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# Ecological Status of Opa Reservoir, Obafemi Awolowo University, Ile Ife, based on the Abundance and Diversity of its Planktonic Flora

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## Abstract

A study investigating the spatial and temporal distribution, composition and abundance of plankton in Opa reservoir, Obafemi Awolowo University, Ile-Ife, Southwest Nigeria, was conducted over a period of an annual cycle. The study was undertaken with a view of providing a more recent catalogue of planktonic flora and possibly an update of the reservoir's trophic status. Quantitative net planktons were collected monthly from both the surface and bottom levels at three sampling stations established at the dam site (lacustrine), mid-lake (transition) and upper inflow (riverine) parts of the reservoir. The divisions recorded were Bacillariophyta > Cyanophyta > Chlorophyta > Euglenophyta > Myzozoa > Ochrophyta = Charophyta > Cryptophyta in order of abundance. Vertically, the highest occurrence of species was recorded at the lacustrine bottom station (71 species), while the least occurrence was observed in the transition bottom station (51 species). A total of sixteen plankton species showed significant seasonal variation in abundance during this study period, while only seven species had significant spatial variation ( $p \le 0.05$ ). Higher abundance was observed during the rainy season (170,797,350 Org/m<sup>3</sup> from seventy-two species) than dry season (5,138,400 Org/m<sup>3</sup> from forty-nine species). Notable bio-indicator plankton species recorded were *Anabaena circinalis, Anabaena flos-aquae, Microcystis* sp., *Aphanocapsa litoralis* and *Microcystis aeruginosa*. Some other pollution indicator species recorded were *Synedra ulna, Oscillatoria agardhii, Phacus* sp., *Surirella* sp., *Closterium* sp., *Aphanocapsa* sp. and *Euglena* sp. Hence, Opa reservoir is very rich in Bacillariophyta (diatoms), followed by Cyanophyta (blue-green) and Chlorophyta (green algae), which are known to characterize eutrophic lakes.

Keywords: bio-indicator species; phytoplankton; taxonomic composition; trophic status; water quality

## Introduction

By the virtue of the position of phytoplankton at the base of the aquatic food web, they stand as the most important factor of production in the aquatic ecosystem (Moshood, 2009). Various ecological changes such as presence, absence, replacement or addition of species can also be monitored using the phytoplanktonic community as a potential tool (Codd, 1995). Therefore, the presence of phytoplankton in reservoirs goes a long way in determining the sustainability and productivity of most aquatic habitats. The growth significance and sustainability of any ecosystem is largely accounted for by the diversities of phytoplankton and their abundance. Both factors are equally related and do change as their interaction is influenced by the environment and population processes (Benedict and Gabriel, 2012).

Phytoplankton are known to be very important in estimation of the potential fish yield (Hecky and Kling, 1981), productivity (Park *et al.*, 2003), water quality (Walsh *et al.*, 2001), energy flow (Simciv, 2005), trophic status (Reynolds, 1999), and water management (Beyruth, 2000). Phytoplankton such as *Microcytis* sp., *Anabaena* sp., *Oscillatoria* sp. are known indicators of pollution while the presence and abundance of Chlorophyceae are indicative of the environment's suitability for fish production (Olasehinde and Abeke, 2012). The suitability of microalgal components as bio-indicators of the water condition is because they confer more tolerance than many other biotas used for monitoring environmental changes (Nwankwo and Akinsoji, 1992).

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Adesakin *et al.* (2017) reported direct discharge of untreated municipal/industrial waste as well as run off from agricultural areas into Opa reservoir, with resultant significant effects on the reservoir's physicochemical parameters both temporally and spatially and this may possibly inflict a level of risk to the inhabiting aquatic biota. This, coupled with the fact that the last published record of plankton research carried out on Opa reservoir was that of Rotifers only by Akinbuwa and Adeniyi (1996), lead to the present study. The study seeks to determine the taxonomic composition, diversity and abundance of phytoplanktonic organisms of Opa reservoir with respect to spatial and temporal distribution, as well as to assess the water quality and trophic status of the reservoir with a view to determining the effects of the discharges.

#### Materials and Methods

#### Plant material

The study site, Opa reservoir (Fig. 1), is located between longitude 004°31'40"E to 004°32'45"E, and latitude 07°30'N to 07°31'N, within the Obafemi Awolowo University community, Ile-Ife, Southwest Nigeria (Fawole and Arawomo, 2000). The reservoir was established in 1978 by the impoundment of River Opa which sources from Oke-Opa, a set of hills on the Eastern side of the Ife/Ilesha road, Ile-Ife, Osun state (Akinbuwa and Adeniyi, 1996). A number of rivers, including Amuta, Esinmirin, Obudu and Opa unite to form the Opa River. The reservoir has a catchment basin of about 116 km<sup>2</sup> (Akinbuwa and Adeniyi, 1996). Its total surface area is  $0.95 \text{ km}^2$ , while the maximum capacity is about 675,000 m<sup>3</sup> with depth of 0.95 m and 6.4 m at littoral zone and open water respectively (Fawole and Arawomo, 2000). The dam wall made of gravel is about 0.28 km long and about 15 m from the foundation to the crest (Akinbuwa and Adeniyi, 1991). As expected of tropical shallow reservoirs, the water volume during the dry season reduces significantly, whereas in the rainy season, there is increased volume of water inflow resulting from floods leading to high turbidity and a general immersion of the vegetation on the shoreline. This seasonal fluctuation in the water discharge into the reservoir directly affects its water level.

Three sampling stations A, B and C were established on the reservoir denoting the lacustrine, transition and the riverine area of the reservoir along the horizontal axis respectively (Fig. 1). The station A is located at the dam-site just beside the wall, an area assumed to be the deepest part of the lake, station B is the middle of the lake, while the C station is towards the inflow into the lake. A permanent buoy (rubber float) was used to demarcate each of the three sampling stations for ease of subsequent recognition. The distances between the stations and the grid coordinate of each station was taken and recorded using the Global Positioning System (GPS) handheld receiver.

#### Sample collection

Water samples were collected monthly from both the surface and bottom levels at the three sampling stations on the reservoir for a period of one year for phytoplankton analysis between October 2012 and November 2013. An improvised water sampler of 2.5 L capacity was used to take bottom water samples at required depths. Net plankton was sampled by pouring 20 litres of water through plankton net of 50  $\mu$ m mesh size and the net planktonic contents was poured into a 30 ml sampling bottle and preserved with few drops of 5% formaldehyde and a drop of Lugol's solution for examination and identification. The preserved subsample containing plankton was examined in the laboratory using OMAX binocular light compound photo and their scaled pictures taken.

Planktonic population abundance was estimated based on the count records of the final concentrate volume of the



Fig. 1. Map of Opa Reservoir showing the investigated sampling stations (A); Nigeria (B); Osun State (C)

sub-sample with respect to the original volume of water filtered with plankton net and the result was then expressed in organisms per cubic metre of the original water sample.

#### Data analysis

Data collected were subjected to various descriptive and inferential analyses such as the means and standard deviations which gave the depiction of planktonic species abundance with respect to season and location. Analysis of variance was used to compare mean abundance of identified planktonic species, while correlation was used to show the relationship between different planktonic groups. Moreover, Principal Component Analysis (PCA) was used to reduce all interactions into components that also showed the relationship between recorded plankton species as applicable using SPSS Version 21 software (SPSS, 2012). Plankton community structure was determined using Species diversity indices (Shannon and Weaver, 1949), Dominance (Magurran, 2004), Species equitability or evenness (Pielou, 1966) and Species richness (Margalef, 1951; Menhinick, 1964).

