Journal of Applied Life Sciences International

13(4): 1-22, 2017; Article no.JALSI.35676
ISSN: 2394-1103

Assemblage Structure and Population Dynamics of Phytoplankton in a Brackish Coastal Creek, Badagry, Southwest Nigeria

Balogun Kayode James[1*]

[1]*Department of Biological Oceanography, Nigerian Institute for Oceanography and Marine Research, Victoria Island, P.M.B. 12729, Lagos, Nigeria.*

Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/JALSI/2017/35676
Editor(s):
(1) Purnachandra Nagaraju Ganji, Department of Hematology and Medical Oncology, Emory University School of Medicine, USA.
Reviewers:
(1) Ibrahim Muhammad Magami, Usmanu Danfodiyo University, Nigeria.
(2) Jorge Castro Mejia, Universidad Autonoma Metropolitana Xochimilco, Mexico.
(3) Aba Mustapha, IbnTofail University, Morocco.
(4) Yayan Mardiansyah Assuyuti, State Islamic University of Syarif Hidayatullah Jakarta, Indonesia.
Complete Peer review History: http://www.sciencedomain.org/review-history/21115

Original Research Article

Received 25th July 2017
Accepted 18th September 2017
Published 23rd September 2017

ABSTRACT

Aims: The objectives of the study were to determine phytoplankton assemblage structure in Badagry creek; to examine spatial-seasonal variations of abiotic factors and to assess their effects on it.
Study Design: Stratified random sampling.
Place and Duration of Study: Nine sampling stations were selected in Badagry creek to represent its three different areas/zones (upper, middle and lower). Three stations randomly chosen in each zone and sampled on bimonthly basis for two years beginning from November 2011 between 9.00 and 12:00 hours.
Methodology: Water and phytoplankton samples were collected and analyzed bi-monthly for two years from each station using standard methods. Water samples were analysed for temperature, pH, salinity, conductivity, turbidity, dissolved oxygen, water depth, nitrate and phosphate. Phytoplankton was identified to species level using relevant texts and counted under a Microstar IV Carl Zeiss binocular microscope calibrated at different magnifications. Diversity was determined using Shannon - Weiner (H), Evenness (e^H/S) and simpson (1-D) indices. Data were analysed

**Corresponding author: E-mail: kayjaybal@yahoo.com;*

using descriptive statistics, ANOVA, cluster and Canonical correspondence analysis (CCA) at α = 0.05.

Results: Overall, 242 phytoplankton species of six main classes were identified. Phytoplankton assemblage was dominated by Baccillariophyceae (133 species; 95.02%) specifically *Aulacoseira granulata* var. *angustissima* (Ehrenberg) Ralfs and *Actinoptychus undulatus* (Bailey). Other Algae groups were green algae (59 species), blue-green algae (27 species), euglenoids cell (17 species), dinoflagellates and Chrysophytes had three species each. Few phytoplankton species were reported to be potentially harmful species. Diversity indices values were highest (H = 2.633; E = 0.138; 1-D = 0.896) for st.8 (Iyagbe) and lowest (H = 1.221; E = 0.036; 1-D = 0.589) at Ajido (st.5). Comparatively, phytoplankton species (184) and individuals (541,655) recorded in the rainy season were higher than the dry season of 174 species and 446,516 individuals. Mean values ranged from 1.12 (st.2) - 7.83 psu(st.9), 2259.33 (st.2) - 13642.00 μScm^{-1}(st.9), 19.67 (st.7) - 36.00 FTU(st.9), 1.38 (st.7) - 6.72 m (st.2) and 3.75 (st.1) - 12.53 µmol/L(st.9) for salinity, conductivity, turbidity, water depth and nitrate, respectively. Seasonal mean variations were pH 7.47; 7.75 and PO_4 6.54; 4.80 µmol/L for dry and rainy seasons, respectively. Correlations between species and variables, suggests the importance of abiotic factors in phytoplankton assemblages. In CCA plot, Phosphate and water temperature have higher correlation ordination axis, closely followed by conductivity (salinity) and water depth.

Conclusion: Abiotic factors evaluated showed some influences on abundance and distribution of phytoplankton assemblage in Badagry creek. This study, however, provides baseline information for establishing predictions of phytoplankton population changes in Badagry creek.

Keywords: Abiotic factors; Badagry creek; phytoplankton; diversity; CCA.

