Journal of Oceanography and Marine Science

Volume 9 Number 1 January, 2018
ISSN 2141-2294

Academic Journals

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Journal of Oceanography and Marine Science

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academicJournals

Vol. 9(1), pp. 1-14, January, 2018
DOI : 10.5897/JOMS2016.0139
Article Number: C53639055697
ISSN 2141-2294

http://www.academicjournals.org/JOMS

Journal of Oceanography and Marine Science

Full Length Research Paper

Spatial distribution and diversity of phytoplankton community in Eastern Obolo River Estuary, Niger Delta

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Received 29 November, 2016; Accepted 25 January, 2017

This paper reported a two season study of diversity, spatial distribution, species composition of phytoplankton and physico-chemical characteristics of the Eastern Obolo River Estuary between June and November 2015 and December and May, 2016. Water conductivity (≥675) showed direct relationship with phytoplankton abundance, turbidity showed strong correlation with species density as well. Species were more evenly distributed across 3 stations at dry season and poorly distributed across 3 stations at wet season. Shannon-wiener index (H) showed differences within the stations and seasons. Simpson's diversity index (D) recorded the lowest in station 2 for both seasons. A wide range of phytoplankton species distributed in 5109 individual species, 85 taxa, 16 orders, 8 classes and in 5 divisions during wet season while in dry season 6906 individual species, 84 taxa, 18 orders, 6 classes and 4 divisions were found. The abundance of phytoplankton in dry season occurred in the sequence Baccillariophyta (79%) > Cyanophyta (12%) > Chlorophyta (7%) Dinophyta (2%) while in wet season the sequence was thus; Bacillariophyta (60%) > Chlorophyta (22%) > Cyanophyta (15%) > Dinophyta (3%) > Euglenophyta (0%) respectively. Bacillariophyta were the most dominant both in abundance and species composition in both seasons.

Key words: Chlorophyll-a, evenness, diversity, spatial distribution.

INTRODUCTION

The study of phytoplankton is quite crucial because it serves as a pathway through which the aquatic ecosystem is supported. Phytoplanktons are primary producers of the open ocean. Phytoplankton serve as food to the zooplankton which in turn serve as food to all larval forms, this makes them form the basis of food chain in an aquatic environment. While phytoplankton constitutes starting point of energy transfer, they are highly sensitive to allochthonously imposed changes in the environment (Khattak et al., 2005; Eletta et al., 2005). Thus, the species composition, biomass, relative abundance, species richness, species evenness, spatial and temporal distribution of this aquatic biota is an expression of the environmental health or biological

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integrity of a particular body of water.

The coastal waters of South-Eastern Nigeria are primarily influenced by rainfall. The annual rainfall in this area is characterized by bimodal regimes, a strong seasonal concentration of a distribution pattern that varies from year to year. For example, a late onset of rainfall will result in a distant incursion of tidal sea water inland while earlier than usual on longer rainfall periods will prolong the duration of fresh water or low brackish conditions in the coastal waters (Nwankwo et al., 1994). The coastline of South-Eastern Nigeria is endowed with creeks and rivers which connect to several estuaries. The environmental dynamics in these creeks are regulated by rainfall and salinity. Estuaries are prominent features along the South-Eastern coast of Nigeria all connecting several rivers and creeks into the Atlantic Ocean. The Eastern-Obolo Estuary with a surface is tidal, shallow and one of the largest in Nigeria.

Phytoplankton algae are free-floating microscopic plants which, obtain chlorophyll and grow by photosynthesis in the presence of sunlight and lacks roots, stems and leaves (Lee, 1999; Nwankwo, 2004; Effiong and Inyang, 2016). It is the power-house of the aquatic food web. Phytoplankton, like land plants are barely distributed completely at random due to variations in reproductive pattern, microhabitat preference or grazing. Most phytoplankton has an uneven distribution despite the fact that they are continuously mixed by water movement. Phytoplankto abundance and distributions have been reported in some estuaries of South-Eastern Nigeria (Nwadairo and Ezefili, 1985; Ekwu and Sikoki, 2006; Akoma, 2008; George et al., 2012).

The physiographic factors, rainfall and salinity determine the hydroclimate of the coastal lagoons of South-Western Nigeria (Effiong and Inyang, 2015). Rainfall, for instance, initiate flood and dilute the ionic concentration of the coastal waters (Hill and Webb, 1958; Olaniyan, 1969; Nwankwo, 1990; Nwankwo, 1993), limits transparency and phytoplankton production. On the other hand, rainfall introduces chelating agents (Nwankwo, 1984; Nwankwo and Akinsoji, 1992), and increases nutrients brought in by rivers and surface runoffs (Nwankwo, 1993). Algae, a vital group of bacteria and plants in aquatic ecosystems, are an important component of biological monitoring programs for evaluating water quality. They are suited to water quality assessment because of their nutrient needs, rapid reproduction rate, and very short life cycle. Algae are valuable indicators of ecosystem conditions because they respond quickly both in species composition and densities to a wide range of water conditions due to changes in water chemistry (Karl, 2013).

The rate of supply or transport of nutrients through the diffusion shell is affected by movement (Prasaad, 2000, Goldman and Horne 1983). In general, the temporal changes within a plankton community itself are largely determined by the growth, mortality, sinking and migration or drifting rate of the individual plankton and their predators (Parsons et al., 1987; Mann, 2000; Prasaad, 2000; Marder, 2001). At present, there is no publication on the diversity and distribution of phytoplankton in Easter-obolo estuary. The objective of this investigation was to study the spatial distribution and diversity of phytoplankton organisms in Eastern-obolo estuary.

MATERIALS AND METHODS

Study area

Coastal water of Eastern Obolo drains into Atlantic Ocean and is connected to Qua Iboe River estuary at the east and Imo River estuary at the west. It is located at 4°33′ N – 4°50′ N; 7°45′ E – 7°55′ E and about 650 m above sea level in the tropical mangrove forest belt east of the Niger Delta, Figure 1. The tidal regime here is semidiurnal and has a range of about 0.8 m at neap tides and 2.20 m during spring tides with little fresh water input joined by numerous tributaries (NEDECO 1961). Eastern Obolo is an area blessed with many communities with diver socio-economic activities such as artisanal fishing, timbering and boat transport. The water is fringed with diversity of floral such as *Rhizophora mangle*, *Avicennia africana*, *Lancungularia*, *Raphia hookeri* and *Nypa fruiticans* and *Sargassum* sp that is normally found during wet season. Oil palm (*Elaeis guineensis*) and coconut palm (*Cocoa nucifera*) are also widely distributed in the villages. The area is also an oil-producing area with several oil exploration wells but there is no oil exploration going on, and many fisheries. Nypa palm and red mangrove are the dominant species of flora. The area is characterized by a lot of creeks and with an extensive mudflat at Iko creek and others dotted all over the environment. A large sand bar is also found at Etizar during neap low tide. As part of tropics, this area experiences two seasons, the dry (October to May) and wet (April to October) with an annual rainfall averaging about 2500 mm (AKUTEC Report, 2006). Samples were taken from ten stations along Okoromokho Creek, Iko River, Iko Creek and Estuary opening.