#### Results

## Species composition and occurrence

A total of eighty-two (82) species of phytoplankton were recorded belonging to fifty-five genera, forty-five families, thirty-two orders, twelve classes and eight divisions of algae as outlined below in Table 1 and summarized in Fig. 2. A total of 38 species occurred at all the three sampling stations at the surface and/or the bottom. These species include seven species of Cyanobacteria division (Anabaena circinalis, Cylindrospermopsis raciborskii, Microcystis sp., Microcytis aeruginosa, Trachodesmium lacustre, Oscillatoria agardhii and Coelosphaerium sp.). Others are seven species belonging to Chlorophyta (Oedogonium sp., Pediastrum simplex, Pediastrum sp., P. duplex, Volvox aureus, Actinastrum hantzschii and Oocystis sp.) and three species (Euglena oxyuris, Euglena acus and Phacus longicauda) representing Euglenophyta. Furthermore, species found only once throughout the sampling period and specific to a sampling station include Anabaena flos-aquae, Chroococcus sp., Lyngbya sp., Cosmarium depressum, Cosmarium subcrenatum, Schizothrix lardacea, Aphanocapsa litoralis, (Lacustrine); Melosira oamaruensis, Guarnardia flaccida, Thalasionema sp., Prasiola sp., Peridinopsis thompsonii, Trachelomonas caudata (Transition) and Melosira sp. (Riverine).

## Spatial variation

Phytoplankton total abundance ranged from 15,855,150 Org/m<sup>3</sup> at transition (surface) to 53,956,350 Org/m<sup>3</sup> at the lacustrine zone (surafce) of the reservoir. The recorded abundance as compared with zooplankton abundance recorded during the study period showed an average of 112 times (5.71-175.04 times) higher phytoplankton than the zooplankton recorded (Table 2).

The maximum mean abundance was also recorded at the lacustrine surface portion of the reservoir (963,506 Org/m<sup>3</sup>) which had highest number of species (56 species) (Table 2). Horizontally, *Pediastrum* sp., *Actinastrum hantzschii* and *Dinophysis* sp. showed significant difference across zones ( $p \le 0.05$ ), while *Amphipleura jenneri*, *Pediastrum simplex*, *Pediastrum duplex* and *Volvox aureus* showed highly significant spatial difference ( $p \le 0.01$ ) (Table 3).

#### Seasonal variation

Higher abundance was observed during the rainy season (170,797,350 Org/m<sup>3</sup> from seventy-two species) than dry season (5,138,400 Org/m<sup>3</sup> from forty-nine species) (Table 2). The most abundant species during the dry season include *Guinardia flaccida, Cylindrospermopsis raciborskii, Oscillatoria agardhii, Perdiniopsis pernardii, Pediastrum simplex* and *Oedogonium* sp. (Table 3). Species showing highly significant seasonal difference ( $p \le 0.01$ ) include *Nitzschia* sp., *Pediastrum simplex, Pediastrum sp., Pediastrum duplex, Volvox aureus* and *Dinophysis* sp. While *Amphipleura jenneri, Surirella tenara, Chaetocerous subtilis, Anabaena circinalis, Microcystis aeruginosa, Ceratium inflatum, Euglena oxyuris* and *Trachelomonas caudata* all showed statistically signicant difference seasonally ( $p \le 0.05$ ) (Table 4).



Fig. 2. Percentage composition of recorded phytoplankton taxa

# Table 1. Outline classification and taxa composition of the phytoplankton flora

Division	Class	Subclass	Order	Family	Genus/Species
Crunch constru	Courseland	Name and have it as	Nemela	Nama	Are sh sere s sinoire slip
Cyanobacteria	Cyanophyceae	Nostocophycidae	Nostocales	INOstocaceae	Anabaena circinaus
					Anabaena flos-aquae
				Aphanizomenonaceae	Cylindrospermopsis raciborskii
		Oscillatoriophycidae	Chroococcales	Chroococcaceae	Chroococcus sp.
				Microcystaceae	Microcystis sp.
					Microcystis aerosonosa
			Oscillatoriales	Gloeotrichiaceae	Gloeotrichia echinulata
				Microcoleaceae	Arthrospira sp.
					Trachodesmium lacustre
				Oscillatoriaceae	Oscillatoria agardhii
				Oscillatoriaceae	I undu e contont e
					Lyngoya comorta
			<b>N</b> 1 1 1		Lyngbya sp.
		Synechococcophycideae	Pseudanabaenales	Schizotrichaceae	Schizothrix lardacea
			Synechococcales	Merismopediaceae	Aphanocapsa litoralis
				Coelosphaeriaceae	Coelosphaerium sp.
Chlorophyta	Chlorophyceae		Oedogoniales	Oedogoniaceae	Oedogonium sp.
			Sphaeropleales	Hydrodictyaceae	Pediastrum duplex
					Pediastrum simplex
					Pediastrum sp.
					Hydrodictyon reticulatum
			Chlamydomonadales	Volvocaceae	Valvor globulus
			Chiamydomonadaics	volvocaccac	Voluon aman
			011 111	011 11	v olvox aureus
	I rebouxiophyceae		Chlorelalles	Chlorellaceae	Actinastrum hantzschu
					Dictyosphaerium sp.
				Oocystaceae	Oocystis crassa
					Oocystis sp.
			Prasiolales	Prasiolaceae	Prasiola sp.
Euglenophyta	Euglenophyceae		Euglenales	Euglenaceae	<i>Euglena</i> sp.
					Euglena oxyuris
					Euglena viridis
					Euglena acus
					Trachelomonas sp
					Trachelomon ac caudata
				pl	Dhama langianda
				Phacaceae	Pracus longicauda
					Phacus pyrum
Myzozoa	Dinophyceae		Perdianiales	Perdiniaceae	Peridinium sp.
					Peridinium willei
					Peridinium cinctum
				Glenodiniaceae	Peridiniopsis pernardii
					Peridiniopsis thompsonii
			Gonyaulacales	Ceratiaceae	Ceratium inflatum
			Dinophysiales	Dinophysaceae	Dinophysis sp.
Cryptophyta	Cryptophyceae		Cryptomonadales	Cryptomonadaceae	Cryptomonas ovata
Oshaanhum	Sumurombyzee		Symptomotical	Mallamonadassas	Mallomon as a sudata
Ochiophyta	Synthophyceae		Demilie	Demit	Dem: 1:
			Desmidiales	Desmidiaceae	Desmiaium sp.
					Cosmarium depressum
					Cosmarium subcrenatum
Charophyta	Conjugatophyceae		Zygnematales	Closteriaceae	Closterium sp.
					Closterium lanceolatum
				Zygnemataceae	Spirogyra setiformis
					Mougeotia boodlei
Bacillariophyta	Bacillariophyceae	Bacillariophycidae	Naviculales	Amphipleuraceae	Amphipleura jenneri
	1 . 7	.1 . /		1 1	Frustulia sp.
				Naviculaceae	Nanicula en 1
				i vaviculated	Numerican 2
					Navicula sp. 2
					Navicula sp. 3
				Pleurosigmataceae	Pleurosigma sp.
				Stauroneidaceae	Stauroneis sp.
				Pinnulariaceae	Pinnularia viridis
					Pinnularia sp.

