Phosphate (mg/l)	0.04±0.01^{b}	0.02±0.00^{b}	0.01±0.00^{b}	0.04±0.01^{ab}	0.02±0.00^{ab}	0.01±0.00^{ab}	0.08±0.03^{ab}	0.01±0.00^{ab}	0.02±0.00^{a}
Alkalinity (mg/l)	1.27±0.31^{a}	1.50±0.07^{a}	1.97±0.52^{a}	2.36±0.40^{a}	1.65±0.59^{a}	2.25±1.56^{a}	1.68±0.98^{a}	2.43±0.94^{a}	2.10±0.34^{a}
DO (mg/l)	6.63±0.99^{b}	6..63±1.05^{ab}	7.43±1.20^{ab}	6.75±1.03^{ab}	6.53±1.21^{ab}	6.68±1.21^{ab}	7.37±0.92^{ab}	6.46±1.02^{a}	6.22±1.07^{a}
Salinity (‰)	0.52±0.23^{b}	0.28±0.02^{b}	0.32±0.05^{b}	0.42±0.02^{b}	0.29±0.03^{b}	0.29±0.07^{ab}	0.43±0.02^{ab}	0.31±0.06^{ab}	0.39±0.06^{a}
Nitrate (mg/l)	5.96±0.59^{a}	3.52±0.27^{a}	2.87±0.23^{a}	3.31±0.56^{a}	4.15±0.30^{a}	3.045±0.27^{a}	4.73±0.25^{a}	4.43±0.50^{a}	4.10±0.42^{a}
TSS (mg/l)	0.16±0.02^{a}	0.04±0.00^{a}	0.07±0.02^{a}	0.08±0.01^{a}	0.15±0.03^{a}	0.21±0.03^{a}	0.07±0.01^{a}	0.07±0.02^{a}	0.16±0.02^{a}
BOD (mg/l)	2.08±0.83^{a}	3.05±1.30^{a}	2.85±0.17^{a}	2.38±0.77^{a}	3.09±0.14^{a}	3.17±0.18^{a}	2.21±0.92^{a}	2.04±0.13^{a}	3.26±0.12^{a}
TDS (mg/l)	407.57±34.7^{c}	78.18±4.08^{dc}	211.55±41.09^{ab}	122.78±38.19^{ab}	117.69±72.18^{ab}	147.36±36.18^{abc}	478.27±36.61^{abc}	162.06±95.09^{ab}	457.11±37.06^{a}

*BOD-Biochemical oxygen demand, TSS-Total suspended solids, DO-dissolved oxygen, TDS-total suspended solids.
Key: 1-Brushpark, 2-River Oni, 3- Open water, 4-River Mosafejo, 5- Imeki, 6-River Osun, 7-Emina, 8- Lekki, 9-Yuboye

Transparency ranged between 0.42±0.03 m and 0.72±0.02 m in Stations 9 and 8 respectively. Highest mean conductivity was recorded in Station 1 (792.06±73.01 µs/cm) while the lowest mean value was recorded in Station 2, (145.45±72.81 µs/cm). Stations 1 and 7 recorded the highest mean sulphate concentrations (74.21±4.23 and 73.52±4.58 mg/L respectively) while the lowest mean value was recorded in Station 2 (39.35±9.05 mg/L). Highest mean phosphate was recorded in Station 7 (0.08±0.03 mg/L), while lowest mean values were recorded in Stations 3, 6 and 8 (0.01±0.00 mg/L each). Nitrate values ranged from 5.96±0.59 mg/L in Station1 to 2.87±0.23 mg/L in Station3. Highest mean alkalinity was recorded in Station 8 (2.43±0.94 mg/L), while the lowest mean value was recorded in Station 1 (1.27±0.31 mg/L). Salinity was highest in Station 1 (0.52±0.23 $^{0}/_{00}$) and lowest at Station 2 (0.28±0.02 $^{0}/_{00}$). The highest mean value of dissolved oxygen was recorded in Station 3 (7.43±1.20 mg/L), followed by Station 7 (7.37±0.92 mg/L), while the lowest mean value was recorded in Station 9 (6.22±1.07 mg/L). Biochemical Oxygen Demand (BOD) ranged between 2.04 and 3.26 mg/l (Station 8 and 9 respectively).