Determination of water chemistry parameters

Water samples for physical and chemical analysis were collected 25 cm below the water surface with 250 ml plastic bottle from ten stations. Surface water temperatures, dissolved oxygen, pH, conductivity and salinity were measured in-situ using their respective meters. Nitrate-nitrogen and soluble reactive phosphorus were measured by APHA (2005). Total dissolved solid (TDS) was determined gravimetrically by evaporating a known volume of water to dryness in a pre-weighed crucible on a steam bath. Total suspended solids (TSS), was determined by filtering a known volume of sample through a thoroughly dried filter paper and the residue weighed.

Phytoplankton studies

Samples for plankton were collected using 55 µm mesh size standard plankton net, tied unto a motorized boat and towed at a low speed for 5 min. Thereafter the net was hauled in and the plankton transferred into a well labeled 250 ml plastic container with a screw-cap, and preserved with 4% unbuffered formalin. The density of phytoplankton was counted using the sedimentation technique as described by Lund et al. (1958). One ml of each

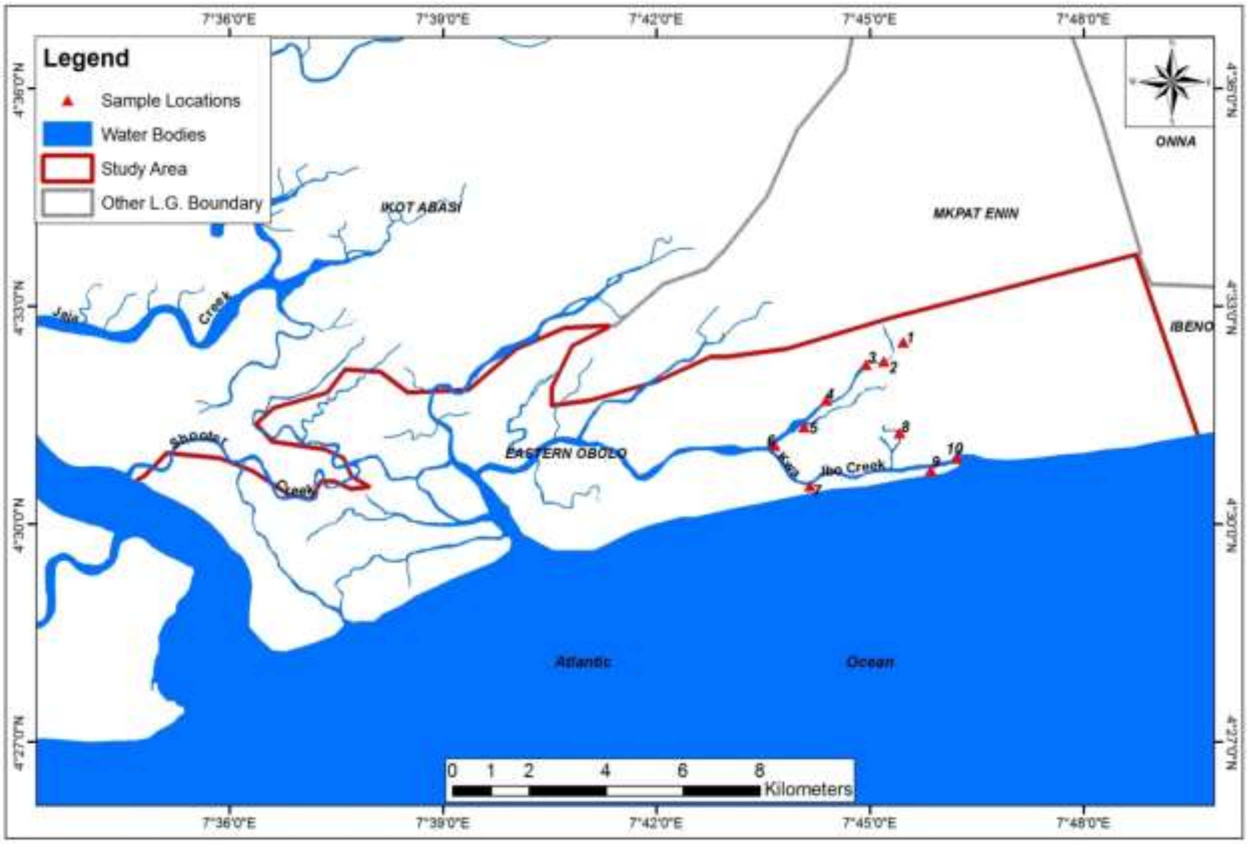

Figure 1. Map of the coastal water of Eatern Obolo showing the study stations.

shaken samples was pitted into a 1 ml counting chamber of a wild M40 inverted microscope and allowed to settle. Examination, identification, counting and recording were done successfully. Phytoplankton species were identified at a magnification of ×1000 and were tallied along transect across the bottom of setting chambers. A record of total organisms was taken and equated per ml. Identification of species was done using (Wimpenny, 1966; Davis, 1955; Compère, 1975; Compère, 1976; Amoros, 1984; Tomas, 1997; Jorgen, 2003).

Chlorophyll-a determination

Chlorophyll-a was determined using method described by Holm-Harsen (1970). 250 ml of water was filtered and the chlorophyll-a was extracted by methanol. The extraction was centrifuged at 320 rpm for 10 min and absorbance was measured at different wave length, the chlorophyll-a concentration was measured using the formula below

Calculation

$$\text{Chlorophyll-a } (\mu g/L) = \frac{(Abs[665nm]-Abs[750nm]x\ A\ x\ Vm}{Vf\ x\ L} \quad (1)$$

Where A = Absorbance coefficient of chlorophyll-a in methanol
Vm = Volume of methanol used for extraction
Vf = Volume of sample filtered
L = Path Length of curvette.

Community structure analysis

Community structure analysis was determined by three indices.

Shannon-Wiener Information Index (H)

This index is sensitive to the number of species present. It is sensitive to both species and dominance diversity.

$$H = \frac{N \log N - \sum filogfi}{N} \quad (2)$$

Where:
H = Shannon-Wiener Information Index
∑ = Summation
fi = Observed proportion of individuals that belong to the ith species
log = Natural logarithm

Species Equitability or Evenness (J) Jaccard

This is a measure of how evenly the individuals are distributed among the species present in a sample. It ranges between 0 and 1, the maximum value. One represents a situation where individuals are spread evenly among the species present Jaccard (1912).

