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Physicochemical Characteristics and Plankton Diversity of Lagos Lagoon and its Adjoining Abule-Agege and Abule-Eledu Tidal Creeks, Lagos State, Nigeria

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ABSTRACT: Plankton have great ecological importance as they fix carbon dioxide, produce oxygen, and serve as autotrophs at the base of various food chains in the different aquatic environments worldwide. Hence, the objective of this paper was to investigate the physicochemical characteristics and plankton diversity of Lagos Lagoon and its adjoining Abule-Agege and Abule-Eledu Tidal Creeks, Lagos State, Nigeria using appropriate standard techniques. Result of the physicochemical conditions varied from fresh through low to high brackish water conditions at the study locations. Thirty-five (35) taxa belonging to 21 genera were observed for the phytoplankton. The blue-green algae recorded 2 species from 2 Orders (5.71 %), while the diatoms are the more abundant group with a total of 33 taxa from 2 Orders (94.29 %). Zooplankton forms recorded a total of 17 taxa belonging to 14 genera from three main groups. Arthropods were the most abundant group with 13 taxa from 3 classes (52 %), while the Rotifers made up 4 species from 4 genera (16 %) and 5 Juvenile stages (32 %) respectively. Notable phytoplankton species reported were *Microcystis aeruginosa, Oscillatoria* sp., *Synedra crystallina*, and the zooplankton species were *Paracalanus parvus, Enterpina acutifrons, Cyclops strenus, Daphnia magma, Keratella cochlearis*, Baranacle nauplii, Gastropod and Polychaetes larva. Importantly as salinity increased, the diversity of plankton form groups increased in these ecosystems.

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The most prominent lagoon especially with regards to the effects and fallouts of human activities in Lagos is the Lagos Lagoon. The waste materials from Lagos and Ogun states usually empty into this lagoon through the Ogun River and other drain channels (Nwankwo *et al*., 2012). The Lagos Lagoon is known for its use in water transportation, thermal electricity generation, dredging activities, sand mining, provision of natural food and other economic activities (Onyema, 2009), finfish and shell fish fisheries, mariculture sites as well as the disposal of domestic and industrial wastes sites (Chukwu and Nwankwo, 2004; Onyema *et al.*, 2007). Creeks are water channels that flow into rivers, estuaries, lagoons, and other aquatic systems, especially those en route to the sea (Onyema, 2009). However, creek ecosystems in the Lagos area are rich and diverse and serve as feeding, nursery and breeding grounds for finfish, shellfish and even migratory and

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shore birds (Lefcheck *et al*., 2019). In tidal creeks, the tidal influence is an important control on microscopic biomass which constitutes various types of plankton and can be found all year round. Periods of sharp rise and fall in salinity levels in these coastal ecosystems are usually associated with low biodiversity linked to the death of the species (Nwankwo, 1996; Chukwu *et al*., 2009). Despite the ecological and economic significance of the creeks and lagoon of Southwest Nigeria, they are also use as sinks for the disposal of increasing waste types directly or indirectly (Chukwu, 2011; Onyema *et al*., 2014). Records of plankton have been reported by researchers to reflect the environmental conditions of an aquatic ecosystem per time thus they act as bio-diagnostic components that could reflect the health of the marine environment (Varadharajan and Soundarapandian, 2014; Onyema *et al.,* 2007) playing a key and foundational role, especially regarding trophic relationships (Emmanuel and Onyema, 2007). The growth and development of the phytoplankton abundance is dependent on turbidity and available nitrates, phosphates, silicates and sulphate in the aquatic ecosystem. The availability of these organic limiting elements such as nitrogen, phosphorus and silica is an important factor affecting primary production (Onyema, 2021). According to Adesalu and Nwankwo (2005), phytoplankton organisms are the basis of aquatic productivity and any alteration in their constitution may have negative consequences in the food chain and the entire community structure. They also play a significant role in the silica cycle and contribute to other biogeochemical cycles, especially in carbon fixation in the carbon cycle by converting CO_2 into biomass in a large proportion (Kale *et al.,* 2015). Zooplankton are animal-like plankton that eat the phytoplankton for the source of energy, due to the fact they cannot harness the energy from the sun. The copepods are the herbivores zooplankton that are called the KIA (Key Industry Animals) because they can convert plant tissue to animal tissue. The crucial role of zooplankton in the aquatic food web and their grazing activities in phytoplankton species have been documented. They function as intermediaries between fish and lower trophic levels as well as food to juvenile and adult fish (Ogbeigbu, 2001). Zooplankton generally occupy a central role in the aquatic food web as many of them are heterotrophs feeding largely on algae and bacteria and serve as predators to several invertebrates and fish predators. The phytoplankton and zooplankton are an important source of food for many aquatic organisms including fish and invertebrates in lagoons (Emmanuel and Onyema, 2007). Phytoplankton production usually determines the amount of zooplankton present at any time (Castro and Huber, 2005). The diversity and the distributions of zooplankton components are strongly influenced by a combination of seasonal physical and chemical characteristics of water they inhabit (Onyema *et al.,* 2010). The zooplankton of southwestern Nigeria waters has not received enough attention. Information dealing with diatom, blue-green algae and zooplankton species of Lagos Lagoon and its environs is quite scanty. Hence, the objective of this paper was to investigate the physicochemical characteristics and plankton diversity of Lagos Lagoon and its adjoining Abule-Agege and Abule-Eledu Tidal Creeks, Lagos State, Nigeria.

MATERIALS AND METHODS

Description of Study Area: The study area for this research comprises two tidal creeks Abule-Agege Creek (St. 1) - 3°24′0″E and 6°30′52″N; Abule-Eledu Creek (St. 2) - 3°23′44″E and 6°31′16″N as well as adjoining the Lagos lagoon (St. 3) - 3°24′8″ E and 6°31′4″ N. These locations are situated on the northeastern side of the University of Lagos.