1. INTRODUCTION

Assemblages of flora and fauna species differ from ecosystem to ecosystem because of habitat conditions. In most aquatic ecosystems, there are plant species that are vulnerable to slightest change in their surrounding environment. Changes in their distribution and abundance can provide a good indication of "health" of coastal environment/aquatic ecosystem [1].

All aquatic ecosystems are provided with phytoplankton, which is microscopic and cosmopolitan in distribution. Phytoplankton increases its growth in aquatic ecosystem with sufficient nutrient and suitable ecological conditions, which play a key role in their availability and abundance. Its abundance increases productivity of water, as they form the basic food source in any aquatic environment [2]. Phytoplankton has long been used as indicators of water quality [3]. They respond quickly to environmental changes, because of their short life spans. Phytoplankton thrives well in coastal waters predisposed to eutrophication. Furthermore, the distribution, abundance, species composition and diversity studies of the phytoplankton are used to assess the biological integrity of water body.

One of the main objectives of community ecology is knowledge and prediction of community characteristics in response to different environmental factors. In an aquatic ecosystem, abiotic factors play a significant role in distribution pattern and species composition of phytoplankton. The high biomass and species composition variability is the result of species-specific sensitivity of phytoplankton physiology to aquatic ecosystems conditions, such as, temperature, salinity, and nutrient concentrations [4].

The phytoplankton community ecology in coastal waters of south-western, Nigeria had been investigated and reported in different studies [5,6,7,8,9,10,11,12,13]. Despite these studies, no comprehensive work has attempted to characterize phytoplankton community in Badagry creek and elucidate the processes responsible for their composition and abundance. The specific composition of phytoplankton communities, the relative abundance of different species, and the dominance of one population over another are all traits and phenomena in constant evolution that characterize phytoplanktonic successions. Hence, the specific objectives of the study were to: (1) determine spatial and seasonal variations in relevant abiotic factors of this creek; (2) evaluate distribution, abundance, and species diversity of phytoplankton and; (3) assess the effect of abiotic factors on phytoplankton community of Badagry creek, Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is Badagry creek (Fig. 1), located at west of barrier lagoon complex (one of the four coastal geomorphic divisions in Nigeria) between 2°42'; 3°23'E and 6°23'; 6°28'N. The creek is approximately equidistant from Lagos and Cotonou harbor's entrance. In Nigeria, Badagry creek is fed with freshwater inputs by Yewa River, and links Ologe Lagoon. It is part of 260 km-long lagoon system stretching from Cotonou to Niger Delta. The creek has an estimated size of 1875 ha, which supports artisanal fisheries, water ways transportation and cultural heritages [1]. Badagry creek depth range was between 0.45 and 8.84m. The sediment granulometric is low in diversity and comprised of sand (62 – 100%), silt (0 – 26%) and clay (0 – 16%) [1]. The predominant vegetation along shorelines are made up of woody plants, shrubs, coconut and oil palm trees in sandy areas, while the marshy areas are covered by white mangrove (*Avicennia africana*). There is currently an increasing development of the area, with new constructions such as houses, hotels and resorts along shorelines that may impact creek quality. Road runoff, boat activity, leachate from waste dumping ground on creek shorelines are potential contaminant sources in Badagry creek.

The regional climate of Badagry creek is highly seasonal, comprising two main seasons (rainy and dry) with average annual (precipitation) rainfall of 1650 – 1750 mm. While rainy season lasts from May to October with a sharp drop in rainfall (downpour) in august month (August break), dry season lasts from November to April. The rainfall of Badagry is largely influenced by southwest trade winds from Atlantic Ocean and dust-laden northeast trade (dry) winds from Sahara Desert become dominant during dry months producing hazy weather conditions [14].

Badagry creek can be divided into three zones based on geographic locations and logistical characteristics, viz., upper, middle and lower zones [1]. In this study, a total of nine sampling stations were selected to represent its three different areas (three stations chosen in each three established zones) (Fig. 1).