It was calculated as follows:

$$j = \frac{H}{Hmax} \text{ or } j = \frac{H}{\log S} \quad (3)$$

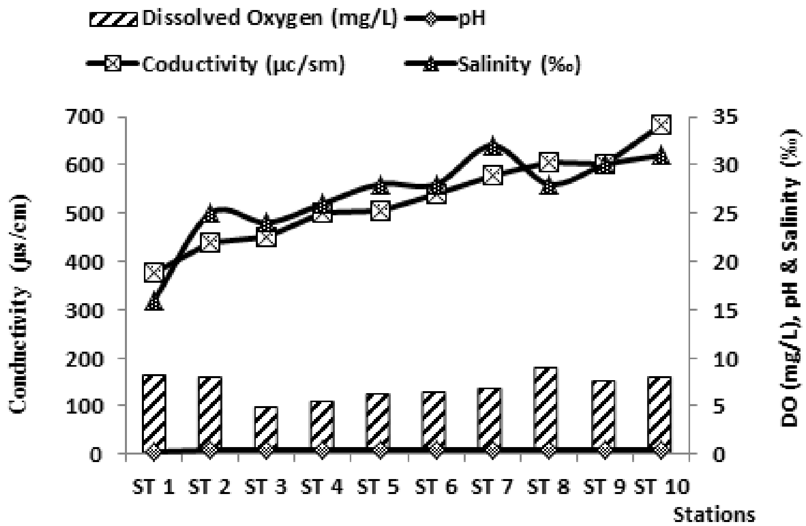

Figure 2. Variation in pH, Dissolved Oxygen, Conductivity and Salinity in Eastern Obolo River Estuary (Dry Season). 2016.

Where:
J = Equitability measure
H = Shannon-Wiener Information Index.

Simpson's Diversity Index (D)

This is a measure of diversity used to quantify the biodiversity of a habitat. It takes into account the number of species present as well as abundance of each species. It measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species).

$$D = \frac{\sum n(n-1)}{N(N-1)} \quad (4)$$

Where:
n = the number of organisms of a particular species
N = the total number of organisms of all species.
The value of D ranges between 0 and 1.

RESULTS

Physical and chemical characteristics of water

The result of some physical and chemical features of the sampling stations at Eastern Obolo coastal water is presented in (Table 1), and some of its variables summarized in (Figures 2 and 3). The highest water temperature (33.7°C) in the dry season was recorded at St.8 (Iko Creek) while the lowest (29.9°C) was recorded at S10 (Estuary mouth). The highest surface water temperature (26.8^{o}C) in the wet season was recorded at St.8 while the lowest (25.0°C) was recorded at St.10. Similarly, pH, Dissolved Oxygen (DO), Salinity and Conductivity values were higher during dry season than during wet season (Tables 1 and 2) and were progressively increased toward the Atlantic Ocean. On the other hand, Turbidity, Total Suspended Solids (TDS) and Nutrients values were higher in the wet season than during dry season. Reactive silicate recorded a progressive increase into the wet season (≥0.4; ≤0.75) but Nitrate levels increased in dry season.

Phytoplankton community

The phytoplankton population during the study was dominated by 28 pinnate diatoms and 23 centric diatoms during the wet season, whereas in the dry season, it was dominated by 31 centric diatoms and 21 pennate diatoms. *Coscinodiscus*, *Melosira* and *Biddulphia* dominated the centric diatoms at wet season while *Coscinodiscus* and *Biddulphia* dominated in the dry season. *Nitzschia* and *Pseudonitzschia* dominated the pinnate diatoms in both seasons. Species of *Coscinodiscus centralis* (442 cells/ml), *Biddulphia mobillensis* (212 cells/ml) and *Thalassiothrix frauenfeldii* (212 cells/ml) contributed the largest number of individual of the total cell numbers throughout the study period, during the dry season in St.9.

However, species of *C. centralis, Biddulphia mobillensis, Ditylum brightwelli* and *T. frauenfeldii* had the largest spread by appearing across more than seven of the ten sample stations. Other genera with high number of individuals were *Biddulphia granulata* (179 cells/ml), *Lyngbya martensiana* (168 cells/ml), and *Thalassionema nitzschiaoides* (163 cells/ml). Generally, the phytoplankton of Eastern Obolo coastal water belong to five main divisions; Baccilariophyta, Dinophyta, Chlorophyta, Cyanophyta and Euglenophyta but during dry season the division Euglenophyta was consistently

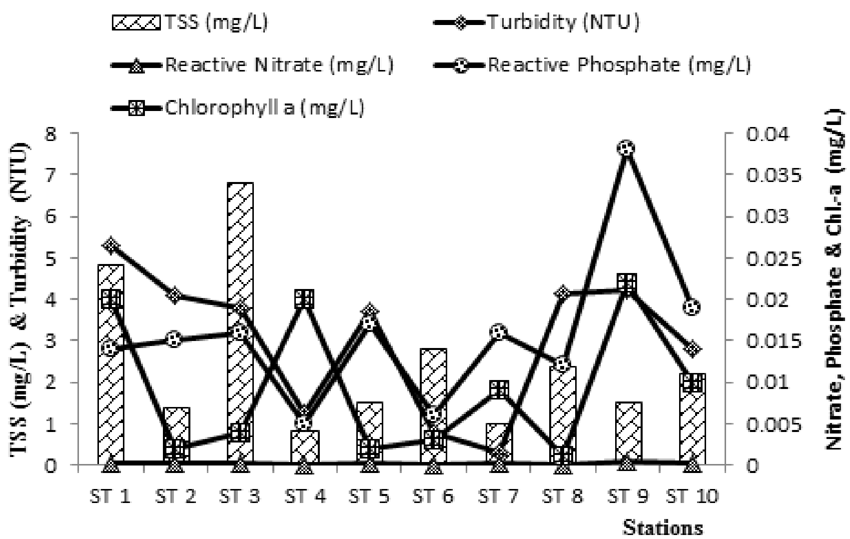

Figure 3. Variation in pH, Dissolved Oxygen, Conductivity and Salinity in Eastern Obolo River Estuary (Wet Season). 2016.

Table 1. Variations in some physical and chemical parameters Eastern Obolo River Estuary (2016).