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		Bacillariales	Bacillariaceae	Nitzschia sigma
				Nitzschia sp.
				Bacillaria sp.
				Bacillaria paradoxa
		Cocconeidales	Cocconeidaceae	Cocconeis pediculus
		Surirellales	Surirellaceae	Surirella tenara
				Surirella minuta
	Eunotiophycidae	Eunotiales	Eunotiaceae	Eunotia formica
Coscinodiscophyceae	Melosirophycidae	Melosirales	Melosiraceae	Melosira oamaruensis
				Melosira sp.
			Coscinodiscaceae	Hyalodiscus sp.
				Hyalodiscus radiatus
		Rhizosoleniales	Rhizosoleniaceae	Rhizosolenia sp.
				Guinardia flaccida
Fragilariophyceae		Fragilariales	Fragilariaceae	Fragilaria capucina
		Licmophorales	Ulnariaceae	Synedra ulna
		Thalassionematales	Thalassionemataceae	Thalassionema sp.
				Thalassionema nitzschioides
Mediophyceae	Chaetocerotophycidae	Chaetocerotales	Chaetocerotaceae	Chaetocerous subtilis
	Thalassiosirophycidae	Leptocylindrales	Leptocylindraceae	Leptocylindrus danicus
				Leptocylindrus minimus
		Thalassiosirales	Stephanodiscaceae	Stephanodiscus sp.

## Table 2. Spatial and temporal abundance distribution of phytoplankton species

	Τ	1				Spatial						
Organisms	1 er	nporal	Lacus	strine	Transition		Riverine					
Organisms	Dry season	Wet season	Surface	Bottom	Surface	Bottom	Surface	Bottom				
				Cyanob	acteria							
Anabaena circinalis	730,050	38,550	173,700	30,000	113,850	405,750	24,450	20,850				
Anabaena flos-aquae	0	150	0	150	0	0	0	0				
Cylindrospermopsis raciborskii	75,600	3,709,650	1,349,100	717,000	1,086,900	155,400	36,750	440,100				
Chroococcus sp.	150	0	0	150	0	0	0	0				
Microcystis sp.	44,400	41,700	24,450	3,900	24,900	5,100	26,250	1,500				
Microcystis aeruginosa	12,900	1,050	2,250	0	7,500	150	3,150	900				
Gloeotrichia echinulata	0	600	300	0	0	0	150	150				
Arthrospira sp.	1,050	300	1,050	150	0	0	0	150				
Trachodesmium lacustra	1,950	1,350	1,050	150	600	600	600	300				
Oscillatoria agardhii	1,052,100	12,399,150	5,510,550	766,500	96,600	6,589,950	185,700	301,950				
Lyngbya contorta	0	450	0	150	0	0	300	0				
<i>Lyngbya</i> sp.	0	150	0	150	0	0	0	0				
Schizothrix lardacea	0	150	150	0	0	0	0	0				
Aphanocapsa litoralis	0	150	0	150	0	0	0	0				
Coelosphaerium sp.	3,000	3,150	3,450	150	300	0	2,100	150				
				Chloro	phyta							
Oedogonium sp.	31,200	269,100	12,300	170,850	450	103,500	0	13,200				
Pediastrum simplex	303,600	188,100	171,900	96,600	106,800	28,200	75,150	13,050				
Pediastrum sp.	110,850	52,650	56,400	30,150	30,150	27,900	14,100	4,800				
Pediastrum duplex	52,650	22,050	47,550	4,800	13,650	450	7,500	750				
Hydrodictyon reticulatum	0	300	0	150	0	0	0	150				
Volvox globulus	0	1,800	750	0	0	0	1,050	0				
Volvox aureus	5,100	150	750	150	450	0	2,100	1,800				
Actinastrum hantzschii	4,950	450	300	150	1,200	3,450	150	150				
Dictyosphaerium sp.	0	750	450	0	300	0	0	0				
Oocystis crassa	4,500	0	4,200	0	0	0	300	0				
Oocystis sp.	900	21,300	1,350	750	7,050	0	5,850	7,200				
Prasiola sp.	0	300	0	300	0	0	0	0				
				Eugleno	ophyta							
<i>Euglena</i> sp.	600	2,850	450	900	900	600	0	600				
Euglena oxyuris	16,350	4,350	1,800	9,150	1,050	450	0	8,250				
<i>Euglena</i> sp.	750	0	0	600	0	0	150	0				
Euglena acus	36,300	92,550	25,650	26,400	30,900	2,700	28,500	14,700				

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Trachelomonas sp.	1,800	0	0	0	150	0	1,650	0
T. caudata	0	150	0	150	0	0	0	0
Phacus longicauda	4,350	33,750	11,850	6,900	15,150	300	3,600	300
Phacus pyrum	0	7,500	900	0	6,300	0	300	0
				Myzoz	zoa			
Peridinium sp.	3,900	208,050	57,450	96,450	18,000	2,850	35,400	1,800
Peridinium willei	0	3,450	1,950	150	1,,200	0	0	150
Peridinium cinctum	0	32,850	18,000	7,350	6300	450	600	150
Peridiniopsis pernardii	714,150	5,266,200	1,034,550	1,608,150	3,337,350	0	0	300
Peridiniopsis thompsonii	0	150	0	0	0	0	150	0
Ceratium inflatum	1,350	0	0	0	0	450	300	600
Dinophysis sp.	99,450	51,450	30,300	24,150	20,100	12,900	25,800	37,650
				Cryptop	phyta			
Cryptomonas ovata	22,950	100,500	17,250	12,900	8,100	9,150	69,750	6,300
Ochrophyta								
Mallomonas caudata	0	450	0	300	150	0	0	0
Desmidium sp.	5,100	145,200	25,200	4,800	300	120,000	0	0
Cosmarium depressum	0	300	0	300	0	0	0	0
Cosmarium subcrenatum	0	150	0	150	0	0	0	0
				Charop	hyta			
Closterium sp.	0	300	150	0	150	0	0	0
C. lanceolatum	600	450	450	0	150	450	0	0
Spirogyra setformis	0	1,200	0	750	0	0	150	300
Mougeotia boodlei	0	14,554,200	580,650	13,431,300	48,450	144,300	15,750	333,750
				Bacillario	ophyta			
Amphipleura jenneri	750	0	300	450	0	0	0	0
Frustulia sp.	0	150	150	0	0	0	0	0
Navicula sp. 1	600	1,800	150	1,500	150	450	0	150
Navicula sp. 2	150	150	0	0	0	0	150	150
Navicula sp. 3	0	150	0	0	0	0	150	0
Pleurosigma sp.	0	3,150	0	1,650	0	1,500	0	0
Stauroneis sp.	300	150	0	0	0	0	0	450
Pinnularia viridis	150	10,200	8,700	0	1,500	150	0	0
Pinnularia sp.	0	150	0	150	0	0	0	0
Nitzschia sigma	750	450	150	150	450	150	0	300
Nitzschia sp.	2,100	600	450	600	0	300	0	1,350
Bacillaria sp.	0	300	300	0	0	0	0	0
Bacillaria paradoxa	0	5,400	1,350	3,450	300	0	0	300
Cocconeis pediculus	300	300	150	0	300	0	0	150
Surirella tenara	3,150	0	150	0	0	300	600	2,100
Surirella minuta	300	2,400	300	2400	0	0	0	0
Eunotia formica	2,250	412,350	34,950	55,500	10,650	206,250	2,250	105,000
Melosira oamaruensis	300	300	0	0	300	0	0	300
Melosira sp.	0	150	0	0	0	0	150	0
Hyalodiscus sp.	0	450	0	0	0	0	450	0
Hyalodiscus radiatus	300	450	300	0	0	0	150	300
Rhizosolenia sp.	0	1,200	150	750	0	0	300	0
Guinardia flaccida	1,750,650	132,891,000	44,681,700	17,239,800	10,782,150	10,293,300	19,633,650	32,011,050
Fragilaria capucina	0	7,500	450	600	150	5,700	150	450
Synedra ulna	0	1,350	150	0	150	900	0	150
Thalassionema sp.	21,900	0	21,450	0	450	0	0	0
Thalassionema	450	0	0	0	0	0	0	450
nitzschioides	490	0	0	0	Ū	0	U	450
Chaetocerous subtilis	1,200	39,900	10,500	7,200	9,000	3,150	9,450	1,800
Leptocylindrus danicus	9,750	109,350	17,250	19,800	43,800	3,000	26,550	8,700
L. minimus	450	0	0	0	0	300	0	150
Stephanodiscus sp.	0	48,450	8,700	5,100	20,400	300	8,700	5,250
Number of species	40	72	56	5/1	47	20	/2	/0
identified	7/	/ 2	טנ	T	7/	30	+J	7/
Mean	104,865	2,372,185	963,506	636,897	337,344	477,126	470,941	680,623
Total Abundance	5,138,400	170,797,350	53,956,350	34,392,450	15,855,150	18,130,800	20,250,450	33,350,550
Zooplankton Abundance (Bolawa, 2016)	900,600	1,219,300	308,250	222,300	644,700	70,650	570,250	303,750
Ratio of Phytoplankton to Zooplankton	5.71	140.08	175.04	154.71	24.59	256.63	35.51	109.80