Collection of Water Samples: Sampling was carried out at each stations for six months from November 2021 to April 2022 between 08.00 and 10.00 hours on each sampling day. The 75 cl plastic bottles were dipped into the surface water to collect the water samples and were taken to a standard laboratory for physical and chemical analysis.

Collection of Plankton Samples: Plankton samples were collected with a 55 µm mesh size standard plankton net using the filtration method. The filtered plankton was emptied into well-labelled 750 ml plastic containers with screw caps. Each sample was preserved with unbuffered dilute 10% formalin and transferred to the laboratory for further microscopy analysis.

Analysis of Water Quality Parameters: Water temperature was measured using a digital thermometer. Rainfall values were obtained from the Nigerian Meteorological Agency, Lagos (NiMET). pH, total suspended solids (TSS), electrical conductivity, salinity, alkalinity, dissolved oxygen, biochemical oxygen demand, nitrate, phosphate, sulphate and silica were measured using American Public Health Association (APHA, 2005) protocols for water analysis. Iron, manganese and zinc were estimated with an Atomic Absorption Spectrophotometer using Perkin Elmer Application methods (2002).

Evaluation of Plankton Species: The drop count microscopic analysis method as described by Onyema (2008; 2009) and Wu *et al.,* (2014) was used to evaluate the plankton samples. Five drops of concentrated plankton samples were used (using a long nose disposable pipette/dropper) of the concentrated sample (10 ml) was investigated differently at different magnifications (50X, 100X and 400X) using a Leica DMLB binocular microscope with a calibrated eyepiece (X10) and the average number of plankton species were recorded. The final data were presented as the number of organisms (cells, filaments, colonies, and organisms) per ml. Appropriate texts were used to aid identification of the plankton species.

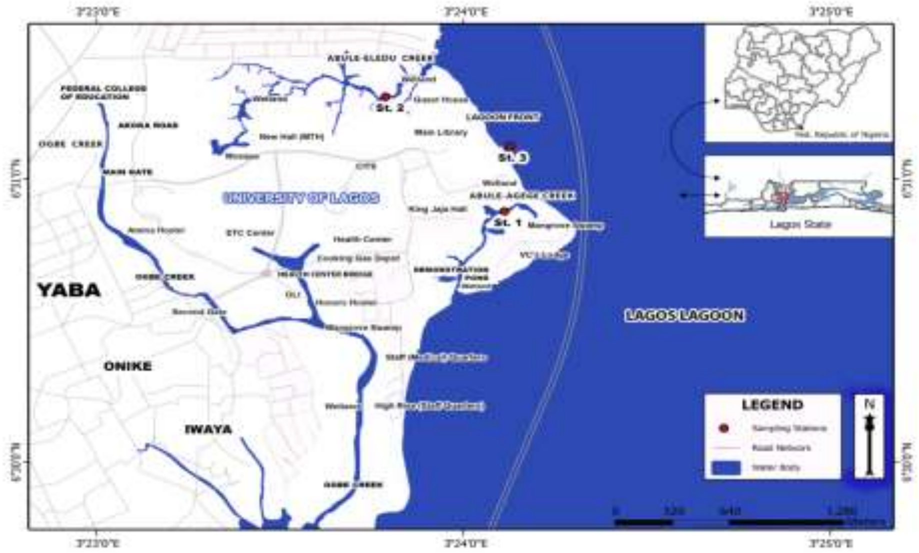

Fig. 1: University of Lagos, Nigeria showing Lagos Lagoon and adjoining Tidal Creeks
Source: Geography Department, University of Lagos
*Abule-Agege Creek (St. 1), Abule-Eledu Creek (St. 2) and the Lagos Lagoon (St. 3)

Data Analysis: The physicochemical parameters data generated were statistically analyzed using descriptive (min, max, mean, and standard deviation) and inferential statistics (Canonical Correspondence Analysis CCA, Spearman correlation and Bray-Curtis Similarity) was used to analyze the relationship between the physicochemical parameters and plankton data.

RESULTS AND DISCUSSION

Physicochemical Parameters: The trends in the different physicochemical parameter play important roles in the development and abundance of plankton in marine environments (Sun *et al.,* 2022). Physicochemical parameters in the study areas varied from fresh through low brackish to high brackish water conditions. The range of the records for; rainfall (0.40 – 224.10 mm), water temperature (24 - 35℃), salinity (0.52 - 21.45 ‰), dissolved oxygen (2.11 – 8.55 mg/L), nutrients (nitrate $\geq$ 0.61 mg/L, phosphate $\geq$ 0.10 mg/L, sulphate $\geq$ 36.10 mg/L), alkaline pH (6.55 – 7.48), alkalinity (59.50 – 340 mg/L), iron (0.04 – 0.12 mg/L), manganese (0.02 – 0.40 mg/L), zinc (0.00 – 0.30 mg/L) and chlorophyll *a* concentration (0.75 – 14.66 µg/L) were reported among others (Table 1). The trends in the water quality were greatly influenced by seasonal changes on the different water bodies that were studied. The observed water temperature in this study is similar with the findings of Olaleye and Nwankwo (2022) who reported that the temperature of inland waters usually ranged between 24 – 35 ºC. Most aquatic organisms are known to be affected by pH due to their pH-dependent metabolic activities. The slightly acidic pH levels in the Abule-Agege and Abule-Eledu creeks could be attributed to many anthropogenic activities ongoing around these creeks. The observed alkaline pH in this study was in agreement with the research work of Onyena and Okoro (2016) who reported the acidic pH could be because of mechanic workshops close to Ogbe creek.