Variables	Dry Season									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Surface water temp. (°C)	30.6	31.1	30.5	31.1	31.1	30.8	30.5	33.7	30.0	29.9
Conductivity (µc/cm)	375	429	440	493	497	532	568	596	594	675
Salinity	16	25	24	26	28	28	32	28	30	31
pH	3.35	8.37	8.65	8.7	8.53	8.6	8.68	8.36	8.4	8.65
Dissolved Oxygen (mg/L)	8.2	7.9	4.8	5.5	6.3	6.4	6.8	9	7.5	7.9
TSS (mg/L)	0.01	3.04	0.09	1.05	0.09	1.52	0.06	0.05	0.08	2.01
TDS (mg/L)	186	215	225	251	246	268	280	297	308	308
Turbidity (NTU)	0.01	2.76	0.56	0.92	0.96	1.07	0.51	0.41	0.62	1.30
Reactive Nitrate (mg/L)	1.02	1.06	1.04	0.68	1.1	0.48	0.58	0.72	0.8	0.46
Reactive Phosphate (mg/L)	0.014	0.002	0.007	0.018	0.008	0.01	0.016	0.015	0.005	0.009
Reactive Silicate (mg/L)	0.82	0.42	0.65	0.4	0.44	0.42	0.48	0.68	0.72	0.64
Ammonia (mg/L)	0.18	0.14	0.16	0.2	0.12	0.1	0.08	0.28	0.19	0.6
Chlorophyll *a* (mg/L)	0.01	0.01	0.002	0.01	0.01	0.008	0.006	0.01	0.01	0.017

Variables	Wet Season									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Surface water temp. (°C)	25.5	25.8	25.5	26	26.3	26.3	26.3	26.8	24.2	24.5
Conductivity (µc/cm)	45	20	23	21	253	169	267	236	249	354
Salinity	0	0	0	6	10	7	16	2	16	17
pH	7.12	7.4	7.81	7.22	6.98	7.33	6.89	7.43	7.4	7.76
Dissolved Oxygen (mg/L)	4.2	4.8	5.3	5.3	5.6	4.9	6.3	6	7.0	7.6
TSS (mg/L)	4.85	1.4	6.8	0.85	1.53	2.8	1	2.4	1.53	2.2
TDS (mg/L)	262	249	302	188	285	254	225	270	404	178
Turbidity (NTU)	5.28	4.09	3.78	1.26	3.69	0.77	0.29	4.13	4.24	2.81
Reactive Nitrate (mg/L)	0.044	0.04	0.048	0.018	0.047	0.018	0.032	0.027	0.076	0.036
Reactive Phosphate (mg/L)	0.014	0.015	0.016	0.005	0.017	0.006	0.016	0.012	0.038	0.019
Reactive Silicate (mg/L)	0.79	0.42	0.68	0.4	0.7	0.54	0.46	0.66	0.62	0.63
Ammonia (mg/L)	0.16	0.13	120	0.09	110	0.14	0.19	0.09	0.09	118
Chlorophyll a (mg/L)	0.02	0.002	0.004	0.02	0.002	0.003	0.009	0.001	0.022	0.01

Table 2. Taxonomic listing, percentage composition and spatial distribution of phytoplankton species colonizing Eastern Obolo coastal water during wet season.

WET SEASON		
Taxa across stations	**% occurrence**	**spread**
Phylum: Bacillariophyta		
Order I: Centrales		
Coscinodiscus centralis Ehrenberg	5.3	+ + +
Coscinodiscus kützingii A.Schmidt	3.1	+ +
Coscinodicus stellaris Roper	0.09	+
Coscinodiscus concinus W.Smith	2.2	+ +
Coscinodiscus nitidus W. Gregory	2	+ +
Melosira spaerica Héribaud-Joseph	0.1	+
Melosira distans var. lirata (Ehrenberg) VanLandingham	0.6	+
Melosira moniliformis (O.F.Müller) C.Agardh	0.1	+
Hyalodiscus stelliger J.W.Bailey	0.3	+
Stephanodiscus Ehrenberg	0.4	+
Cyclotella kuetzingiana Thwaites	1.5	+ +
Cyclotella striata var. striata (Kützing) Grunow	0.1	+
Bacteriastrum hyalinum Lauder	1.4	+ +
Chaetoceros decipiens Cleve	0.4	+
Leptocylindrus danicus Cleve	0.4	+
Triceratium Ehrenberg	1.4	+
Ditylum brightwelli(T. West) Grunow	0.3	+ +
Rhizosolenia styliformis T.Brightwell	0.6	+
Eucampiagroen landica Cleve	3	+
Hemiaulus Heiberg	0.1	+
Biddulphia granulata Roper	3	+
Biddulphia mobillensis (Bail) Grun.	0.8	+ + +
Biddulphia rhombus Ehrenberg	0.2	+
Order II: Pennales		
Encyonemapro stratum Kutzing	0.2	+
Asterionella japonica Cleve	6.9	+ +
Asterionella bleakeleyi W.Smith	0.1	+
Thalassiothrix frauenfeldii (Grunow)	0.4	+
Frustulia Rabenhorst	1.1	+
Thalassionema nitzschoides Hustedt	0.7	+
Bacillaria paxillifer (O.F. Muller) T. Marsson	0.9	+
Nitzschia vermicularis (Kutz.) Hantzsch	0.1	+
Pseudo-nitzschiaaustralis Frenguelli	1	+
Nitzschia filiformis (W.Smith) Van Heurck	0.3	+
Surirella robusta Ehrenberg	0.3	+
Surirella robusta var. splendida (Ehrenberg) Van Heurck	0.5	+
Nitzschia gracilis Hantzsch	0.4	+
Nitzschia sublinearis Hustedt	0.2	+
Ulnaria ulna (Nitzsch) Ehrenberg	0.7	+
Synedra acus Kutz.	0.3	+
Encyonema caespitosum Kützing	1.5	+
Cymbella turgid W.Gregory	0.8	+
Placoneis placentula	0.3	+
Neidium affine (Ehrenberg) Pfitzer	0.8	+
Eunotia Ehrenberg	0.5	+
Neidium iridis(Ehrenberg) Cleve	0.7	+
Pleurosigma strigosum W. Smith	0.1	+

Table 2. Contd.