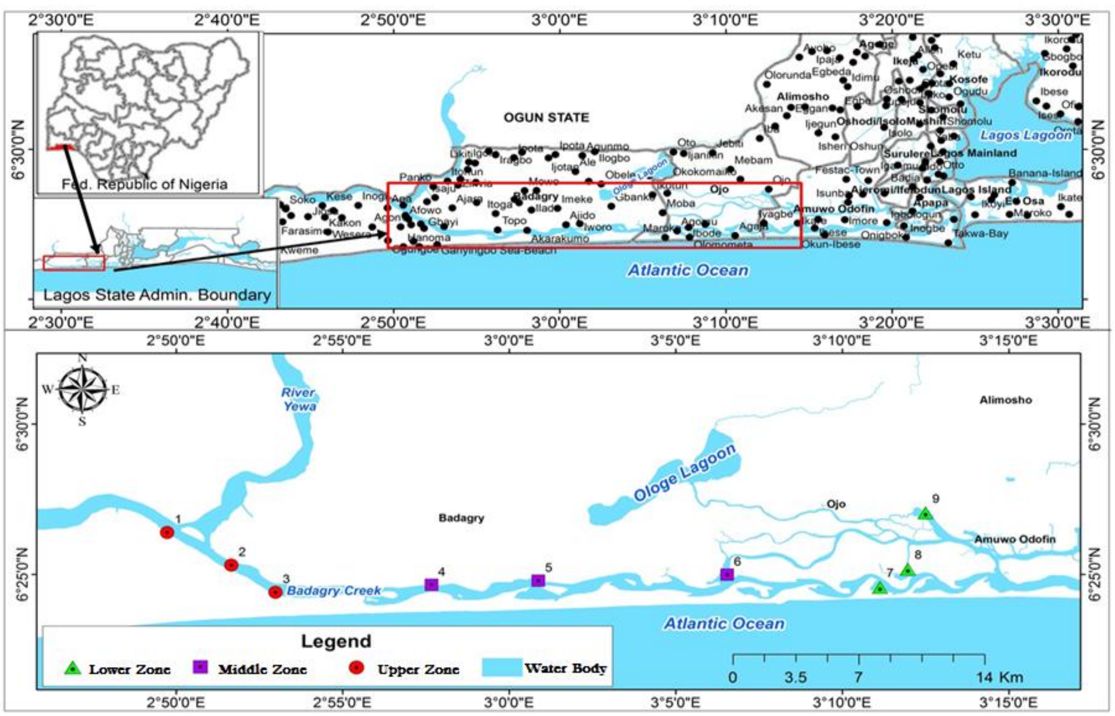

Fig. 1. Map of Badagry creek and its environs showing sampling stations

Upper zone: Stations 1(Apa), 2(Gbaji), 3(Badagry/Yovoyan jetty).
Middle zone: Stations 4(Akarakunmo), 5(Ajido), 6(Irewe).
Lower zone: Stations 7(Igbolobi), 8(Iyagbe), 9(Ojo).

2.2 Collection of Samples

Bi-monthly samplings of phytoplankton were carried out from November 2011 to September 2013.

Phytoplankton sample trail was carried out horizontally on each sampling trip from each station with a 55 µm mesh size standard plankton net held against the current of ebbing tide at low speed (< 4 knots) for five minutes from an outboard engine boat. Phytoplankton samples were concentrated and transferred to a 500 mL well labelled plastic container with screw cap and preserved with 4% unbuffered formalin and stored in laboratory prior to microscopic analysis [15].

At same time with phytoplankton sampling, water samples for physical-chemical parameters determination were collected just under surface at each station with a 5 L Teflon coated Niskin sampler and transferred into 1 L screw-capped plastic containers and stored in a refrigerator at 4°C ± 1°C prior to analyses. For dissolved oxygen determination, under surface water samples were collected in 250 mL dissolved oxygen bottles at each station and fixed according to Winkler's method using Manganese Sulphate solution and Alkaline Potassium iodide reagents.

2.3 Phytoplankton Identification

Preserved phytoplankton samples were reduced to a concentration of about 20 mL by decanting the supernatant aliquot. Phytoplankton identification and counting were made with a Sedgwick Rafter counting chamber under a Microstar IV Carl Zeiss binocular microscope calibrated at different magnifications (x10, x40 and x100 objectives). For each 1 mL of water sample, at least 10 transects were thoroughly investigated with each transect at right angle to first. Enumeration was done on natural unit count and reported in terms of abundance (organism mL^{-1}) [15]. All phytoplankton were identified to species level using relevant taxonomic texts [16,17,18].