The highest mean Total Suspended Solids (TSS) was recorded in Station 6 (0.21±0.03 mg/L), while lowest mean value was recorded in Station 2 (0.04±0.00 mg/L). Highest mean of Total Dissolved Solid (TDS) was recorded in Station 7 (478.27±36.61 mg/L), while the lowest mean values was recorded in Station 2 (78.18±4.08 mg/L). Temperature, sulphate, alkalinity, nitrate, total suspended solids, and biological oxygen demand showed no significant ($p>0.05$) spatial variation. The reverse ($p<0.05$) was however observed for pH, depth, transparency, conductivity, phosphate, dissolved oxygen, salinity and total dissolved solid. Temperature, sulphate, alkalinity, nitrate, total suspended solids, and biological oxygen demand showed no significant ($p>0.05$) spatial variation, however, pH, depth, transparency, conductivity, phosphate, dissolved oxygen, salinity and total dissolved solids were significantly different among stations.

Multivariate Analyses

Community Structure

Table 3 shows the community structure of phytoplankton in the study area. Station 3 had the highest number of individuals (25809 ind/ml.), followed by Station 4 (22407 ind/ml.), Station 7 (21084 ind/ml.), Station 5 (20265 ind/ml.), while Station 8 had the lowest number of individuals (10038 ind/ml.). The highest number of species was recorded in Station 3 (21), followed by Stations 2 and 6 (20 each), and Stations 5 and 9 (18 species each), Station 7 (16), while Station 1 had 14 species. Margalef species richness decreased in the order of 6>2>3>4>9>5>7>8>1. Station 2 had the highest evenness index followed by Station 7 while Station 1 had the least. Shannon diversity and Simpson dominance indicies ranged from 2.012-2.589 and 0.782-0.901 respectively. The highest values of the two indicies were recorded in Station 2, and the least value in Station 1.

Table 3: Community structure of phytoplankton in Lekki lagoon

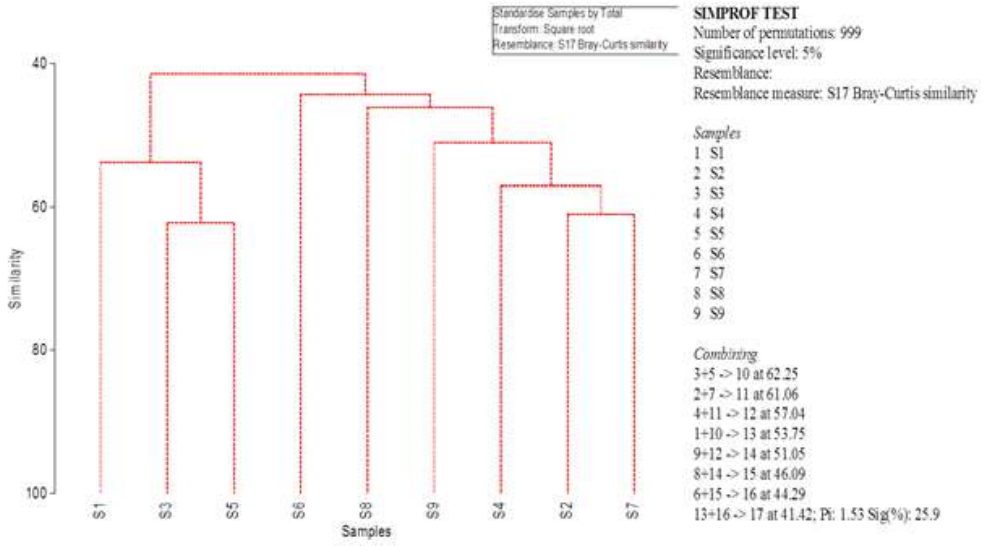
Diversity indices	1	2	3	4	5	6	7	8	9
Number of species	14	20	21	20	18	20	16	14	18
Number of individuals	18795	12432	25809	22407	20265	10857	21084	10034	12411
Margalef species richness (d)	1.321	2.015	1.969	1.897	1.714	2.405	1.507	1.411	1.804
Pielou's evenness index (J)	0.763	0.864	0.828	0.746	0.817	0.787	0.859	0.822	0.774
Shannon diversity index (H')	2.012	2.589	2.520	2.236	2.361	2.358	2.383	2.169	2.237
Simpson dominance index	0.782	0.901	0.897	0.847	0.883	0.854	0.892	0.842	0.847