Pleurosigma capense Karsten	0.9	+ +
Gyrosigma scalproides (Rabh.) Cleve	0.4	+
Gyrosigma attenuatum (Kützing) Rabenhorst	0.1	+
Leptocylindrus danicus Cleve	0.2	+
Amphora pediculus var. minor Grunow	0.5	+
Amphora ovalis Kutzing	0.5	+
Phylum: Dinophyta		
Order I: Peridiniales		
Protoperidinium diabolum (Cleve) Balech	0.3	+
Protoperidinium obtusum (Karsten) Parke & Dodge	0.2	+
Order II: Gonyaulacales		
Ceratium furca (Ehrenberg) Claparède & Lachmann	0.7	+
Ceratium tripos var. atlanticum (Ostenfeld) Paulsen	0.6	+
Ceratium macroceros (Ehrenberg) Vanhöffen	0.3	+
Phylum: Chlorophyta		
Order I: Cladophorales		
Cladophoraglo merata (Linnaeus) Kutzing	0.3	+
Pithophora Wittrock	1.2	+
Order II: Chaetophorales		
Chaetophora attenuata Hazen	3	+
Order III: Sphaeropleales		
Microspora pachyderma (Wille) Lagerheim	0.3	+
Microspora floccosa (Vaucher) Thuret	0.5	+
Oedogonium Wittrock	0.8	+
Order IV: Zygnematales		
Mougeotia C.Agardh	0.5	+
Order V: Bryopsidales		
Dichotomsiphontur berosus (A. Braun ex Kutzing) A. Ernst	0.8	+
Order VI: Chlorellales		
Oocystis eremosphaeria G.M.Smith	1.1	+ +
Geminella sp.	4.3	+
Order VII: Coleochaetiales		
Chaetosphae ridiumglobosum (Nordstedt) Klebahn	2.6	+
Phylum: Cyanobacteria		
Order I: Oscillatoriales		
Lyngbya major Meneghini	0.9	+
Lyngbya kuetzingii Schmidle	0.2	+
Oscillatoria bornetii (Zukal) Forti	0.6	+
Oscillatoria princeps Vaucher ex Gomont	0.2	+
Oscillatoria minima Gicklhorn	0.2	+
Phormidium papyraceum Gomont ex Gomont	0.7	+
Order II: Nostocales		
Nostoc commune Vaucher ex Bornet & Flahault	0.2	+
Nostoc sphaericum Vaucher ex Bornet & Flahault	4.7	+
Order III: Chroococcales		
Gloeocapsa minima (Keissler) Hollerbach	0. 4	+
Chrococcus dispersus (Keiss) Lemm.	0.1	+
Chroococcus varius A. Braun	0.5	+
Synechococcus aeruginosa Nag.	0.9	+
Microcystis aeruginosa Kutzing	0.2	+

Table 2. Contd.

Gomphosphaeria aponina Kützing	0.7	+
Order IV: Synechococcales		
Microcrocisge minata Geitier	0.2	+
Phylum: Euglenophyta		
Order I: Euglenales		
Euglena ehrenbergii var. baculifera (R.H.Thompson) Gojdics	0.7	+

missing. Of all the divisions of phytoplankton found, the Euglenoids appeared least. A total of 85 species belonging to 16 orders were identified in wet season while a total of 84 species belonging to 18 orders were identified during dry season, (Tables 2 and 3, Figures 4, 5 and 6).

Statistical analysis

Species were more evenly distributed across St.3, St.4 and St.8 at dry season whereas St.1, St.2 and St.10 recorded the lowest species evenness index (J) at wet season. Shannon-wiener index (H) was highest in St.3, St.7 and St.9 at dry season while St.4 recorded the highest at wet season. Simpson's diversity index (D) recorded the lowest in St.2 for both seasons. St.9 recorded the highest individual cells at dry season while St.1, St.4 and St.10 recorded very high individual cells at wet season, as given in (Tables 4 and 5).

Generally, diversity was low at S2 in both seasons, a pattern possibly related to dominance by few species notably *C. centralis* Ehrenberg, *Coscinodiscus concinus* W. Smith and *Coscinodiscus granii* L. F. Gough.

DISCUSSION

The physical and chemical variations observed in the system may have been a reflection on the influence of seasons. For instance, the wet season was accompanied by high TSS, Ammonia and high turbidity. On the other hand, conductivity, pH, DO and salinity increased during dry season. Similar observations were made by Nwankwo and Amuda (1993) while studying the periphytic diatoms of three floating macrophytes in a polluted South-West Nigerian creek. Variations in water parameters were not too far apart in each station probably due to the control of similar factors. The results pointed out that high temperature of a dry season may have caused a rapid decomposition of oxidizable organic matter immediately after the rains. The increase in available nutrients like the reactive nitrate coupled with less current speed maybe responsible for the relative increase in diatom density at the period. Stations 9 and 10 with the lowest temperature values in both seasons recorded the highest phytoplankton abundance.

According to Pudo (1989), physical and chemical factors in Nigerian coastal waters are serious environmental limitations and have influence on organisms' development and biocenosis formation. Changes in some parameters during wet season may be linked to impacts of leachates into the estuary from Eastern Obolo River, associated creeks and wetlands in wet season. Similar observations were made by Nwankwo (1993) in Lagos lagoon Effiong and Inyang (2016) in Yew lagoon. Odum (1957) related pH levels to the amount of carbonate present in the water and often considered it an indicator of the aquatic chemical environment. The observed pH value (pH≤8.6) falls within the range reported by Nwankwo and Akinsoji (1992) for Epe lagoon and Inyang et al. (2015a) at Ejirin part of Epe lagoon. Change in pH value has a tremendous effect on the conductivity of water. The pH value in both seasons may reflect the role fresh water swamp exudates which regulate the acidity of the water body. The inflow of water during the wet season caused sudden drops in salinity whereas cessation of flood resulted to increased incursion of tidal seawater, Nwankwo (1991) working on a tropical open lagoon in South-West Nigeria made similar observation. These fluctuations may have resulted in low phytoplankton growth between the beginning of one season and towards the end of another. Hill and Webb (1958) concluded that salinity gradient in Lagos lagoon is a consequence of the movement of fresh water downstream coupled with inland movement of saline water from the sea. Such movement may result to elimination of some species except the opportunistic forms at critical periods when the salinity was either falling or rising rapidly (Nwankwo 1991).

In most cases depletion of oxygen is as a result of bacterial degradation of the organic constituents utilizing oxygen (Nwankwo and Onitiri 1992). The low DO value observed during wet season could be due to this bacterial degradation of the organic constituents utilizing oxygen introduced into the water (Inyang et al., 2015b). Effiong and Inyang (2015) made similar observation while working on epiphyton algae in a tropical lagoon in South-Western Nigeria. The depths of light penetration or water transparency during dry season may have responsible for

Table 3. Taxonomic listing, percentage composition and spatial distribution of phytoplankton species colonizing Eastern Obolo coastal water during dry season.