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Lah	10 5	A	111		/ A	ctatic	t1CC	chowin	0 0101	<b>11</b> † 1.	cont (	chattal	Variatio	nc 1n 1	shuto	nin	Vton c	nected 1	hund	ance
1 au	ю э.			<u> </u>		statis	ucs	3110 1111	2 3121	1111	cant	patia	variation	115 111 1	JIIYUO	Jian	KLOH S	pecies a	ouna	ance
									, ,											

	Lacustrine	Transition	Riverine	ANOV	γA
Organisms	$Mean \pm SD (Ind/L)$	Mean $\pm$ SD (Ind/L)	$Mean \pm SD (Ind/L)$	F Ratio	р
Pediastrum sp.	3,606.25±6,397.151	2,418.75±4,673.882	787.50±1,154.504	3.698*	0.031
Actinastrum hantzschii	18.75±67.264	193.75±735.485	12.50±42.349	3.165*	0.049
Dinophysis sp.	2,268.75±2,668.407	1,375.00±1,993.740	2,643.75±3,151.029	3.404*	0.040
Amphipleura jenneri	31.25±98.701	0	0	5.376**	0.007
Pediastrum simplex	11,187.50±13,079.383	5,625.00±7,601.959	3,675.00±7,153.382	7.342**	0.001
Pediastrum duplex	2,181.25±3,739.676	587.50±1,358.248	343.75±957.387	13.184**	0.000
Volvox aureus	37.50±127.048	18.75±67.264	162.50±356.386	9.095**	0.000

\*\* Highly Significant
\*Significant

Table 4. ANOVA statistics showing significant seasonal variation among phytoplankton species

	00	<i>c</i> , <i>i</i> , <i>i</i>	-	
Ouron ison a	Dry season	Wet season		ANOVA
Organisins	Mean ± SD	Mean ± SD	F ratio	р
Amphipleura jenneri	250±141.42	0	4.881*	0.030
Surirella tenara	630±743.37	0	4.452*	0.038
Chaetocerous subtilis	400±187.08	2,216.667±1,660.23	6.485*	0.013
Leptocylindrus danicus	886.363636±1,362.00	2,865.789±4,228.21	5.112*	0.027
Anabaena circinalis	48,670±100,770.99	3,255±6,032.18	5.913*	0.018
Microcystis aeruginosa	2,580±2,581.39	525±375	4.924*	0.030
Ceratium inflatum	450±122.47	0	6.146*	0.016
Euglena oxyuris	2,335.71429±1,958.81	862.5±920.85	6.437*	0.013
Trichocerca caudata	0	150±0	4.242*	0.043
Nitzschia sp.	350±70.71	200±70.71	8.889**	0.004
Pediastrum simplex	13,800±13,943.03	4,518.75±5,455.77	14.349**	0.000
Pediastrum sp.	5,834.21053±7,575.24	1,755±1,935	10.125**	0.002
Pediastrum duplex	3,510±4,028.95	1,073.684±1,740.64	8.754**	0.004
Volvox aureus	510±380.66	150±0	16.430**	0.000
Oocystis sp.	300±122.47	777.7778±839.68	7.031**	0.010
Dinophysis sp.	4,735.71429±3,453.75	1,172.093±947.17	29.942**	0.000

\*\* Highly Significant \*Significant

#### Diversity

The species richness recorded in the rainy season was higher than that of the dry season. Simpson's index shows a higher diversity in the dry season than wet and this agrees with the Hill's second diversity, which measured the number of very abundant species to be higher in the dry season than the wet season. Similarly, Shannon's index supports a slightly increase in the number of species and more evenness of distribution in the dry season than the wet. This is more revealed by a higher number of abundant species as Hill's first diversity index (Table 5).

Spatially, however, the maximum richness occurred in the lacustrine surface station, while the lowest occurred in the riverine surface.

The highest diversity occurred in the lacustrine bottom as revealed by both Simpson's and Shannon's indices. The station with the most evenly distributed species is the riverine bottom (Table 5).

## Species association

Principal Component Analysis (PCA) based on correlation analysis, was used to reduce the component factors to those with most influence (Table 6). Twentyeight factors were found to have an Eigen value greater than 1, that is the strongest correlation between the components and the original set of flexible quantities accounting for a cumulative variance of 87.70 but only five were selected.

Component 1 with the highest total variance of 7.56% and maximum Eigen value of 6.28 showed strongest loading (0.881) for abundance of *Bacillaria paradoxa*. Other species that had strong positive loadings within component 1 were *Anabaena flos-aquae*, *Peridinium* sp., *Cosmarium depressum* and *C. subcrenatum*. Seventeen species showed positive correlation within the first component with seven of them having high or moderate loading. Component 2 showed positive correlation for twenty species recorded, which was the highest number of positive correlations recorded (Table 6).

## 294 Table 5. Spatial and temporal diversity of phytoplankton species

		Tem	poral	Spatial						
		1 (11)		Lacu	Lacustrine			Riverine		
		Dry season	Wet season	surface	bottom	surface	bottom	surface	bottom	
Richness Index	R1	3.11	3.64	3.26	3.11	2.71	2.63	2.49	2.77	
Simpson's Index	λ	0.21	0.61	0.70	0.41	0.51	0.45	0.83	0.91	
Hill's 2nd diversity	N2	4.79	1.64	1.43	2.46	1.96	2.20	1.20	1.10	
Shannon's index	H'	1.95	0.89	0.71	1.14	1.03	1.02	0.43	0.27	
Hill's 1st diversity	N1	7.03	2.44	2.03	3.14	2.79	2.77	1.54	1.31	
Evenness Index 1	E4	0.68	0.67	0.71	0.78	0.70	0.79	0.78	0.84	
Evenness Index 2	E5	0.63	0.45	0.42	0.68	0.54	0.68	0.37	0.31	

Table 6. Principal component analysis for the phytoplankton species based on abundance