Over the years by several researchers, salinity has been reported as a crucial parameter in determining the lack/occurrence and density of prevalent species in coastal waters of Nigeria (Nwankwo 2009, Onyema 2008). The salinity levels varied from freshwater through low brackish to high brackish water conditions which was higher from January to April. A similar condition and regimes have been reported by Onyema and Akanmu (2013) for the physicochemical characteristics of the East mole area of the Lagos habour. Species of drifting water hyacinth (*Eichhonia crassipes*) were common sights on the surface of the water in these areas at different seasons. During the month of November and December, 2021, water hyacinth (*Eichhonia crassipes*) were green in colour due to low salinity, but during the month of January and February, 2022, Water hyacinth were yellowish to brownish in colour and die off probably due to high salinity (Chlorosis). The incursion of contaminants coming from domestic waste and other anthropogenic effluents through urban storms into the sampling sites led to changes in the physicochemical conditions of the creeks and lagoon thereby increasing the alkalinity, nutrients, and pH of the creeks (Abule-Agege and Abule-Eledu creek) and the Lagos lagoon. The nutrient levels were fluctuating, Olaniyan (1969) while working on the lagoon of southwestern Nigeria revealed the variation in nutrient content was related to the pattern of rainfall. The marked variation in nitrate (0.61 – 23.90 mg/L) and phosphate (0.10 – 5.95 mg/L) is notable during the study which are the main inorganic nutrients required by plankton for their growth and reproduction. Most tropical water has low nutrient values, a feature considered common for natural and polluted water. Nitrate and phosphate recorded low values during the study period probably due to the low amount of organic waste which enters the study area while the high values of sulphate (36.10 – 1287.00 mg/L) recorded may be a reflection of the high amount of biodegradable waste discharge in the region and reduced dilution effect of flood water. There will be a marked increase in the phytoplankton population when there is an increase in nutrients. The increase in nutrients levels value in November, 2021 may be attributed to low freshwater influx and predominately the results of biologically activated reactions.

Table 1: Monthly Variation of the Pysicochemical Parameters at Lagoon lagoon and adjoining Abule-Agege and Abule-Eledu Tidal Creeks, November 2021 - April 2022).

		St. 1-Abule-Agege Creek				St. 2-Abule-Eledu Creek				St. 3 – Lagos Lagoon			
SN	**PARAMETERS**	**MIN.**	**MAX.**	**MEAN**	**±SD.**	**MIN.**	**MAX.**	**MEAN**	**±SD.**	**MIN.**	**MAX.**	**MEAN**	**±SD.**
1	Water	24.00	35.00	28.67	4.08	25.00	31.00	28.33	2.42	27.00	32.00	29.17	2.14
2	Rainfall (mm)	0.40	224.10	69.38	89.31	0.40	224.10	69.38	89.31	0.40	224.10	69.38	89.31
3	Turbidity (NTU)	0.52	193.12	60.93	68.93	17.89	80.90	38.71	0.00	5.53	99.70	31.29	39.26
4	Total Suspended Solids (mg/L)	14.00	85.00	39.83	27.26	18.00	42.00	30.33	10.44	7.00	36.00	17.50	11.59
5	pH (at 25°C)	6.55	7.20	6.96	0.24	6.85	7.48	7.08	0.22	6.93	7.46	7.14	0.21
6	Electrical	1061.00	36100.00	22263.50	12567.16	1058.00	31600.00	19864.50	11500.31	1203.00	35200.00	23182.17	13146.96
7	Salinity (‰ at	0.52	21.45	12.98	7.52	0.52	18.81	11.52	6.90	0.59	20.65	13.57	7.89
8	Alkalinity (mg/L, as $CaCO_3$)	59.50	136.50	100.92	33.13	86.40	340.00	148.73	95.38	72.00	100.10	86.08	11.56
9	Dissolved	4.50	6.70	5.52	0.92	2.11	4.91	3.82	1.14	4.51	8.55	5.79	1.57
10	Biochemical Oxygen Demand	5.00	23.00	9.00	6.90	4.00	29.00	9.83	9.45	4.00	37.00	10.67	12.94
11	Nitrate (mg/L, as	0.61	7.15	4.67	2.41	1.08	23.90	8.09	8.47	0.64	8.64	6.21	2.95
12	Phosphate (mg/L, as PO_4^{3-})	0.10	1.66	0.46	0.60	0.31	5.95	1.75	2.14	0.17	0.39	0.25	0.08
13	Silica (mg/L, SiO_2^-)	4.65	25.32	9.32	7.90	4.11	28.29	9.93	9.10	1.04	18.60	6.40	6.28
14	Zinc (mg/L)	0.01	0.09	0.06	0.03	0.00	0.30	0.06	0.12	0.00	0.08	0.02	0.03
15	Iron (mg/L)	0.05	0.09	0.07	0.01	0.04	0.12	0.08	0.03	0.05	0.09	0.07	0.01
16	Manganese	0.10	0.28	0.17	0.07	0.10	0.40	0.25	0.13	0.02	0.22	0.14	0.08
17	Chlorophyll *a* (µg/L)	2.66	13.2	6.4	4.18	0.75	4.9	2.89	1.4	4.75	14.66	7.77	4.34
18	Chlorophyll *b*	0.07	0.82	0.47	0.36	0.05	1.06	0.5	0.48	0.20	0.98	0.52	0.32
19	Chlorophyll *c*	0.03	0.14	0.07	0.04	0.02	0.09	0.06	0.03	0.03	0.11	0.06	0.03
20	Phaeophytin a	0.02	0.08	0.05	0.02	0.02	0.21	0.07	0.07	0.02	0.31	0.08	0.11