DRY SEASON		
Taxa across stations	**% occurrence**	**spread**
Phylum: Bacillariophyta		
Order I: Centrales		
Coscinodiscus centralis Ehrenberg	16.1	+ + +
Coscinodicus stellaris Roper	4.8	+ +
Coscinodiscus concinus W.Smith	4.5	+ +
Coscinodiscus nitidus W. Gregory	1.4	+
Coscinodiscus granii L. F. Gough	5.1	+ +
Cocconies scutellum Ehrenberg	1.7	+
Hyalodiscus stelliger J.W.Bailey	0.4	+
Encyonema prostratum Kutzing	0.1	+
Cyclotella kuetzingiana Thwaites	1.1	+ +
Actinocyclus octonarius Ehrenberg	0.1	+
Bacteriastrum delicatulum Cleve	0.1	+
Bacteriastrum hyalinum Lauder	3.0	+ +
Chaetoceros decipiens Cleve	0.4	+ +
Leptocylindrus danicus Cleve	0.3	+
Hemidiscus cuneiformis Wallich	3.2	+ +
Hemidiscus hardmanianus (Greville) Mann	0.1	+
Hemiaulus hauckii Grunow ex Van Heurck	0.1	+
Triceratium Ehrenberg	0.6	+
Ditylum sol Cleve	0.9	+
Ditylum brightwelli (T. West) Grunow	5.7	+ + +
Rhizosolenia setigera Brightwell	0.1	+
Biddulphia alternans Bail	0.1	+
Biddulphia granulata Roper	2.7	+
Biddulphia sinensis Grev.	0.9	+
Biddulphia arctica (Brightwell) Bory	0.4	+
Biddulphia mobillensis (Bail) Grun.	5.3	+ +
Biddulphia ragia (Schuitze) Ostenfeld	1.0	+
Bidullphia favus Ehrenberg	0.4	+
Biddulphia biddulphiana (Smith) Boyer	0.07	+
Terpsinoe americana (Bail.) Grunow	0.07	+
Detonula schroderi (P. Bergon)	0.07	+
Order II: Pennales		
Thalassiothrix frauenfeldii (Grunow)	4.8	+ + +
Thalassionema nitzschoides Hustedt	3.7	+ +
Thalassiosira nordenskioldii Cleve	0.08	+
Bacillaria paxillifer (O.F. Muller) T. Marsson	0.3	+
Nitzschia vermicularis (Kutz.) Hantzsch	0.1	+
Pseudo-nitzschia pungens (Grunow ex Cleve) G.R.Hasle	2.7	+
Pseudo-nitzschia delicatissima (Cleve) Heiden	0.4	+ +
Pseudo-nitzschia australis Frenguelli	0.3	+
Pseudo-nitzschia seriata (Cleve) H. Peragallo	0.2	+
Nitzschia longissima (Brebisson) Ralf	0.07	+
Nitzschia frigid Grunow	0.07	+
Ulnaria ulna (Nitzsch) Ehrenberg	1.8	+ +
Synedra crystallina (C. Agardh) Kutzing	0.1	+
Navicula pusilla W. Smith	0.2	+
Navicula crucicula (W. Smith) Donkin	0.07	+

Table 3 contd.

Cavicula scutiformis Grunow ex A. Schmidt	4.5	+
Pinnularia didyma Ehrenberg	0.5	+
Diploneis elliptica (Kutzing) Cleve	0.4	+
Diploneis didyma (Ehrenberg)	0.1	+
Pleurosigma strigosum W. Smith	0.9	+ +
Cymatopleura elliptica var. *nobilis* (Hantzsch) Hustedt	0.5	+
Phylum: Dinophyta		
Order I: Peridiniales		
Protoperidinium excentricum (Paulsen) Balech	0.4	+
Protoperidinium pentagonum (Gran) Balech	0.2	+
Protoperidinium diabolum (Cleve) Balech	0.3	+
Protoperidinium obtusum (Karsten) Parke & Dodge	0.1	+
Protoperidinium Meuniere	0.1	+
Order II: Dinophysiales		
Amphisolenia bidentata Schroder	0.3	+
Order III: Gonyaulacales		
Lingulodinium polyedrum (F. Stein) J.D. Dodge	0.4	+
Phylum:Chlorophyta		
Order I: Cladophorales		
Cladophora glomerata (Linnaeus) Kutzing	1.8	+
Pithophora Wittrock	0.1	+
Order II: Chaetophorales		
Stigeoclonium sp.	0.1	+
Order III: Sphaeropleales		
Golenkinia radiata var. *longispina* G.M. Smith	0.4	+
Order IV: Zygenmatales		
Mougeotia C.Agardh	2.0	+
Closterium Ehrenbergii	1.0	+
Order I: Bryopsidales		
Dichotom siphonturberosus (A. Braun ex Kutzing) A. Ernst	1.5	+
Order: Chlorellales		
Lagerheimia sp Chodat	0.2	+
Phylum: Cyanobacteria		
Order I: Oscillatoriales		
Lyngbya martensiana Meneghini ex Gomont	3.5	+
Gloeotrichiae chinulata (J.J. Smith)	0.04	+
Oscillatoria bornetii (Zukal) Forti	0.4	+
Order II: Nostocales		
Anabaena Bory ex Bornet et Flahaut	0.1	+
Hapalosiphon fontinalis Bornet	1.9	+
Nostoc commune Vaucher ex Bornet & Flahault	0.2	+
Aphanizomenon flos-aquae (L.) Ralfs	0.4	+
Stigonema informe Kutzing	1.1	+
Richelia intracellularis J. Schmidt	0.1	+
Order III: Chroococcales		
Gloeocapsa Kutzing	0.8	+
Gloethecem embranacea (Rabh.) Bornet	0.1	+
Chrococcus dispersus (Keiss) Lemm.	0.07	+
Synechococcus aeruginosa Nag.	0.1	+

Table 3 contd.

Microcystis firma Kutz.	0.5	+
Johannesbaptista pellucida (Dickis)	0.6	+
Aphanocapsa C. Nägeli	0.5	+
Order IV: Synechococcales		
Microcrocis geminate Geitier	0.5	+

+ + + = Spread across 7 stations and above, + + = Spread between 4 stations and 6 stations & + = spread across 3 stations and below.