2.4 Determination of Abiotic Factors

Water temperature was determined *in-situ* with mercury in glass thermometer. Salinity and pH were measured *in-situ* using a Multi-meter water checker (Horiba) Model U-10. Turbidity was measured directly in a smart–spectrophotometer at turbidity wavelength against distilled water as reference. Dissolved oxygen in water samples were estimated using modified iodometric Winkler's method [19]. Water depth (m) profile was determined by means of a cylindrical rod calibrated along its length in centimetres. Nitrate was analysed using the standard pink azo-dye method. Phosphate was determined using molybdenum-blue methods. In all cases, nutrient analyses were done according to Parsons et al. [20] methods.

2.5 Processing Data

All collected data were tabulated and appropriate graphs were created. Biological index were evaluated according to Shannon diversity index (H), Simpson index (1 -D), and Pielou's evenness index (e^H/S) using software package 'PAST' [21].

2.6 Statistical Analysis

All values were recorder in Excel database to obtain descriptive analysis. Inferential statistics were made using XLSTAT statistical software. A Levene's test was run to determine if variances were homogeneous for each dependent variable. To determine significant differences between stations and seasons, one-way analysis of variance (ANOVA) ($P \leq 0.05$) were made. When significant differences were obtained, mean values were separated using post-hoc Tukey's (HSD) test. Spearman rank correlation (*r*) was used to determine associations between overall abiotic variables and dominant species abundance. Minitab 16 statistical software was used for the hierarchical cluster analysis of species abundance.

Canonical Correspondence Analysis (CCA) ordination techniques in Excel using XLSTAT statistical software was run with abiotic factors, species and station data to define relationships between them and to identify abiotic variables that best explained species distribution patterns at study areas. To reduce the effect of rare species, only 25 most dominant species were considered in CCA [22]. A Monte Carlo randomization test (1000 permutations) was run to assess probability of observed pattern being due to chance [23].

3. RESULTS

3.1 Abiotic Parameters

Minimum, maximum and mean values of investigated abiotic factors data at sampling stations and seasons in Badagry creek are presented in Tables 1 and 2, respectively. Salinity, conductivity, turbidity, water depth and nitrate variables were significantly different among sampling stations while pH and phosphate differed significantly between seasons.

Water temperature was stable in all stations studied and throughout study duration but with slightly higher values in dry (months) season. While pH differences among sampling stations were not significantly different (P = 0.96), pH of rainy season was significantly higher (P<0.001) than dry season. Salinity decreased gradually from lower zone to upper zone, with a significant freshwater inflow. Seasonally, rainy months mean salinity was lower than dry (months) season, but these values were not significant (P = 0.17). Conductivity showed similar trend with salinity, decreased drastically from lower to upper zone and was higher in the dry season than rainy season. Turbidity showed spatial variation with lowest mean at station 7 and highest mean value in station 9. Dry season mean turbidity value was slightly higher than rainy season value, but these values were not significantly different (P = 0.23). Mean water depth in station 2 and 3 were significantly higher than other stations (P<0.001). Rainy season mean water depth was higher than dry season, but difference was not seasonally significant (P = 0.44). Dissolved oxygen (DO) mean values varied between 3.73 mg L^{-1} at station 9 and 5.28 mg L^{-1} in station 7. Dry season mean DO value was slightly higher than rainy season. However, there was no significant difference in DO values among stations (P = 0.16) and between seasons (P = 0.31). Nitrate showed spatial significant variation (P = 0.01), with the least (3.75 µmol L^{-1}) and highest (12.53 µmol L^{-1}) mean values at station 1 and 9, respectively. Seasonally, nitrate dry (months) season mean was higher than rainy (months) season, but the difference was not significant (P = 0.97). Phosphate mean values varied among stations, with high values at station 9 and 8 (lower zone), but the differences were not statistically significant (P = 0.47). The dry season phosphate mean value was significantly higher than rainy season mean value (P = 0.02).

3.2 Phytoplankton Composition

A total of 242 phytoplankton species belonging to 123 genders were identified in the present study. The checklist of phytoplankton identified in Badagry creek, Nigeria comprises of six major classes and 17 orders (Table 3). Phytoplankton classes included Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae, Dinophyceae and Chrysophyceae. Diatoms constituted 133 species from 73 genders (centrale and pennale forms of Bacillariophyceae had 53 and 80 species, respectively), green algae consisting 59 species from 27 genders, blue-green algae (27 species from 13 genders), euglenoids cell recorded 17 species from four genders, dinoflagellates and Chrysophytes had three species from three genders each (Table 3). Notable species in order of dominance in Badagry creek were *Aulacoseira granulata* var. *angustissima* (Ehrenberg) Ralfs, *Actinoptychus undulatus, Coscinodiscus lineatus, Surirella robusta* var. *splendida and Amphiprora costata* Hustedt.