**Abule-Agege Creek (St. 1), Abule-Eledu (St. 2) and the Lagos Lagoon (St. 3)*

Heavy metal concentrations iron (0.04 - 0.12 mg/L), copper (0.01 - 0.04 mg/L), and manganese (0.02-0.40) at the three stations were low but had some significant effects on plankton population during the study. The availability of some heavy metals can be due to the release of industrial effluents into the water system. The impact of sand mining and dredging is also quite important. Trace metals and especially iron (Fe) availability are the key control for community composition and biomass (Martin *et al*., 1990; Boyd *et al*., 2007; Sunda, 2012). The Co-limitation of iron (Fe) with manganese (Mn) has been reported early in Drake Passage (Martin *et al*., 1990) and was observed at the Abule-Agege creek (St. 1), Abule-Eledu creek (St 2) and the Lagos lagoon (St. 3). Concentration of iron and manganese has been reported to promote a shift in the species composition and helps the cells of phytoplankton to prevent oxidative stress and to reach maximum photosynthetic efficiency (Browning *et al*., 2021; Pausch *et al.*, 2019; Wu *et al*., 2019). Although both Fe and Mn play major roles in photosynthesis, the consequences of Fe limitation on growth and photosynthetic activity are more severe than those induced by Mn limitation (Bruland *et al*., 1991; Sharon *et al.*, 2014; Rudolf *et al.,* 2015). Indeed, Fe is more commonly a limiting factor in the growth and photosynthetic activity of phytoplankton and zooplankton in natural environments (Asada, 2006). The pattern of variation of chlorophyll *a*, *b*, *c* and phaeophytin *a* values observed during this study indicates that chlorophyll *a* have higher value than the other photosynthetic pigment analyzed. It is possible that higher primary productivity gave rise to higher chlorophyll *a* concentration which lead to a similar trend in dissolved oxygen concentrations since oxygen is a by-product of photosynthesis. The concentration of chlorophyll *a* pigment and low total suspended solids recorded in the dry season during this study is an indicator of improved water clarity which probably allowed greater light penetration. According to Suzuki *et al*. (2002), low chlorophyll *a* value reflecting limited phytoplankton growth in an investigation of a Mexican lagoon was associated with dark water which reduced light penetration into the lagoon considerably.

Table 2: Checklist of Phytoplankton and Zooplankton at the Lagoon lagoon and adjoining Abule-Agege and Abule-Eledu Tidal Creeks (November, 2021 – April, 2022).

	Phytoplankton taxa		**Zooplankton taxa**		
	Division: cyanophyta		**Phylum - arthropoda**		**Juvenile stage**
	Class: cyanophyceae		**Subphylum - crustacea**	18.	Barnacle nauplii Larvae
	Order i: chroccocales		**Class - cladocera**	19.	Copepod Egg
1.	*Microcystis aeruginosa* Kutzing		**Family i - daphniidae**	20.	Copepod nauplii Larvae
	Order ii: hormogonales	1.	*Daphnia magma* straus	21.	Cypris Larvae
2.	*Oscillatoria* sp.		**Family ii ¬- sididae**	22.	Gastropod Larvae
		2.	*Diaphanosoma branchyurum* Lievin	23.	Fish Eggs
	Division: bacillariophyta			24.	Polychaete Larvae
	Class: bacillariophyceae		**Class - copepoda**	25.	Unknown Stage.
	Order i - centrales		**Order i - calanoida**		
3.	*Actinoptychus splendens* Ehrenberg		**Family i - paracalanidae**		
4.	*Aulacoseira granulata var. Angstissima* Muller	3.	*Paracalanus parvus* Claus		
5.	*Odontella biddulphiana* Bayer		**Family ii - calanidae**		
6.	*Odontella rhombus* Ehrenberg	4.	*Calanus finmarchicus* Gunnerus		
7.	*Coscinodiscus centralis* Ehrenberg		**Family iii - acartiidae**		
8.	*Coscinodiscus marginatus* Ehrenberg	5.	*Acartia clausii* Giebretcht		
9.	*Coscinodiscus radiatus* Ehrenberg	6.	*Acartia discaudata* Giesbrecht		
10.	*Cyclotella meneghiniana* Kutzing	7.	*Acartia longiremis* Lilljeborg		
11.	*Cyclotella striata* (Kutzing) Grunow		**Family iv - temoridae**		
12.	*Hemidiscus cuneiformis* Wallich	8.	*Temora stylifera* Dana		
13.	*Skeletonema coastasum* Cleve	9.	*Temora turbinata* Dana		
14.	*Terpsinoe musica* (Ehrenberg) Hustedt		**Family v - cyclopinidae**		
	Order ii - pennales	10.	*Cyclopina longicornis* boeck		
15.	*Achnanthes longipes* Agardh		**Family vi - oithoridae**		
16.	*Amphora ovalis* Kutzing	11.	*Oithona nana* Giesbrecht		
17.	*Cocconeis placentula* Ehrenberg				
18.	*Gomphonema parvulum* Grunner		**Order ii - cyclopoida**		
19.	*Gyrosigma balticum* (Ehrenberg) Rabenhorst		**Family- cyclopidae**		
20.	*Gyrosigma scalproides* (Rabenhorst) Cleve	12.	*Cyclops strenus* Fischer		
21.	*Navicula bicapitata* Ehrenberg				
22.	*Navicula expansa* Hagelstein		**Order iii - harpaticoida**		
23.	*Navicula mutica* Kutzing		**Family- tachidiiae**		
24.	*Nitzschia sigmoidea* (Witesch) Wm. Smith	13.	*Enterpina acutifrons* Dana		
25.	*Pleurosigma angulatum* (Quekett) Wm. Smith				
26.	*Pleurosigma elongatum* (Quekett) Wm. Smith		**Phylum - rotifer**		
27.	*Pleurosigma hippocampus* (Quekett) Wm. Smith		**Class - monogononta**		
28.	*Pinnularia* sp.		**Order - ploima**		
29.	*Pinnularia sudetica* Hilse		**Family i - brachionidae**		
30.	*Surirella elegans* Ehrenberg	14.	*Brachionus plicatilis* Muller		
31.	*Surirella ovata* Kutzing	15.	*Keratella cochlearis* Goose		
32.	*Surirella striatula* Turpin		**Family ii - lecanidae**		
33.	*Surirella* sp.	16.	*Lecane* sp.		
34.	*Synedra ulna* (Nitzsch) Ehrenberg		**FAMILY III - dicranophoridae**		
35.	*Synedra crystallina* (Agardh) Kutzing	17.	*Dicranophorus* sp.		