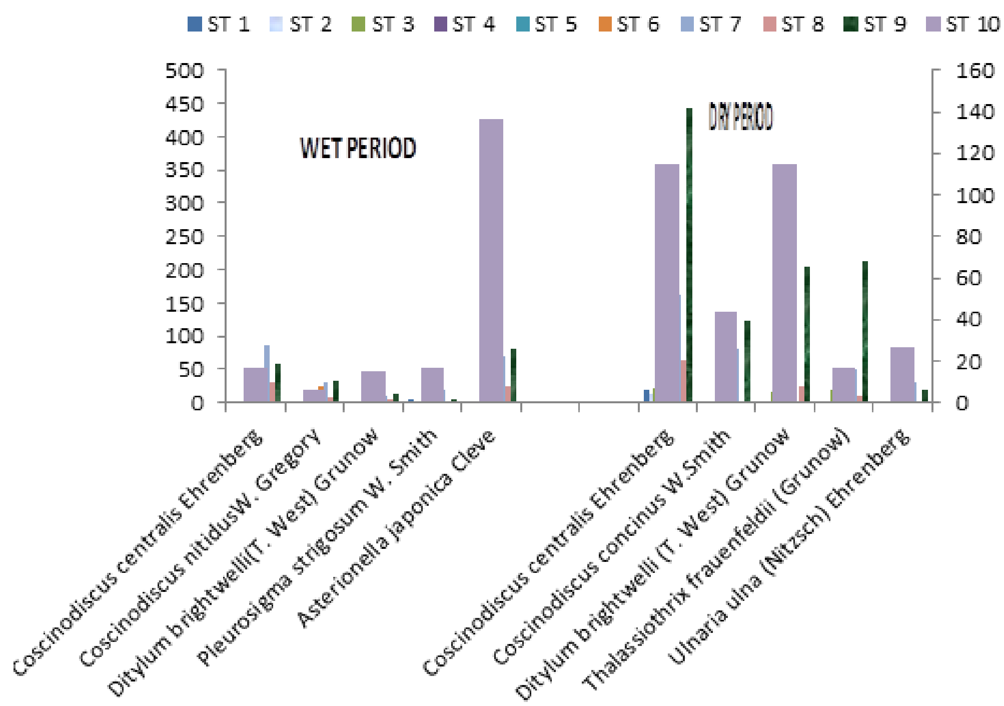

Figure 4. Seasonal variations in the density of major species of phytoplankton in both wet and dry seasons across the sampling stations in Eastern Obolo River Estuary (2016).

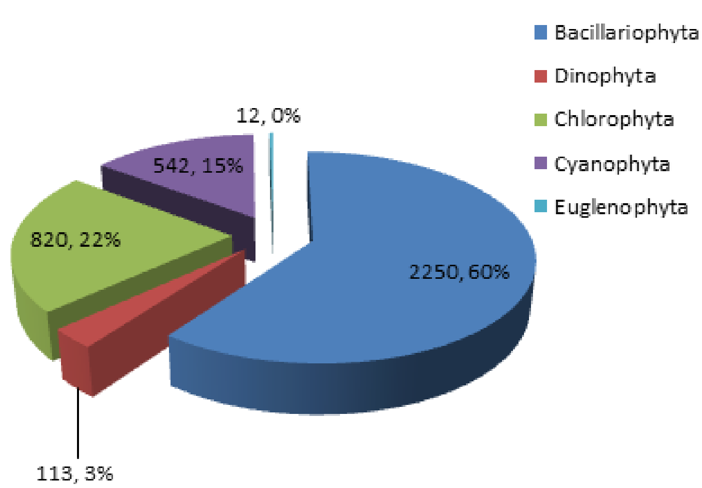

Figure 5. Relative abundance of phytoplankton divisions that occurred in Eastern Obolo coastal water during wet season, 2016.

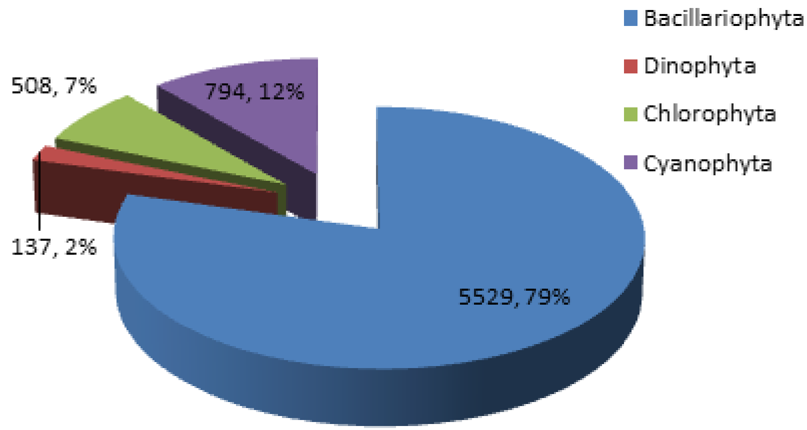

Figure 6. Relative abundance of phytoplankton divisions that occurred in Eastern Obolo coastal water during dry season, 2016.

Table 4. Variations in Evenness, Equitibility index (J), Shannon-wiener index (H), Simpson's Diversity index and individual dominance across the coastal water of stations Eastern Obolo during dry season.

Indexes	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Taxa_S	14	10	21	14	16	20	27	22	34	22
Individuals	614	236	300	224	285	624	1001	327	2630	718
Dominance_D	0.1502	0.2283	0.06507	0.113	0.1242	0.1079	0.07455	0.0835	0.07306	0.1059
Simpson_1-D	0.8498	0.7717	0.9349	0.887	0.8758	0.8921	0.9255	0.9165	0.9269	0.8941
Shannon_H	2.181	1.808	2.871	2.4	2.388	2.636	2.882	2.78	2.913	2.544
Evenness_e^H/S	0.6322	0.6097	0.8408	0.7875	0.681	0.6977	0.6608	0.7329	0.5416	0.5788
Equitability_J	0.8262	0.7851	0.943	0.9095	0.8614	0.8798	0.8743	0.8994	0.8261	0.8231

Table 5. Variations in Evenness, Equitibility index (J), Shannon-wiener index (H), Simpson's Diversity index and individual dominance across the coastal water Eastern Obolo during wet season.

Indexes	St 1	St 2	St 3	St4	St 5	St 6	St 7	St 8	St 9	St 10
Taxa_S	11	7	16	29	11	15	18	16	20	18
Individuals	525	253	376	560	262	348	482	251	406	564
Dominance_D	0.26	0.405	0.09	0.043	0.102	0.075	0.087	0.075	0.09	0.192
Shannon_H	1.709	1.329	2.6	3.248	2.344	2.645	2.674	2.664	2.704	2.097
Evenness_e^H/S	0.502	0.54	0.842	0.887	0.948	0.939	0.806	0.897	0.747	0.452
Equitability_J	0.713	0.683	0.938	0.965	0.978	0.977	0.925	0.961	0.903	0.726

high plankton biomass in the season. Unlike lagoons which could be either physically or biologically influenced, all estuaries are physically influenced in that they have direct influence with the tidal sea incursion. Species abundance was more in St.9 and St.10 which are closer to the sea, meaning that most species are brackish form. Reactive silicate values were less in months where there is high diatom biomass; this may be due to the fact that diatoms use reactive silicate to build its frustules. The abundance of phytoplankton algae population during dry season may be due to stability of estuarine water, higher photosynthetic depth, lower turbidity and lower TSS. On other hand, the paucity of diatom taxa during the wet season of the study maybe due to changes in the favorable environmental conditions. Patrick and Riener (1975) suggested that the number of diatom genera in an aquatic environment is reduced by pollution. Effiong and Inyang (2016) working on the diversity of phytoplankton in Yewa lagoon made similar observation. Chlorophyll-a abundance showed positive correlation with DO, conductivity and transparency. The varying species composition observed across the two seasons maybe due to the varying levels and other environmental factors (Webb 1960). St.10 during wet season could be a reflection of greater individual species abundance caused by the introduction of many benthic forms through flood water. According to Karentz and Mcintire (1977), the number of species in an assemblage and the degree of evenness are closely related to the species diversity. Low values of the diversity index indicate dominance by one or two species and high values indicate the species numbers are more evenly spread. This may explain the low (J) values observed in St.2 for both seasons when species like *C. centralis* Ehrenberg, *C. concinus* W. Smith and *C. granii* L. F. Gough were predominant in the plankton hauls. This explains the high diversity values are usually associated with relative unpolluted habitats.