Base where6.325.545.515.546.44Toth Pratures7.567.166.436.4355.555Commuter variance7.5614.2221.362.585.555Amplifier syname3.47"3.69"3.69"3.69"Proteiding p3.47"7.11"3.69"3.69"Narrodi g p5.546.09"2.54"3.69"3.69"Narrodi g p3.64"3.69"2.54"3.69"3.69"Narrodi g p3.64"3.69"2.54"3.69"3.69"Narrodi g p3.64"3.69"3.64"3.64"3.64"Narrodi g p3.64"3.64"3.64"3.64"3.64"Narrodi sonar3.23"7.59"2.54"3.553.55Address sonar going3.64"3.54"3.54"3.54"3.54"Narrodi sonar going3.64"3.55"3.54"3.55"3.55"Advine sonar going3.54"3.55"3.55"3.55"3.55"Advine sonar going3.51"3.55"3.55"3.55"3.55"Advine sonar going3.51"3.55"3.55"3.55"3.55"3.55"3.55"Advine sonar going3.51"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3.55"3		1	2	3	4	5
Tods® seame7.567.166.6436.4535.55Comulative entrops gener30533.55Amplefore gener30733.55Natiolar J	Eigen value	6.28	5.94	5.51	5.34	4.61
Camalare variance7,614/221,62303,53Paularia phylora syme307307307307Narria lag 1234557307307Narria lag 2214"524"307307Narria lag 2234"557"307307Narria lag 2234"557"307307Narria lag 2308"308308308308Narria lag 3308308308308308Narria lag 3308358358358Palaarana lagie310"358"358358Palaarana lagie310"354"367367Narria lagia310"354"369369Palaarana lagie310"354"369"369"Palaarana lagie310"354"369"369"Palaarana lagie310"354"369"369"Palaarana lagie310"354"369"369"Palaarana lagie310"354"369"369"Palaarana lagie310"354"369" <td>Total % variance</td> <td>7.56</td> <td>7.16</td> <td>6.643</td> <td>6.435</td> <td>5.555</td>	Total % variance	7.56	7.16	6.643	6.435	5.555
Anaplage3.0°Finalida (p)4.3°Navoola (p)5.3°Navoola (p)711"Planvagen (p)5.11"Planvagen (p)2.54°Savanaki (p)3.8°Savanaki (p)3.8°Natakins (p)3.8°Navoola (p)3.8°Navoola (p)3.8°Navoola (p)3.8°Navoola (p)3.8°Navoola (p)3.8°Navoola (p)3.8°Navoola (p)3.8°Navoola (p)3.8°Navoola (p)3.3°Navoola (p)3.3°Navoola (p)3.3°Navoola (p)3.3°Navoola (p)3.4°Navoola (p)3.4°Navool	Cumulative variance	7.56	14.72	21.36	27.80	33.35
Image5.3°5.6°Navola q.2511°35°Plauoigna q.254°65°88°Saaronot y.254°65°25°Saaronot y.358°25°55°Panalar straha358°25°55°Rainfar q.46°55°55°Bailfarta p.46°55°55°Bailfarta p.46°55°55°Bailfarta p.353°25°55°Bailfarta p.353°25°55°Sarrick tama323°739°25°Sarrick tama323°35°55°Medica sanaronoit35°35°55°Paladones radout36°35°55°Paladones radout36°35°55°Palatines apolito distan36°55°55°Palatines apolito distan36°55°55°Palatines apolito distan36°55°55°Palatines apolito distan36°55°55°Palatines apolito distan36°55°55°Palatines apolito distan55°55°55°Palatines apolito distando distanti distanta distanti distanta55°55°Palatines apolito distanta55°55°55°Palatines apolito distanta distanta55°55°55°Palatines apolito distanta55°55°55°Palatines apolito distanta distanta55°55°55°Palatines apolito distanta55°55°55°<	Amphipleura jenneri		.310*			
Narrola 9.1S37S37S37Planaropic 9.1391393291Samonic 9.1393291393Samonic 9.1393291393Samonic 9.1393291393Natabari 9.1393291393Satabari 9.1393393393Satabari 9.1323739"383Satabari 9.1354354354Satabari 9.1354354354Satabari 9.1354354354Satabari 9.1354355355Satabari 9.1353355355Satabari 9.1363355355Satabari 9.1365355355Satabari 9.1365355355Satabari 9.1355355355Satabari 9.1355355355Satabari 9.1355355355Satabari 9.1355355355 <td>Frustulia sp</td> <td>.447*</td> <td></td> <td></td> <td></td> <td></td>	Frustulia sp	.447*				
Narioday 2Summa 2Planvigues p254'650"254'Summa is virili30"254'Plandaris virili30"20"Barthari p40"20"Barthari p40"30"Barthari p40"314'Barthari p313'7.9"Barthari p313'7.9"Samiral seama313'7.9"Samiral seama313'7.9"Samiral seama313'7.9"Pladiante samamai314'7.9"Pladiante samamai316'39'Pladiante samamai316'267'Pladiante samamai316'267'Pladiante samamai316'267'Pladiante samamai316'267'Pladiante samamai316'315'Pladiante samama316'315'Pladiante samama310'314'Pladiante sama316'314'Pladiante sama310'314'Pladiante sama310'314'Pladiante sama311'314'Pladiante sama311'314'Pladiante sama311'311'Pladiante sama311'311'Pladiante sama311'311'Pladiante sama311'311'Pladiante sama311'311'Pladiante sama311'311'Pladiante sama311'311'Pladiante sama311'311'Pladiante sama311'311'Pladia	Navicula sp 1				.523**	.360*
Parameters	Navicula sp 2			.711**		
Manuskies op254'660"254'Nursches op405'200'Nursches op447'50'Bacallaris op and som op333'7.9"Survila runna333'7.9"2.56'Survila runna333'7.9"2.56'Survila runna333'7.9"2.56'Survila runna333'7.9"2.56'Survila runna54''2.65''3.8''Malaris op54''3.8''3.5''Halokour otholaria6.31''4.35''2.5''Rhonokonia op7.34''4.35''3.5''Tholacianema op6.31''4.35''3.5''Palatarun singlesA.18''6.5'''3.5''Palatarun singles3.68''3.5'''3.5''''Palatarun singles3.63'''3.5''''''''''''''''''''''''''''''''''''	Pleurosigma sp				.489	.359
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Nambaiq447°Bardharia paradaca881°Sarirella mina325°Sarirella mina256°Advira paradaca540°Melarina paradaca540°Melarina paradaca540°Melarina paradaca540°Melarina paradaca540°Billa davia radata500°Billa davia radata631°Melarina paradaca631°Melarina paradaca631°Septambarda436°Laposylandrus davias436°Septamadaca paradaca631°Septamadaca paradaca631°Palastram informada636°Palastram informada346°Palastram informada347°Palastram informada633°Palastram informada347°Palastram informada<	Pinnularia viridis	.398*			.290*	
Realins panaseA47°Relins panase881°Surriella minuta323'7.39°2.58°Surriella minuta332'7.39°2.58°Surriella minuta332'7.39°2.58°Mediora and active300'300'300'Hydebara rahatau500''387''387''Mediora and active6.31°'4.35''2.54''Rhizoedhaar rahatau6.31°''4.35''2.54''Rhizoedhaar rahatau4.36''6.55''3.55'''Rhizoedhaar and active and act	Nitzschia sp		.405*			
Reading parallayaX881"Shrride humata333"7.97"2.58"Shrride humata2.56"6.04"4.24"Médoira sumariosis5.40"5.90"5.90"Hybolocos radiatis7.30"3.83"3.83"Britzscholeta et5.00"3.83"3.83"Britzscholeta et5.01"3.83"3.83"Britzscholeta et6.631"4.55"2.54"Britzscholeta et6.631"4.55"2.54"Defourme mönder4.14"6.05"5.15"Polastrum ofsplex3.08"5.55"5.55"Polastrum ofsplex3.84"6.05"5.15"Polastrum ofsplex3.08"5.55"5.55"Valoux aureix3.81"6.35"5.55"Valoux aureix3.81"6.35"5.55"Valoux aureix defor3.81"6.35"5.55"Valoux aureix defor3.81"6.35"5.55"Valoux aureix defor3.81"6.35"5.55"Valoux aureix defor3.81"6.35"5.55"Operator auseix defor3.63"3.59"2.92"Aushansa iterizadi3.0"3.54"5.54"Aushansa iterizadi3.0"3.54"5.54"Aushansa iterizadi3.0"3.54"5.54"Aushansa iterizadi3.0"3.54"5.54"Aushansa iterizadi3.64"3.54"5.54"Aushansa iterizadi3.65"3.55"3.55"Aushansa iterizadi3.64"3.54"3.54	Bacillaria sp	.447*				
Murid atoman323736"254'Melani a numaeusi544"544"Melani a numaeusi544"390"Hydedius contanue390"383"Rhizondenia sp736"383"Rhizondenia sp736"383"Thakasionen sp640"383"Lapachladiu dauisu366263"269"Stepkanodicos sp513"355"Pelatarum impletA18605"10"Pelatarum implet308"555"355"Pelatarum daples308"555"355"Pelatarum hatzobi314"633"10"Valves globulusA14"348"255"Pelatarum hatzobi314"633"255"Anubara teritedii366264"30"Mirescytic assa777"**37"37"Anubara teritedii360"358"29"Anubara teritedii386"288"29"Anubara teritedii380"38"39"Celopharine no386"288"39"Teschabarine hactore386"38"39"Perdenini frame326"35"39"Celopharine no326"35"39"Perdenini frame326"35"39"Teschabarine frame37"37"37"Anubara teritedii380"38"35"Celopharine no37"37"37"Teschabarine frame37"37"37"Dinophysis aperardii254" </td <td>Bacillaria paradoxa</td> <td>.881**</td> <td></td> <td></td> <td></td> <td></td>	Bacillaria paradoxa	.881**				
Sarrellamination256'604"A24'Meloriz consuration544"200"100"Hybolicous culutus500"383"383"Rhizouolenia qu736"435254"Rhizouolenia qu364"265"269"Stephanoducou qu513"435254"Pedastram impleeA18"605"100"Pedastram impleeA18"605"100"Pedastram impleeA18"605"100"Pedastram impleeA18"605"100"Pedastram implee384"633"100"Pedastram implee384"633"10"Pedastram implee384"633"10"Pedastram implee384"633"25"Pedastram harizabit360"264"10"Proteinan harizabit360"264"10"Aubasana fite-aque777"397"397"Mitrocytis qu310"374"10"Aubasana fite-aque777"397"397"Aubasana fite-aque360"264"10"Calospharium qu360"264"10"Calospharium faite qu360"264"10"Aubasana fite-aque360"264"10"Aubasana fite-aque360"264"10"Calospharium qu360"264"10"Calospharium qu360"264"10"Peridiniqui faite fite-aque360"264"10"Proteinin aput cutum360"254"	Surirella tenara		.323*	.739**		.258*