Key: 1=Brushpark, 2=River Oni, 3= Open water, 4= River Mosafejo, 5= Imeki, 6= River Osun, 7=Emina, 8=EbuteLekki, 9=Yuboye

Similarity in phytoplankton community among stations

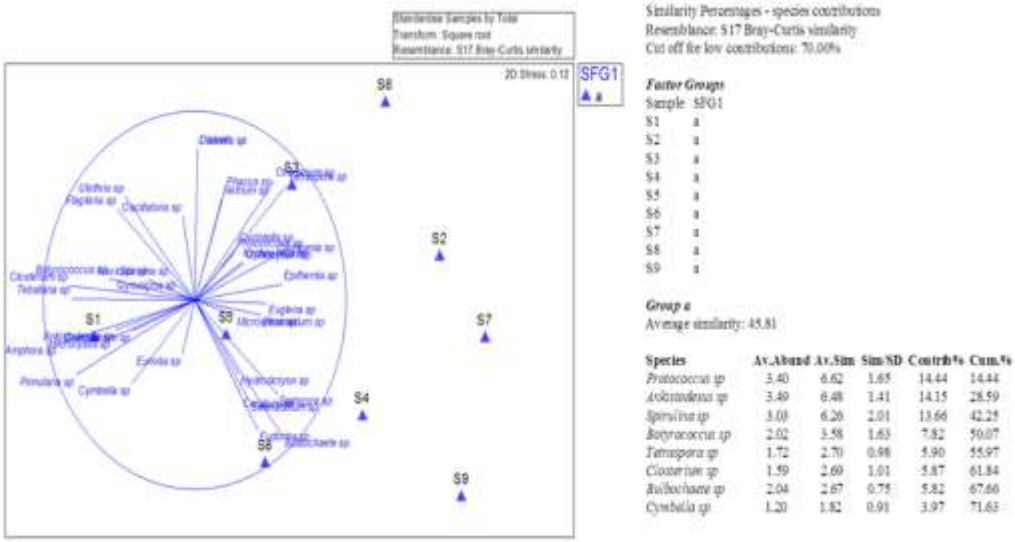
The hierarchical cluster analysis of the stations based on the abundance and distribution of phytoplankton is presented in Figure 2. Two clusters were observed at a Bray-Curtis similarity level of 41.42%. SIMPROF TEST showed that the two clusters were not significantly ($p>0.05$) different. Stations 1, 3 and 5 formed the first cluster at 53.75% similarity level, while Stations 6, 8, 9, 4, 2 and 7 formed the second cluster at a similarity level of 44.29%. The non-metric multidimensional scaling (nMDS) map (Figure 3) also categorized all the stations into a single group (*a*) showing no significant ($p>0.05$) difference among them. The vector plot showed that species such as *Diatoma* sp., *Tetraspora* sp., *Characium* sp., *Bulbochaete* sp., *Pinullaria* sp., *Amphora* sp. and *Ulothrix* sp. had larger effect on the ordinations of the stations compared to other phytoplankton species. Further analysis using Similarity Percentage (SIMPER) showed that *Protococcus* sp, *Ankistrodesmus* sp.,

Spirulina sp., *Botyrococcus* sp., *Tetraspora* sp., *Closterium* sp., *Bulbochaete* sp., and *Cymbella* sp. were responsible for the similarity among the Stations. However, *Protococcus* sp., *Ankistrodesmus* sp. and *Spirulina* sp. contributed most (14.44%, 14.15% and 13.66% respectively) to the average similarity (45.81%) observed.