Diatoms have been used by ecologists to indicate pollution in water bodies and other variations of ecological conditions. Species diversity index also could be used to determine the growth rate, occurrence, distribution and the species composition of the phytoplankton community. Some phytoplankton species that could be used as indicators of organic pollution include some species of *Coscinodiscus*, *Cyclotella*, *Nitzschia*, *Biddulphia*. Others may include species like *Protoperidinium excentricum* (Paulsen) Balech, *Protoperidinium pentagonum* (Gran) Balech, *Protoperidinium diabolum* (Cleve) Balech, *Protoperidinium obtusum* (Karsten) Parke & Dodge, *Protoperidinium* Meuniere etc. This shows that Eastern Obolo coastal water is relative contaminated with organic pollutants.

Conclusion

Phytoplankton biomass was higher in stations with brackish water (mezohaline), it was also higher in dry season due to relative stability of the estuarine water and higher light penetration. This means that during wet season, the estuary received a tremendous amounts of inland waters through its many other sources like creeks, canals, rivers etc resulting to low light penetration, high turbidity and high TSS, this generally resulted in the paucity of diatoms in the wet season. Phytoplankton species like *C. centralis, B. mobillensis, D. brightwelli and T. frauenfeldii* were more evenly spread across the stations than other species. A total of 5109 individual of 85 phytoplankton species belonging to 5 divisions were identified during the wet season, whereas 6906 individual of 84 phytoplankton species belonging to 4 divisions were identified during the dry season. The centrales diatoms dominated the phytoplankton species during the dry season while the pinnate diatoms dominated the phytoplankton species during the wet season. Diatoms have been used by ecologists to indicate pollution status of water bodies and other variations of ecological conditions. Some species of the genera; *Coscinodiscus*, *Biddulphia*, *Cyclotella*, *Nitzschaia*, *Protoperidinium excentricum* (Paulsen) Balech, *Protoperidinium pentagonum* (Gran) Balech, *Protoperidinium diabolum* (Cleve) Balech, *Protoperidinium obtusum* (Karsten) Parke & Dodge, *Protoperidinium* Meuniere etc which have been identified are known to be indicators of water pollution, this shows that Eastern Obolo River Estuary maybe organically polluted.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors are appreciative of Mr. Ekpo of Ministry of Sciences and Technology, Uyo, Akwa Ibom State and staff of planktology Lab. of the Department of Marine Biology, Akwa Ibom State University, Ikot Akpaden.

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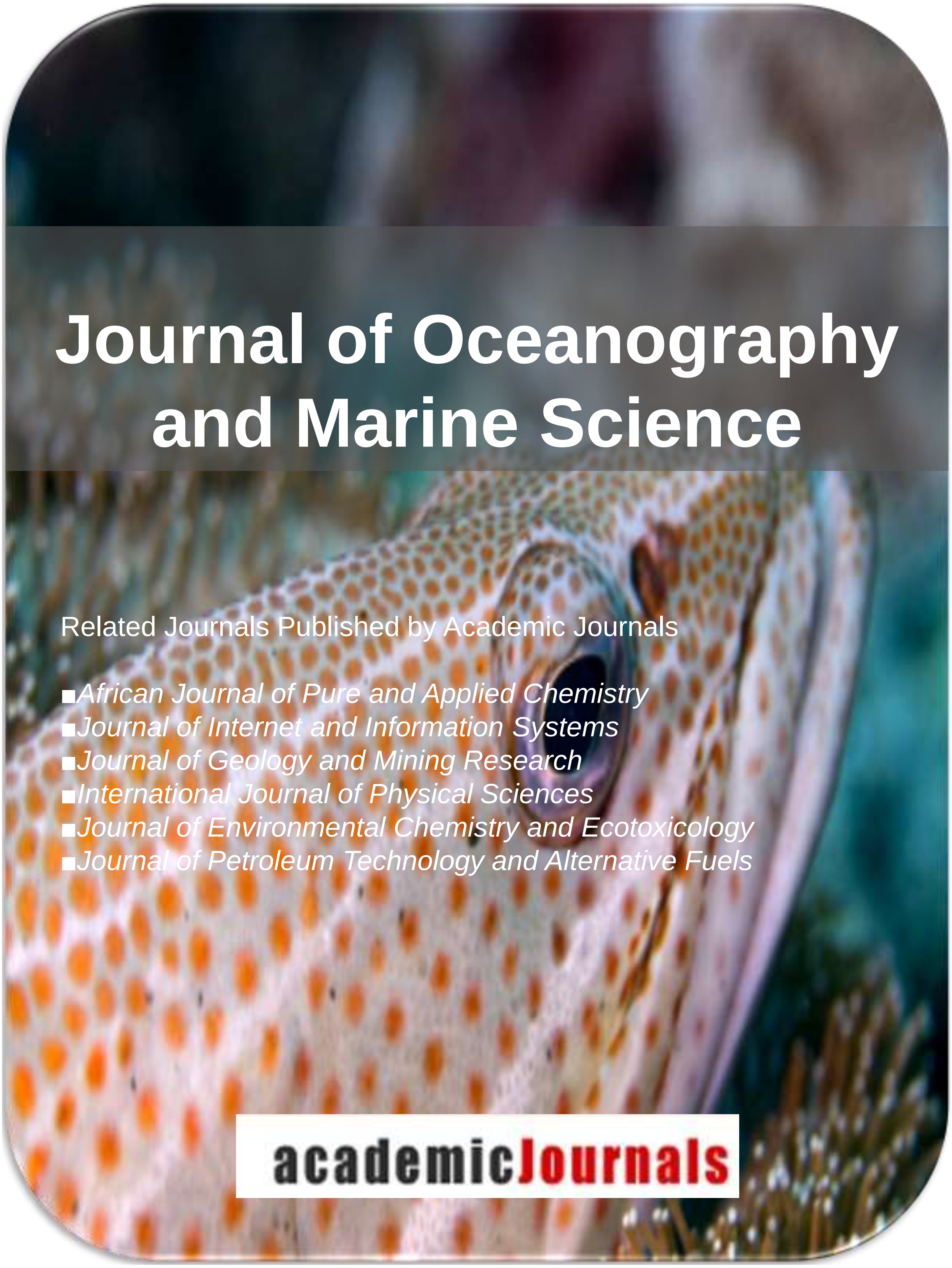
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