This report also is in agreement with the observation by Kadiri, (2008) who reported on the seasonal fluctuation in abundance of phytoplankton as influenced by changes in the physical and chemical condition in some coastal waters of Nigeria. The diversity checklist of plankton species (Phytoplankton and Zooplankton) at the Abule-Agege creek, Abule-Eledu creek and the Lagos Lagoon between November, 2021 and April, 2022 are presented in Table 2, Fig. 2. Phytoplankton population were more abundant in January through to April, 2022 when rainfall was lowest and lower in November through to December, 2021 when rainfall volumes were higher. The phytoplankton diversity was represented by two Divisions namely; Cyanophyta and Bacillariophyta. Thirty thirty-five (35) species belonging to 21 genera were observed. The Cyanophyta were represented by two species (5.7 %) from two Orders (Chroccocales – 1 taxa and Hormogonales – 1 taxa). The Bacillariophyta were represented by thirty-three (33) taxa (94.3%) from two Orders (Centrales – 12 taxa and Pennales – 21 taxa) (Fig. 2.). Generally, diatoms were found to be the most abundant group in terms of numbers and diversity (93.2% and 94.3%) compared to the blue-green algae (6.8% and 5.7%) across the three stations. However, Lagos lagoon recorded a higher numerical abundance of cyanobacteria compared to other stations (Abule-Agege and Abule-Eledu creeks). The notable species of the Bacillariophyta were the *Odentella biddulphiana, Odentella rhombus, Cosinodiscus radiatus, Skeletonema coastasum* from the Order Centrales and the Order Pennales were represented by *Navicula bicapitata, Pinnularia sudetica, Surirella ovata, Surirella striatula* and *Synedra crystallina.* The Cyanophyta were represented by *Microcystis aeruginosa* and *Oscillatoria* sp. The qualitative dominance of diatoms in this study area is noteworthy because they have been known to be indicators of water quality and environmental conditions (Onyema and Akanmu, 2013; Adesalu *et al*., 2017; Adejumobi *et al*., 2019)...

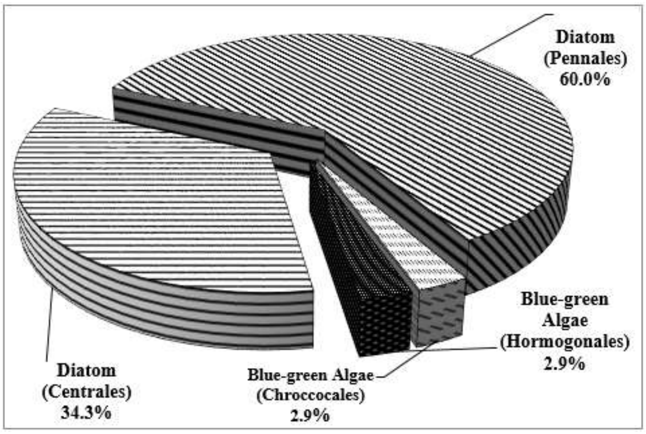

Fig. 2: Relative Species Diversity (S) of Phytoplankton at Abule-Agege Creek (St.1), Abule-Eledu Creek (St. 2) and the Lagos Lagoon (St. 3) (Nov., 2021 – Apr., 2022).

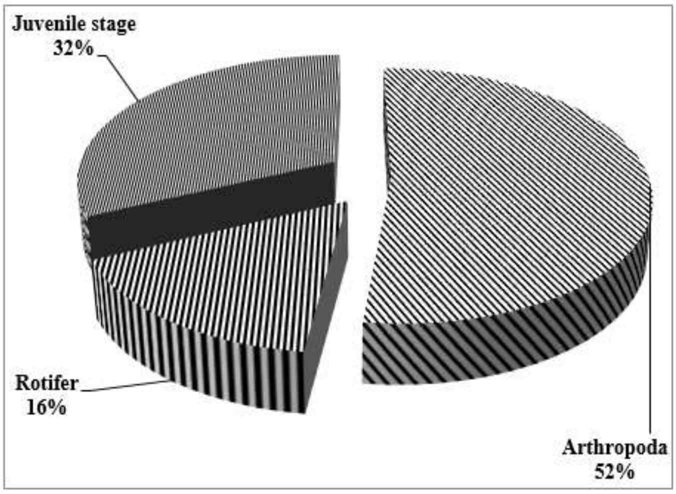

Fig. 3: Relative Species Diversity (S) of Zooplankton at Abule-Agege Creek (St.1), Abule-Eledu Creek (St. 2) and the Lagos Lagoon (St. 3) (Nov., 2021 – Apr., 2022).

It was observed that the pennate forms of diatoms were the most dominant species among the diatoms across the three stations which could be due to the introduction of bottom-dwelling forms into plankton either through the artisanal fishing and scouring effects of fishing gears or as a result of shallow depth (Adesalu and Nwankwo, 2008). Similarly, a direct relationship was shown between the total suspended solids and total dissolved solids. This influence was reflected in the composition of phytoplankton species which was dominated by pennate diatoms such as *Achnanthes brevipes*, *Achnanthes longipes*, *Cocconeis diaphana*, *Cocconeis littoralis*, *Cocconeis placentula* and *Pinnularia* sp.

Table 3: Spearman's Correlation Coefficient Associations for Phytoplankton and Zooplankton Species Abundance, Richness and Biological Indices at the Abule-Eledu Creek (St. 2) (November 2021 – April 2022).