Melloir a anaransis54°Melaira ap30°Hydolicis radam50°Rhicasohira p73°Rhicasohira p611°Thalasisiema p613°Leposjedniva kariauA36°Sephanolicis p513°Pelastrum simplexA18°Pelastrum simplex308°Sephanolicis p472°Pelastrum simplex308°Sephanolicis p313°Pelastrum simplex308°Sephanolicis p313°Pelastrum simplex308°Sephanolicis p313°Pelastrum simplex318°Sephanolicis p321°Sephanolicis p310°Sephanolicis p321°Sephanolicis p321° <td>Surirella minuta</td> <td></td> <td></td> <td>.256*</td> <td>.604**</td> <td>.424*</td>	Surirella minuta			.256*	.604**	.424*
Melaria op       290'         Hydeolacur radutau       736''       387'         Rhizeolonia op       736''       435'       254'         I hadissinema op       631''       435'       254'         Laptoc/indux danicau       436'       263'       269'       254''         Stephonolosia op       513''	Melosira oamaruensis			.544**		
<i>Phyloblicas radiatus</i> 736*       383* <i>Rhicsolenia sp</i> 631*       385* <i>Lepscylindrus daukas</i> A36       263*       269* <i>Stephanodices op</i> 513**       -       - <i>Rebistrum singher</i> A18       605**       -       - <i>Peldustrum np</i> 472*       -       -       -       - <i>Velows globula</i> 308*       53**       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -       -	Melosira sp			.290*		
Rbiandenia sp736°383°Tholosimena sp631°435°259°Lepopolimine deniaseA36°269°513°517°Peduatrum simplexA18°60°517°517°Peduatrum simplexA18°655°355°557°Peduatrum duplex308°555°355°557°Peduatrum duplex308°555°355°557°Peduatrum duplex308°553°357°557°Peduatrum duplex308°553°357°557°Peduatrum duplex347°251°557°29°Atimatrum hantschi436°557°39°29°Atimatrum hantschi30°574°39°299°Marcogità sp310°574°359°299°Marcogità sp310°574°21°557°359°Marcogità sp310°574°21°557°359°Marcogità sp310°574°21°557°359°Marcogità sp310°574°21°557°36°Marcogità sp310°57°21°36°55°Perdening harandi670°21°557°36°36°Perdening homonin20°55°36°55°36°Perdening homonin20°57°39°39°39°Perdening homonin777°*39°36°55°36°Perdening homonin20°55°36°55°36°Consarium u	Hyalodiscus radiatus			.500**		
Talakasinona q     Á36'     Á35'     254'       Leptorplundru danicas     Á36'     263'     269'       Stephanoldsicas p     513''     -     -       Pediastrum simplex     Á18'     605''     -     -       Pediastrum simplex     A18'     605''     -     -       Pediastrum daplex     308'     555''     -     -     -       Pediastrum daplex     A14'     -     -     -     -       Valvex atreas     -     -     -     -     -     -       Valvex atreas     -     -     -     -     -     -       Objects creasis     -     -     -     -     -     -       Objects creasis     -     -     -     -     -     -       Atubastrum hantschit     -     30'     -     -     -     -       Objects creasis     -     -     30'     -     -     -     -       Atubastrum hantschit     -     598''     -     -     -     -     -     -       Atubastrum hanse     -     -     -     -     -     -     -     -     -     -     -       Atubastrum hanse     -     -	Rhizosolenia sp	.736**				.383*
Leptoylindrus danicus of       356'       263'       269'         Stephanodicus of       513''	Thalassionema sp		.631**		.435*	.254*
Stephanadicas sp       513"         Pelakstram simplex       A18'       605'         Pelakstram duplex       308'       555'       355'         Pedastram duplex       308'       555'       355'         Pelakstram duplex       308'       555''       355'         Pelakstram duplex       308'       555''       355'         Pelakstram duplex       308'       553''       355''         Pelakstram duplex       308''       553''       355''         Valvex areas       381''       633''       555''       25''         Actimistrom haritschi       -429''       255''       25''         Ababisena diritschilis       -430''       25''       29''         Microsytis p       310''       -574''       35''       29''         Microsytis p       310''       -598'''       28'''       29'''         Microsytis p       310''       -598'''       28''''       28''''''         Colophastrik larkaza       A47''       -228'''''       28''''''''''''''''''''''''''''''''''''	Leptocylindrus danicus	.436*		.263*	.269*	
Peliatrum simplex       A18"       605"         Peliatrum simplex       A72'	Stephanodiscus sp	.513**				
Peldastrum 4plex       308°       55°       .35°         Peldastrum 4plex       308°       .55°       .35°         V folvox globulus       A14°       .348°       .         V folvox arreus       .381°       .633°       .         Actinustrum hantschii       .347°       .251°       .         Oopstis crasa       .337°       .429°       .255°         Anabaena ciricnalis       .403°       .264°       .         Anabaena file-saquae       .777°*	Pediastrum simplex	.418*	.605**			
Pediatram daplex     308°     555°	Pediastrum sp		.472*			
Volvox globulus       A14*       .348*         Volvox sureus       .381*       .433*         Artinustrum huntzstöti       .367       .429*       .255*         Oocysis crassi       .406*       .264*       .265*         Anabaena circinalis       .406*       .264*       .397*         Anabaena filos aquae       .777***       .397*       .397*         Microscystis sp       .310*       .374*       .359*       .292*         Tracolodismium lacutere       .539*       .292*       .255*       .255*         Schizatbrix lardaeea       .447*       .288*       .29*       .25*       .25*       .25*       .25*       .25*       .29*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*       .25*	Pediastrum duplex	.308*	.555**		.355*	
Volvox aureus       381'       633''         Actinastrum hanizechii       347'       251'         Actinastrum hanizechii       633''       429'       255'         Oncytis crasa       633''       429'       255'         Anabaena fois aquae       777'''       397'         Anabaena fois aquae       777'''       397'         Microcystis p       310'       374'         Yathropira p       291'       598''       359'       299'         Arthropira p       291'       598''       359'       299'         Schizabrix lardacea       A47'	Volvox globulus	.414*		.348*		
Actinastrun hantzechii       347°       251°         Oroysti erasa       633°       429°       255°         Anabaena ciricinalis       06°       264°       37°         Anabaena ciricinalis       777°**       397°       397°         Anabaena forcinalis       310°       374°       397°         Anabaena forcinalis       310°       374°       397°         Anabaena forcinalis       310°       374°       359°       299°         Arthraspin ap       291°       598°       359°       299°         Sobizobric landaeca       447°       282°       291°         Coleophaerinan p       386°       288°       288°         Peridainan cinctum       386°       288°       349°         Peridaining pernardii       290°       349°       349°         Peridaining fatum       402°       702°       37°         Oconarium inglatum       477°*       397°       397°         Connarium adpressam       777**       397°       397°         Connarium subcrenatum       777**       397°       397°         Connarium subcrenatum       310°       324°       546°       326°         Spirogras seformis       384°	Volvox aureus		.381*	.633**		
Oocysis crassa       633**       429'       255'         Anahaena circinalis       406'       264'       397'         Anahaena flos-aquae       777**       397'         Microcysis p       310'       374'       397'         Microcysis p       291'       598*       359'       292'         Aribropira p       291'       598*       359'       292'         Schizobrick lardacea       447'       292'       100'       100'         Colophaerium p       386'       288'       28'       100'         Peridinion cinctan       402'       702'       100'       100'         Peridinions intenn       200'       100'       100'       100'         Peridinions inflatom       402'       702'       100'       100'         Ocomarium sobcrenation       777**       397'       397'       397'         Cosmarium sobcrenation       777**       391'       324'       546'	Actinastrum hantzschii		.347*	.251*		