Key: 1=Brushpark, 2=River Oni, 3= Open water, 4= River Mosafejo, 5= Imeki, 6= River Osun, 7=Emina, 8=EbuteLekki, 9=Yuboye

Fig. 2: Cluster analysis of sampling Stations based on phytoplankton abundance

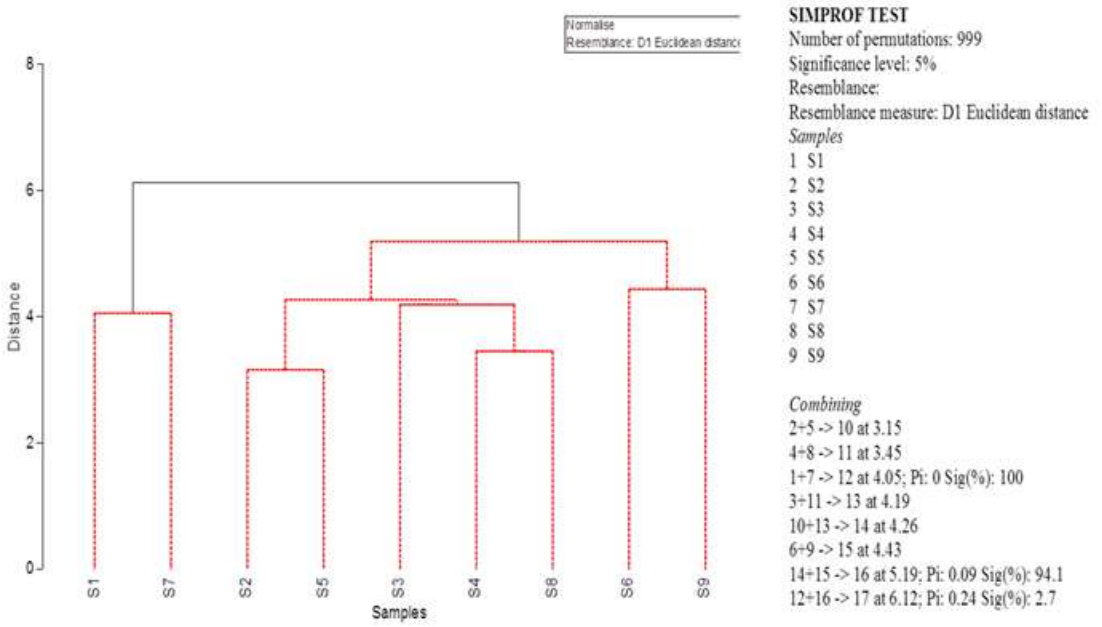


Key: 1=Brushpark, 2=River Oni, 3= Open water, 4= River Mosafejo, 5= Imeki, 6= River Osun, 7=Emina, 8=EbuteLekki, 9=Yuboye

Fig. 3: Non-metric multidimensional scaling of sampling stations in terms of abundance and distribution of phytoplankton.

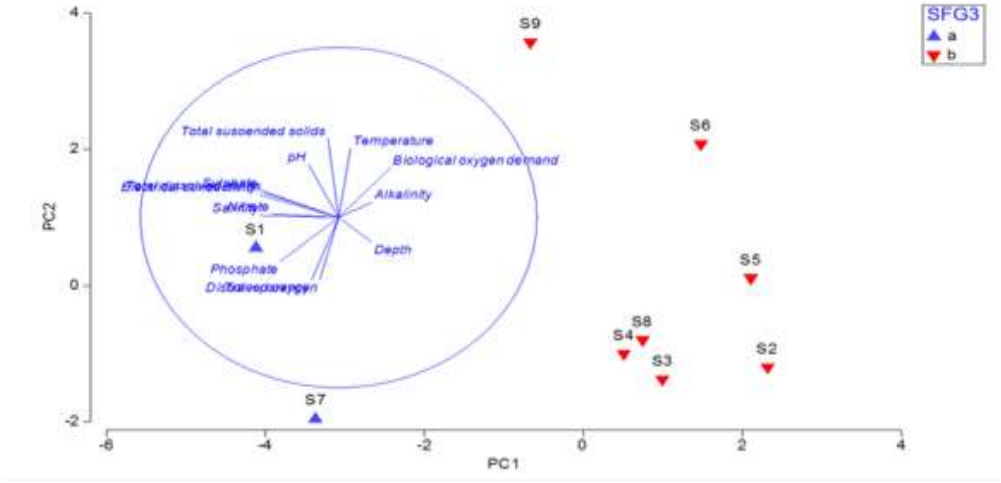
Similarity/dissimilarity in environmental parameters among stations

Figure 4 shows the hierarchical cluster analysis of the sampling stations based on environmental parameters. Two distinct clusters were observed; Stations 1 & 7 and Stations 2, 5, 3, 4, 8 & 6 at Euclidean distance of 6.12. Stations 1 & 7 formed a cluster at a distance of 4.05, while Stations 2, 5, 3, 4, 8 & 6 formed a cluster at a Euclidean distance of 5.19. The Similarity Profile (SIMPROF) test showed that Stations 1 & 7 were not significantly different ($p > 0.05$), likewise Stations 2, 5, 3, 4, 8 & 6.