SN	PARAMETERS	PS	PA	ZS	ZA	Chl *a*	Chl *b*	Chl *c*	Phae
1.	Water Temperature (ºC)	√ (-)	√ (-)	×	√ (-)	√ (-)	√ (+)	√ (+)	√ (+)
2.	Rainfall (mm)	√ (+)	√ (+)	×	√ (+)	√ (-)	×	√ (-)	×
3.	Turbidity (NTU)	×	×	×	×	×	√ (+)	√ (+)	×
4.	Total Suspended Solids (mg/L)	√ (-)	√ (-)	√ (+)	×	√ (-)	√ (+)	√ (+)	√ (+)
5.	pH (at 25°C)	√ (-)	√ (-)	√ (+)	×	√ (-)	√ (+)	√ (+)	√ (+)
6.	Electrical. Conductivity (µS/cm)	×	√ (+)	√ (-)	×	√ (+)	√ (-)	×	√ (-)
7.	Salinity (‰ at 25ºC)	×	√ (+)S	√ (-)	×	√ (+)	√ (-)	×	√ (-)
8.	Dissolved Oxygen (mg/L)	×	√ (-)	×	√ (-)	√ (+)	×	×	×
9.	Biochemical Oxygen Demand (mg/L)	×	√ (-)	√ (+)	×	√ (-)	√ (+)	×	√ (+)
10.	Nitrate (mg/L, as NO_3^-)	√ (+)	√ (+)	×	√ (-)	√ (+)	√ (-)	√ (-)	√ (-)
11.	Phosphate (mg/L, as PO_4^{3-})	×	√ (-)	√ (+)	×	√ (-)	×	×	√ (+)
12.	Silica (mg/L, SiO_2^-)	×	√ (-)	√ (+)	×	√ (-)	×	×	√ (+)
13.	Zinc (mg/L)	×	√ (-)	√ (+)	×	√ (-)	√ (+)	×	√ (+)
14.	Iron (mg/L)	×	×	√ (+)	√ (+)	√ (-)	×	×	√ (+)
15.	Manganese (mg/L)	√ (+)	√ (+)	√ (+)	√ (+)	√ (-)	×	√ (-)	×
16.	Chlorophyll *a* (µg/L)	×	×	√ (-)	√ (-)	√ (+)	√ (-)	×	√ (-)
17.	Chlorophyll *b* (µg/L)	√ (-)	√ (-)	√ (+)	×	√ (-)	√ (+)	√ (+)	√ (+)
18.	Chlorophyll *c* (µg/L)	√ (-)	√ (-)	×	√ (-)	×	√ (+)	√ (+)	√ (+)
19.	Phaeophytin *a* (µg/L)	√ (-)	√ (-)	√ (+)	×	√ (-)	√ (+)	√ (+)	√ (+)
20.	Phytoplankton Species Diversity (S)	√ (+)	√ (+)	×	√ (+)	×	√ (-)	√ (-)	√ (-)
21.	Phytoplankton Abundance (N)	√ (+)	√ (+)	×	√ (+)	×	√ (-)	√ (-)	√ (-)
22.	Zooplankton Species Diversity (S)	×	×	√ (+)	×	√ (-)	√ (+)	×	√ (+)
23.	Zooplankton Abundance (N)	√ (+)	√ (+)	×	√ (+)	√ (-)	×	×	×

KEYS: √ (+) = Strongly Positively Correlated (≥ ±0.40), √ (-) = Strongly Negatively Correlated (≤ ±0.40) and × = Not Strongly Positively/Negatively Correlated. PS = Phytoplankton Species Diversity, PA = Phytoplankton Abundance, ZS = Zooplankton Species Diversity, ZA = Zooplankton Abundance, Chl *a* = Chlorophyll *a*, Chl *b* = Chlorophyll *b*, Chl *c* = Chlorophyll *c* and Phae = Phaeophytin.

These species are known to tolerate higher dissolved solids concentrations as reported by Graham *et al.* (2009). The blue-green algae were also observed to be high in the three stations but especially at stations 1 and 3. Lagos lagoon was comparatively higher and dominated by *Oscillatoria* sp. It was observed that the abundance of the blue-green algae was not significantly affected by any physicochemical parameter. The presence of *Microcystis aeruginosa* and *Oscillatoria* sp. indicates fresh - low brackish water as well as moderate organic pollution (Onyema, 2021). *Odontella biddulphiana*, *Odontella rhombus*, *Coscinodiscus radiatus*, *Skeletonema coastasum*, *Navicula bicapitata*, *Pinnularia sudetica*, *Surirella ovata*, *Surirella striatula* and *Synedra crystallina* indicates mid – high brackish water situation, alkaline pH, very shallow depth and high cation levels, as well as moderate organic pollution at the study stations (Onyema, 2021). *Synedra crystallina* the most dominant diatom species at the three locations for this study has been confirmed to dominate shallow nutrient rich, fresh–low brackish conditions and moderate organic polluted areas (Onyema, 2021). The occurrence of *Synedra crystallina* has been reported by Olaleye and Nwankwo (2022) as indicative of a polysaprobic waterbody. *Synedra crystallina* was reported for this study. The differences in the abundance of most species may be attributed to significant variations in the physico-chemical variables and nutrient levels within these periods. The zooplankton spectrum was represented by two phyla; which were Arthropoda and Rotifera (Holoplankton) and Juvenile stage (meroplankton) forms as presented in Table 2, Fig. 3. A total of 17 species belonging to 14 genera were observed. Phylum Arthropoda was the most abundant group making up thirteen (13) species (52%) from ten (10) genera, while the phylum Rotifer and Juvenile stage made up four (4) species (32%) from four (4) genera and five (5) juvenile stages (16%) respectively. In terms of zooplankton abundance, January – April 2022 recorded the highest outcome, as shown in Fig. 3 above. The Class Copepoda constituted 76.19%, 67.74 and 45.1% of the total recorded individuals at the Abule-Agege Creek, Abule-Eledu Creek and the Lagos Lagoon respectively. The copepods were represented by three Orders: Calanoida, Cyclopoida and Harparticoida, with the most abundant species being *Enterpina acutifons* and *Oithona nana* (19.05%) of the zooplankton population at the Abule-Agege creek. At the Abule-Eledu Creek *Cyclops strenus* (29.03%) and *Cyclopina longicornis* (19.35%) were the most abundant species, while at the Lagos Lagoon, *Paracalanus parvus* (13.73%) and *Acartia discaudata* (11.76%) were the most abundant species respectively. Other identified species were *Acartia clausii*, *Acartia longermis*, *Calanus finmarchicus*, *Temora stylifera* and *Temora turbinata*, (Table 2). The Class Cladocera was represented by *Daphnia magma* and *Diaphanosoma branchyurum* and constituted 4.76%, 0% and 3.92% of the total recorded individuals at the Abule-Agege Creek (St.1), Abule-Eledu creek (St. 2) and the Lagos Lagoon (St. 3) respectively. The Phylum Rotifera recorded 9.52 %, 6.45% and 1.96% of the total recorded individuals at the Abule-Agege Creek, Abule-Eledu Creek and the Lagos Lagoon. The Class Monogononta were also represented by *Brachionus plicatilis*, *Keratella cochlearis*, *Lecane* sp, *Dicranophorus* sp. Juvenile stages were also recorded.