Anabaena circinalis       406°       264°         Anabaena flos-aquae       777**       397°         Anabaena flos-aquae       777**       397°         Microcystis gn       310°       374°       291°         Arthrospira gn       291°       598**       359°       299°         Arthrospira gn       291°       598**       359°       292°         Schizabhric landazea       447°       201°       201°       201°         Codophaeriun gn       870***       288°       288°       288°         Peridinium spn       870***       433°       349°         Peridiniupsis pernardii       254°       494°       349°         Peridiniupsis pernardii       290°       357°       349°         Coromarium subcreatum       777**       397°       397°         Cosmarium subcreatum       777**       397°       397°         Coffension       777**       397°       397°         Commarium subcreatum       777**       397°       397°         Commarium subcreatum       777**       397°       397°         Commarium subcreatum       777**       397°       397°         Claucedutum       351°       326°	Oocystis crassa		.633**		.429*	.255*
Anabaena flos-aquae       777***       397'         Microcystis q       310'       374'         Arthrospira sp       291'       598*       359'       299'         Arthrospira sp       539*'       292'       598'       359'       299'         Schizothrix lacuase       Af'       292'       598'       292'       500'         Colosphaerium sp       380'       288'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500'       500' <td>Anabaena circinalis</td> <td></td> <td>.406*</td> <td>.264*</td> <td></td> <td></td>	Anabaena circinalis		.406*	.264*		
Microcystis sp       310*       374*         Artbrospira sp       291*       598**       359*       299*         Tracbodosnium lacutre       539**       292*       291*         Schisothrix lardaea       A47*       292*       291*         Coelogbaerium sp       386*       288*       298*         Peridinium sp       870**       433*       449*         Peridinium cinctum       254*       494*       349*         Peridiniopsis pernardii       290*       449*       349*         Peridiniopsis pernardii       290*       55*       357         Ceanarium inflatum       402*       702*       56*         Dinophysis sp       558**       357*       397*         Cosmarium subcreatum       777***       397*       397*         Cosmarium subcreatum       777***       397*       397*         C lanceolatum       777***       397       324*       346*         Spirogyra setformis       324*       346*       326*         Spirogyra setformis       556**       324*       346*       326*         Eiglena aus       556*       55**       325*       324*       346*         Findutat	Anabaena flos-aquae	.777***				.397*
Arthropira sp       291'       598''       359'       299'         Trachodesmium lacustre       539''       292'	Microcystis sp	.310*	.374*			
Trachodesmium lacustre       539**       .292*         Schizothrix lardaeea       .447*	Arthrospira sp	.291*	.598**		.359*	.299*
Schizothrix lardacea       .447°         Coelosphaerium sp       .386°       .288°         Peridinium sp       .870°**       .433°         Peridinium cinctum       .433°       .447°         Peridiniupsis pernardii       .254°       .494°       .349°         Peridiniupsis thompsonii       .290°       .       .         Ceratium inflatum       .402°       .702°       .       .         Dinophysis sp       .558**       .357°       .       .       .         Cosmarium depressum       .777***       .397°       .397°       .       .       .         C lanceolatum       .777***       .324°       .546°       .326°       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .       .	Trachodesmium lacustre		.539**		.292*	
Coelosphareiun sp       .870***         Peridiniun sinctum       .433*         Peridiniun sinctum       .433*         Peridiniopsis pernardii       .254*       .494*       .349*         Operidiniopsis thompsonii       .290*       .290*       .290*         Ceratium inflatum       .402*       .702*	Schizothrix lardacea	.447*				
Peridiniun sp       .870***         Peridiniun cinctum       .433*         Peridiniopsis pernardii       .254*       .494*       .349*         Peridiniopsis thompsonii       .290*       .290*         Ceratium inflatum       .402*       .702*       .702*         Dinophysis sp       .558**       .357*       .397*         Cosmarium depressum       .777***       .397*         Cosmarium subcrenatum       .777***       .391*         C lanceolatum       .431*       .361*         Spirogyra setformis       .324*       .546*       .326*         Euglena acus       .557**       .291*       .397*         Fuglena acus       .556*       .291*       .397*         Phacus pyrum       .385*       .558**       .558**	Coelosphaerium sp		.386*		.288*	
Peridinium cinctum       .433*         Peridiniopsis pernardii       .254*       .494*       .349*         Peridiniopsis thompsonii       .290*       .290*	Peridinium sp	.870***				
Peridiniopsis pernardii       .254*       .494*       .349*         Peridiniopsis hompsonii       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290*       .290* </td <td>Peridinium cinctum</td> <td></td> <td></td> <td></td> <td>.433*</td> <td></td>	Peridinium cinctum				.433*	
Peridiniopsis thompsonii       .290*         Ceratiun inflatum       .402*       .702*         Dinophysis sp       .558**       .357*         Cosmarium depressum       .777***       .397*         Cosmarium subcrenatum       .777***       .397*         C. lanceolatum       .431*       .361*         Spirogyra setformis       .324*       .546*       .326*         Euglena sp       .557**       .291*       .397*         Euglena acus       .556**       .556**       .556**         T. caudata       .385*       .558**       .558**	Peridiniopsis pernardii			.254*	.494*	.349*
Certaitum inflatum       4.02*       .702*         Dinophysis sp       .558**       .357*         Cosmarium depressum       .777***       .397*         Cosmarium subcrenatum       .777***       .397*         C. lanceolatum       .777***       .361*         Spirogyra setformis       .324*       .546*       .326*         Spirogyra setformis       .557***       .291*       .397*         Euglena sp       .556**       .556**       .556**         T. caudata       .385*       .558**       .558**	Peridiniopsis thompsonii			.290*		
Dinophysis sp       .558**       .357*       .397*         Cosmarium depressum       .777***       .397*         Cosmarium subcrenatum       .777***       .397*         C. lanceolatum       .777***       .361*         C. lanceolatum       .324*       .546*       .326*         Spirogyra setformis       .557**       .291*       .397*         Euglena sp       .556**       .56**       .56**         T. caudata       .385*       .56**       .56**	Ceratium inflatum		.402*	.702*		
Cosmarium depressum     .777***     .397*       Cosmarium subcrenatum     .777***     .397*       C. lanceolatum     .777***     .361*       C. lanceolatum     .431*     .361*       Spirogyra setformis     .324*     .546*       Spirogyra setformis     .557**     .291*       Euglena sp     .556**     .56*       T. caudata     .385*     .583**	Dinophysis sp		.558**	.357*		
Cosmarium subcrenatum         .777***         .397*           C. Lanceolatum         .431*         .361*           Spirogyra setformis         .324*         .546*         .326*           Euglena sp         .557**         .291*         .397*           Euglena acus         .556*         .56*           T. caudata         .385*         .583**	Cosmarium depressum	.777***				.397*
C. lanceolatum     .431*     .361*       Spirogyra setformis     .324*     .546*     .326*       Euglena sp     .557**     .291*     .397*       Euglena acus     .556*     .56*       T. caudata     .385*     .583**	Cosmarium subcrenatum	.777***				.397*
Spirogyra setformis       .324*       .546*       .326*         Euglena sp       .557**       .291*       .397*         Euglena acus       .556**       .56**         T. caudata       .385*       .290*       .583**	C. lanceolatum		.431*		.361*	
Euglena sp         557**         291*         397*           Euglena acus         .556**           T. caudata         .385*           Phacus pyrum         .290*         .583**	Spirogyra setformis			.324*	.546*	.326*
Euglena acus         .556**           T. caudata         .385*           Phacus pyrum         .290*         .583**	Euglena sp			.557**	.291*	.397*
T. caudata     .385*       Phacus pyrum     .290*     .583**	Euglena acus				.556**	
Phacus pyrum .290* .583**	T. caudata		.385*			
	Phacus pyrum			.290*	.583**	