Key: 1=Brushpark, 2=River Oni, 3= Open water, 4= River Mosafejo, 5= Imeki, 6= River Osun, 7=Emina, 8=EbuteLekki, 9=Yuboye.
Fig. 4: Cluster analysis of sampling stations based on environmental parameters

However, the test showed that the two clusters were significantly ($p<0.05$) different. The Principal Component Analysis (PCA) in Figure 5 also separated the stations into two groups (*a* and *b*). The vector plots revealed that total suspended solids, temperature, dissolved oxygen, sulphate, phosphate, alkalinity and nitrate were the environmental drivers that most influenced the separations observed in the ecosystem. However, the vector plot did not show how significant the influences were.



Key: 1=Brushpark, 2=River Oni, 3= Open water, 4= River Mosafejo, 5= Imeki, 6= River Osun, 7=Emina, 8=EbuteLekki, 9=Yuboye.
Fig. 5: Principal Component Analysis (PCA) of the Stations in terms of the environmental parameters

The Similarity percentage (SIMPER) test showed the environmental parameters that were responsible for the similarity (low Euclidean distance) among stations in the same group and those that were responsible for the dissimilarity (high distance) between groups *a* and *b* observed in the cluster analysis and PCA map. Group *a* (Stations 1 and 7) were similar mainly in terms of dissolved oxygen which contributed 20.33% of the percentage similarity followed by total suspended solids, temperature and nitrate with 13.31%, 10.36% and 9.85% contribution respectively.

On the other hand, total suspended solids, temperature and transparency were responsible for the similarity among stations in group *b* with 10.49%, 9.99%, and 9.38% similarity contribution respectively. The test also showed that phosphate contributed most (11.12%) to the average squared distance (dissimilarity) between groups a and b, followed by nitrate (10.20%), salinity (9.9%), electrical conduc-tivity (9.35%), sulphate (9.20%), total dissolved solids (8.49%), alkalinity (7.42%) and biological oxygen demand (6.95%). Permutation-based Analysis of Variance (PERMANOVA) confirmed that there was a significant ($p<0.05$) difference between the two groups observed in the analysis.

Relationship between phytoplankton distribution and environmental parameters

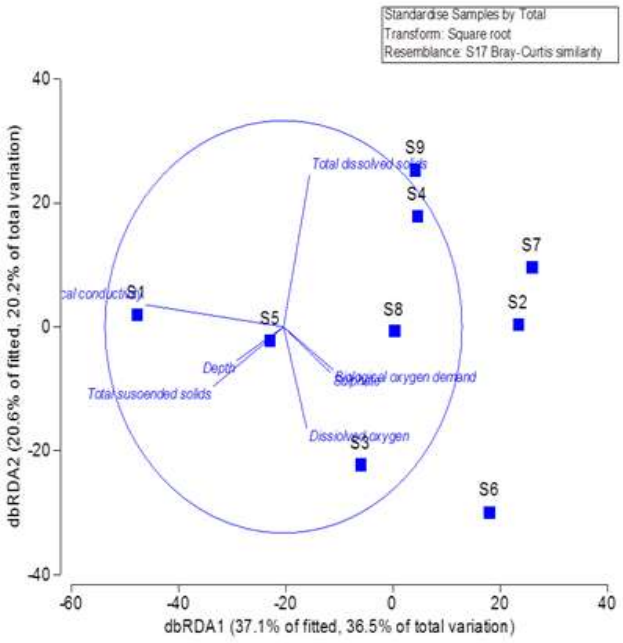
Table 4 shows the result of the Biota and Environmental Matching (BEST) test. The result showed that the best positive correlation between phytoplankton abundance and environmental parameters was when transparency, nitrate and total suspended solids were combined. Positive correlation was also observed when transparency, nitrate, salinity and total suspended solids were combined. However, none of the correlations was significant ($p<0.63$), significant level of sample statistics).