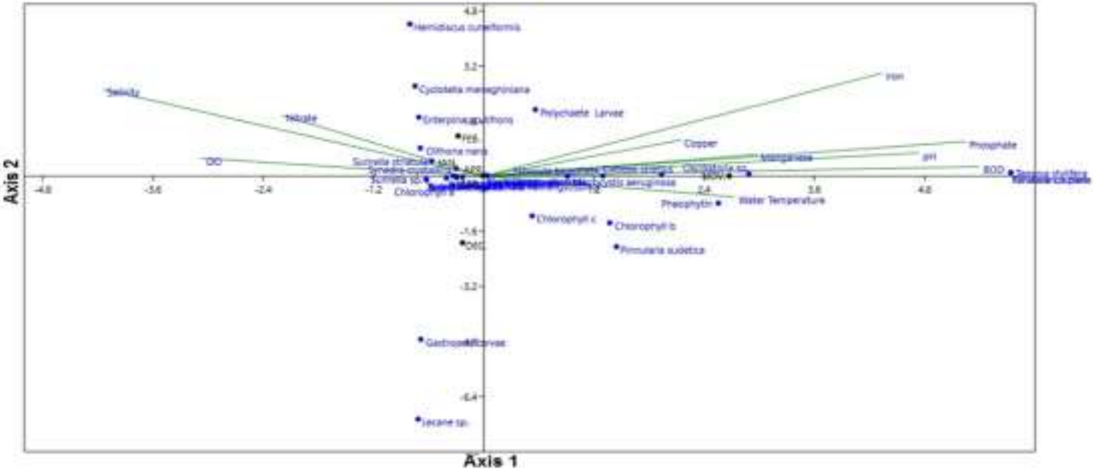

Fig. 4: Canonical correspondence analysis of Physicochemical Parameters and Species Abundance at Abule-Eledu creek (St. 2)

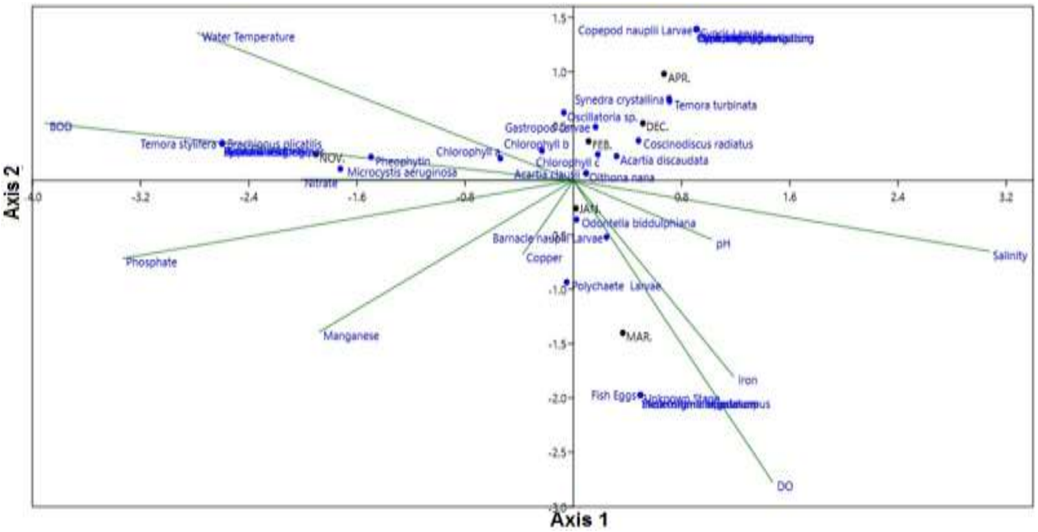

Fig. 5: Canonical correspondence analysis of Physicochemical Parameters and Species Abundance at the Lagos Lagoon (St. 3)

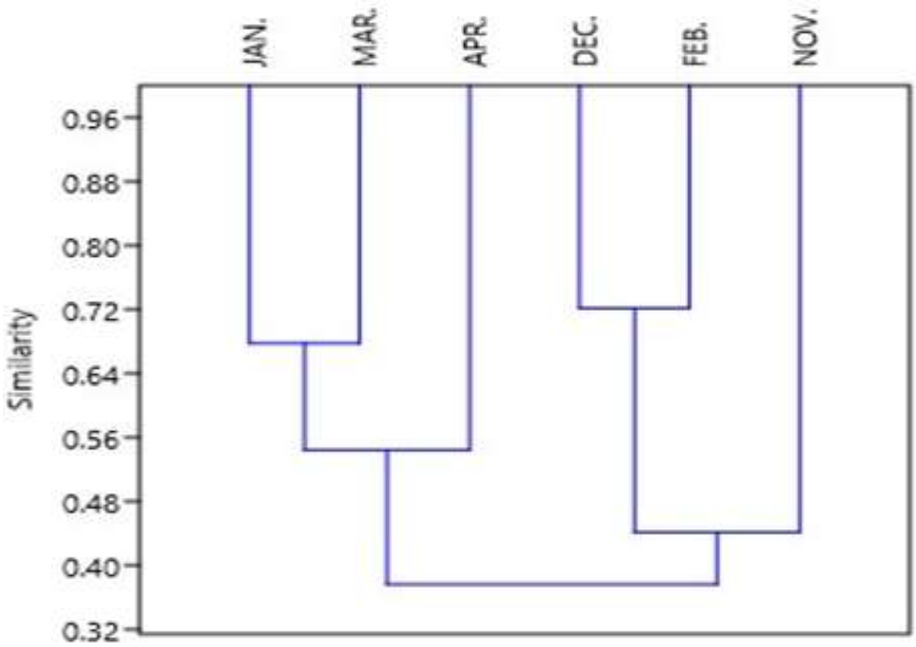

Fig. 6: Bryan-Curtis Similarity of Abule-Eledu Creek (St. 2)