Note: PC loadings < 0.25 are omitted \*Weak loading (0.25 - 0.50) \*\*Moderate loading (0.50 - 0.75) \*\*\*Strong loading (> 0.75) (Yao et al., 2014)

#### Discussion

The study found that Bacillariophyta, Chlorophyta and Cyanophyta dominated the net phytoplankton of Opa Reservoir, which is in agreement with records of other studies on African tropical reservoirs, especially Nigerian reservoirs (Adeniyi, 1978; Bwalla et al., 2010; Edward and Ugwumba, 2010; Offem et al., 2011; and Atobatele, 2013). The record of the family Bacillariophyceae as most abundant is similar to the record of Abowei et al. (2012) (Koluama area) as well as Ogamba et al. (2004) (Elechi creek complex), both of Niger Delta, Nigeria; Emmanuel and Onyema, (2007) (a tropical creek in South western Nigeria); Abowei *et al.* (2008) (Lower Sobreiro river of the Niger Delta); Zabbey et al. (2008) (Imo river); Davies et al. (2009) (Elechi creek, Niger Delta); Achionye-Nzeh and Isimaikaye, 2010 (Ilorin reservoir) and Nkwoji *et al.* (2010) (Lagos lagoon, Nigeria), followed by Cyanobacteria and Chlorophyta, which were more copious in the wet season.

The maximum phytoplanktonic abundance, recorded in the lacustrine zone, might be due to stability of certain environmental variables in this zone as a result of reduced water current, restricted movement and higher transparency (Salem, 2011; Adedeji et al., 2015). The lowest abundance in spite of high species richness recorded in April 2013, a period towards the first peak of the rainy season, could possibly be an effect of the washing away of many individual phytoplankton through flooding and their dislodging from littoral vegetation hence species enrichment (Adeniyi and Adedeji, 2007). The observed irregular variation in phytoplankton distribution from surface to bottom across the three sampling stations could be as a result of high mixing and nutrient re-cycling in the reservoir column during the rainy season (Úgwumba and Ugwumba, 1993; Adedeji et al., 2015). The higher planktonic composition recorded during the rainy season may furthermore be due to an increase in ionic dilution during this period as well as an increase in nutrient inflow and introduction of organic matter (Adedeji et al., 2015).

Generally, phytoplankton has been identified to be important in bio-monitoring of trophic status as well as water quality (Townsend et al., 2000; Davies et al., 2009; Achionye-Nzeh and Isimaikaye, 2010; Offem et al., 2011). Notable bio-indicator phytoplankton species recorded were Anabaena circinalis, A. flos-aquae, Microcystis sp., Aphanocapsa litoralis and Microcystis aeruginosa, which have been reported to produce algal toxins such as microcystin, that is a hepatotoxin and can cause serious illness in both humans and some other mammals (WHO, 2009; Ugwumba et al., 2013). These species were noted to be significantly in abundance during the present study. Other pollution indicator species that were recorded in this study include oscillatoria agardhii, Phacus sp., Surirella sp., Closterium sp., Aphanocapsa sp. and Euglena sp. suggesting the likelihood of pollution in the reservoir (Ugwumba et al., 2013). Moreover, high percentage of Chlorophyceae and Cyanobacteria in a water-body, as obtained from this study, with Cyanobacteria being the second most represented taxa, is a clear indication of eutrophication (Taub, 1984; Olasehinde and Abeke, 2012). The elevated abundance of these species might have resulted from the quick increase in the supplied nutrients to the reservoir from several anthropogenic activities from the basin catchment area (Jaji *et al.*, 2007).

## Conclusions

Opa Reservoir is rich in phytoplankton, which are mostly members of Bacillariophyta (diatoms), Cyanobacteria (blue-green) and Chlorophyceae (green algae) often recorded in eutrophic lakes. As the hereby study revealed, very high abundance of the algae, recorded as compared to zooplankton abundance resulting from the increase in nutrients through continual inflow and seasonal changes, could lead to the lake deterioration with time. The lake should be therefore monitored closely.

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