Table 4: BEST and environmental matching for Phtyoplankton and Environmental Parameters

No. Vars	Corr.	Selections
3	0.380	Tr,Ni,Total s
4	0.342	Tr,Ni,Sa,Total s
5	0.331	pH,Tr,El,Ni,Sa
3	0.329	Tr,Ni,Sa
4	0.326	pH,Tr,Ni,Sa
5	0.311	pH,Tr,Ni,Al,Total s
4	0.308	Tr,Ni,Al,Total s
4	0.307	Tr,Ni,Di,Total s
3	0.302	Tr,Al,Total s
5	0.301	Tr,Ni,Sa,Di,Total s

*****Te=Temperature, De-Depth, Tr=Transparency, El=Electrical conductivity, Su=Sulphate, Pho=Phosphate, Ni=Nitrate, Al=Alkalinity, Sa=Salinity, Di=Dissolved oxygen, Bi=Biochemical oxygen demand, Total d=Total dissolved solids, Total s=Total suspended solids.
* Significance level of sample statistic: 63%.

Distance-based Linear Modelling (distLM) using Best selection procedure and Bayesian Information Criterion showed that a model combining depth, electrical conductivity, sulphate, dissolved oxygen, biological oxygen demand, total dissolved solids and total suspended solids can best be used to describe the pattern of distribution and abundance of phytoplankton community observed in this study ($r^2=0.98$). Figure 6 shows the distance-based Redundancy Analysis (dbRDA) plot of the best relationship observed. The plot showed that the model explained 56.7% of the total variation.



Biota and/or Environment matching (BEST)
Significance level of sample statistic: 63%
Number of permutations: 99 (Random sample)
Number of permuted statistics greater than or equal to Rho: 62
Best results

No.Vars	Corr.	Selections
3	0.380	Tr,Ni,Total s
4	0.342	Tr,Ni,Sa,Total s
5	0.331	pH,Tr,El,Ni,Sa
3	0.329	Tr,Ni,Sa
4	0.326	pH,Tr,Ni,Sa
5	0.311	pH,Tr,Ni,Al,Total s
4	0.308	Tr,Ni,Al,Total s
4	0.307	Tr,Ni,Di,Total s
3	0.302	Tr,Al,Total s
5	0.301	Tr,Ni,Sa,Di,Total s

Distance-based Linear Model (DistLM)
Selection criterion: BIC
Selection procedure: Best
VARIABLES

1	Temperature	Trial
2	pH	Trial
3	Depth	Trial
4	Transparency	Trial
5	Electrical conductivity	Trial
6	Sulphate	Trial
7	Phosphate	Trial
8	Nitrate	Trial
9	Alkalinity	Trial
10	Salinity	Trial
11	Dissolved oxygen	Trial
12	Biological oxygen demand	Trial
13	Total dissolved solids	Trial
14	Total suspended solids	Trial

BIC	R^2	RSS	No.Vars	Selections
67.763	0.15184	10282	1	8
67.546	0.35138	7863.4	2	5,13
67.21	0.51055	5933.7	3	3,7,10
66.405	0.64936	4250.9	4	3,4,7,10
64.272	0.78329	2627.3	5	5,6,11,12,14
60.039	0.89392	1286	6	5,6,10-12,14
45.986	0.98256	211.39	7	3,5,6,11-14

Key: 1=Brushpark, 2=River Oni, 3= Open water, 4= River Mosafejo, 5= Imeki, 6= River Osun, 7=Emina, 8=EbuteLekki, 9=Yuboye
Fig. 6: distance-based Redundancy Analysis (dbRDA) of the best relationship between environmental parameters of water and the distribution and abundance of phytoplankton in Lekki lagoon.