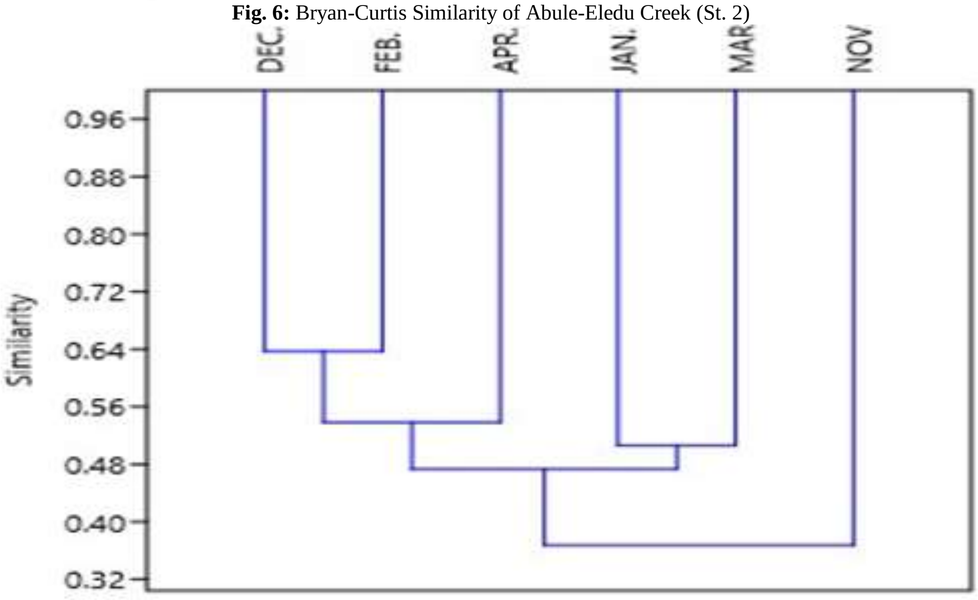

Fig. 7: Bryan-Curtis Similarity of Lagos lagoon (St. 3)

The juvenile stage represented 9.52%, 25.81% and 49.02% of the total zooplankton observed in terms of abundance and was more abundant in January – April 2022 at the three study areas. Within the juvenile stage, Copepod nauplii larvae and Polychaete larvae represent the highest (50%) respectively at Abule-Agege creek and at the Abule-Eledu creek, the Gastropod larvae and Polychaete larvae represented the highest (37.50% and 62.50%). While at the Lagos Lagoon, Barnacle nauplii larvae and Polychaete larvae represented the highest (32% and 40%) respectively. Other identified juvenile stages were Copepod eggs, Cypris larvae, Fish eggs and an unknown stage. The Lagos Lagoon supports more juvenile forms compared to both creeks (Abule-Agege Creek and Abule-Eledu Creek) respectively. Moreover, a study by Souza *et al.*, (2019) in the Amazonian River (Freshwater River) in Brazil reported that zooplankton abundance ranges from copepods followed by cladocerans and then rotifers. They also found that the diversity and abundance of zooplankton were higher in areas of the creeks and the lagoon with higher salinity levels, which was in line with Shin *et al.*, (2022).

In this study, Cladocera and Rotifera had negative correlations with salinity, while copepods had a significant positive correlation with salinity as shown in Table 3. Other studies have focused on the impact of environmental factors on zooplankton in estuarine creeks and lagoons. A study by Wang *et al.* (2021) in the Min River estuary lagoon in China reported that salinity and temperature were the most important factors affecting zooplankton community structure. Similarly, a study by Sousa *et al.* (2016) in a Portuguese estuarine creeks and lagoon found that zooplankton abundance was negatively correlated with water temperature and positively correlated with salinity, which was observed in Abule-Agege Creek and Lagos lagoon. The dominance of zooplankton communities indicates that they are important food sources for fish, which highlights the importance of these ecosystems for fisheries. Juvenile stages (Eggs and Larvae) are often a conspicuous part of the plankton of neritic waters and some of the obvious seasonal changes are related to the reproductive seasons/times of the creeks and lagoon organisms. The diversity of forms of juvenile plankton recorded in this study is similar to that reported by Onyema (2021). The Canonical Correspondence Analysis (CCA) showed the plankton composition was majorly influenced by water temperature, dissolved oxygen, salinity, nutrients, iron and manganese. This is an indication that these physicochemical parameters play significant roles in the diversity of plankton in the studied marine environments (Fig. 4 and 5). Bray-Curtis analysis of similarity observed at Abule-Eledu Creek (St. 2) and the Lagos lagoon (St. 3) grouped the sampling months into two statistically significant clusters using plankton composition as a basis. Cluster one December 2021 and February 2022 has the highest similarity index (0.74 and 0.64) compared to other months. While November 2021 has the lowest level of similarity (0.44 and 0.36) at both study sites. This could indicate more pollution discharged into the ecosystem at that time, as presented in Fig. 6 and 7 above.

*Conclusion***:** The presence of phytoplankton (blue-green algae and diatoms) and zooplankton community structure were influenced by a range of factors including temperature, salinity, dissolved oxygen, nutrient availability, iron and manganese. The physicochemical parameters of the creeks and lagoon were within acceptable limits for the continuous existence of the plankton recorded during this study. Overall, this study highlights the importance of the planktonic organisms especially blue-green algae, diatoms and zooplankton in these creeks and lagoon ecosystems. Thus, further research is needed to understand their ecology and dynamics.

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Data Availability Statement: Data are available upon request from the corresponding author.

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