DISCUSSION

Thirty-seven (37) phytoplankton species from six (6) divisions were recorded during this study. Similarly, Abdul *et al*. (2015) also reported 6 phytoplankton divisions in Ogun state coastal estuary which is a portion of the study area but higher number of species (42) was recordedcompared to the present study. Dushyant and Singh (2013) and Adesalu (2012) recorded higher number of species (117 and 61 respectively) in Tighra Reservoir, India and Majidun creek of Lagos lagoon, Nigeria. However, the number of divisionsrecorded by both authors (4 and 3divisions respectively) was lower than the number recorded in this study. Also, this study recorded higher number of species compared to the 27 species reported by Sharma *et al*. (2016) in Baldi stream. Chlorophyta, Cyanophyta and Bacillariophyta were the three most predominant divisionduring this study; similar trend of phytoplankton succession were reported by Dushyant and Signh (2013), Abdul *et al*. (2015) and Sharma *et al*. (2016). Species such as *Oscillatoria*, *Spirogyra*, *Euglena*, *Phacus* and *Closterium* were less predominant, however, only *Closterium* sp. occurred throughout the period of the study among these species. According to Adesalu (2012), Munawar (1972) and Palmer (1969), the presence of species such as *Euglena*, *Phacus* and *Closterium*is a pointer of organic pollution. The presence of *Spirogyra* sp. has been reported to indicate the eutrophic nature of water bodies (Adesalu and Nwankwo, 2008). Adesalu *et al*. (2008) also stated that the presence of *Oscillatoria* sp. indicates organic pollution in an aquatic environment. This indicates that the Lagoon could be prone to organic pollution.

The phytoplankton community fell into a single group a (as shown by cluster analysis and nMDS) implying that there they were not significantly different across the stations. Contrarily, Tilahun and Ayalew (2015) observed significant differences in phytoplankton distribution between stations in, Selameko Reservoir, South Gondar Ethiopia. The homogeneity in the phytoplankton distribution in this study could be attributed to the similarities in the nitrate concentrations in the sampling stations. This is confirmed by the statement according to Halterman and Toetz (1984), Tilman *et al*. (1986), and Crossetti *et al.* (2014) that dissimilarities in nitrate availability may lead to differences in phytoplankton structure, since half-saturation concentrations for nitrate uptake may vary among phytoplankton species.

Multivariate analysis showed positive but insignificant ($p>0.05$) correlation between phytoplankton abundance and water quality parameters when transparency, nitrate and total suspended solid of the water were combined. Positive correlation was also observed for the combination of transparency, nitrate, salinity and total suspended solids. The analysis also revealed that depth, conductivity, dissolved oxygen, biological oxygen demand, total dissolved solids and total suspended solids can best be used to describe the distribution and abundance of phytoplankton in the study area.This has been confirmed by several authors who reported that the composition and abundance of phytoplankton communities are mainly controlled by nutrients (such as nitrate and phosphate), and light (Daniel 2001; Reynolds, 2006; Altman and Paerl, 2012). Similarly, Nowrouzi and Valavi (2011) observed positive correlation of nutrient (especially nitrate) with phytoplankton abundance in Lake Kalfter.Crossetti *et al*. (2014) reported that the combination of environmental variables that best correlates with the dissimilarities observed in phytoplankton distribution in Lake Mangueira, southern Brazil were pH, turbidity, and nitrate. Similarly, nutrients, pH, conductivity andwater temperature were the set of environmental variables that best explained variationsin phytoplankton functional groups in Lake Mangueira in a six year data set (Crossetti *et al*., 2013). Also, Grabowska *et al*. (2014) observed strong relationship between phytoplankton abundance and total suspended solids in the middle basin of the Bubrza River, Poland. Dushyant and Singh (2013) observed positive correlation between phytoplankton and transparency in Tighra Reservoir, India. Gnanamorthy *et al*. (2013) reported good correlation between phytoplankton and dissolved oxygen and positive correlation between phytoplankton and salinity in Parangipettai waters, India.

CONCLUSION

The method used to show the relationship between phytoplankton and environmental parameters in this study proved effective as it did not only show that a correlation exists between the distribution of phytoplankton and environmental parameters, but also show the set of environmental parameters that best explained the similarity in distribution of phytoplankton among the stations. Also, it showed that biota distribution was influenced by multiple environmental variables rather than a single variable. This study showed that the distribution phytoplankton community in the Lagoon was largely correlated with nutrients (nitrate) and the light penetration (transparency and total suspended solids) combined, while depth, conductivity, dissolved oxygen, biological oxygen demand, total dissolved solids and total suspended solids best described their distribution pattern. Therefore, the use of multivariate analysis in ecological studies is advocated and should be encouraged

among scientists as ecosystems are usually driven by multiple environmental parameters.

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