Species compositions were higher among diatoms than other classes. Prominent diatom species were *Aulacoseira granulata* var. *angustissima, Actinoptychus undulatus, Coscinodiscus lineatus, Surirella robusta* var. *splendida, Amphiprora costata* Hustedt, and *Coscinodiscus nitidus.* Chlorophyceae species were dominated by *Eudorina cylindrical, Closterium cornu* var. *javanicum* and *Closterium kuetzingii* var. *vittatum. Cyanophyceae* were more dominated by *Microcystis aeruginosa* Kützing, *Nodularia spumigena* Mertens and *Oscillatoria tenius* Agardh. In Euglenophyceae, *Euglena ehrenberghii, Euglena rostrifera, Phacus longicauda* var. *rotundus* and *Euglena oxyuris* f. charkowiensis were the more represented species. Dinophyceae and Chrysophyceae consisted of three species each (*Noctiluca scintillans, Gonyaulax fragilis and Peridinium cinctum)* and *(Tribonema monochloron, Tetrasporopsis perforata,* and *Goniochloris gigas*), respectively.

In all collected samples, dominant species at station 1 (Apa) were *Actinoptychus undulatus* (27.16%), *Surirella robusta* var. *splendida* (21.71%), *Coscinodiscus nitidus* (13.54%), *Coscinodiscus lineatus* Ehrenberg (13.25%), *Microcystis aeruginosa* (6.80%) and *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs (5.05%). Samples taken at station 2 (Gbaji) were dominated by *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs (41.41%), *Actinoptychus undulatus* Bailey (21.46%), *Coscinodiscus lineatus* Ehrenberg (14.95%) and *Aulacoseira granulata* var. *angustissima* f. spiralis Müller (9.18%).

Table 1. Mean values of spatial variation of abiotic factors of Badagry creek, Nigeria (Nov. 2011 – Sept. 2013) (Range values in parenthesis)

Variable	Station sampling									P-value (F-value)
	1	2	3	4	5	6	7	8	9	
W.T	29.63 (26-33)	29.04 (22-33)	29.38 (23-32)	29.42 (26-32)	29.75 (26-33)	29.54 (26-31)	29.58 (26-31)	29.13 (26-31)	29.58 (26-32)	0.99 (0.18)
pH	7.70 (6.76–8.27)	7.63 (6.20–8.45)	7.66 (6.33–8.36)	7.67 (6.28–8.37)	7.65 (6.28–8.02)	7.45 (6.29–7.81)	7.61 (7.02–8.05)	7.56 (6.21–8.04)	7.57 (6.22–8.52)	0.96 (0.31)
Sal	1.27^{b} (0–7.2)	1.12^{b} (0–6.3)	1.59^{b} (0 – 10.2)	1.64^{b} (0–12.2)	1.68^{b} (0–11.0)	3.40^{ab} (0–12.0)	4.61^{ab} (0–11.2)	6.80^{a} (0-14.5)	7.83^{a} (0.1–14.2)	<0.001 (5.97)
EC	2674^{b} (144-15300)	2259^{b} (121-12000)	2855^{b} (136-16000)	2838^{b} (138-18000)	3141^{b} (129-19000)	7288^{ab} (158-22000)	8629^{ab} (200-21000)	12116^{a} (180-23000)	13642^{a} (294-23000)	<0.001 (6.70)
Turb.	29.92^{a} (16–52)	24.00^{a} (12–68)	34.33^{a} (15-72)	19.75^{a} (8-40)	35.58^{a} (20-58)	33.00^{a} (14-85)	19.67^{a} (6-42)	24.17^{a} (11-49)	36.00^{a} (16-64)	0.01 (2.63)
WD	2.98^{bcd} (1.49-5.60)	6.72^{a} (2.85-9.52)	6.52^{a} (4.55-8.84)	4.08^{b} (1.46-5.13)	2.37^{cde} (1.32-3.31)	3.33^{bc} (2.24-4.70)	1.38^{e} (0.45-2-95)	2.32^{cde} (1.04-4.12)	1.64^{de} 0.86-4.25)	<0.001 (32.30)
DO	4.58 (2.4-6.0)	5.07 (2.8-7.60)	4.88 (2.8-7.60)	5.13 (2.8-8.0)	4.73 (3.2-6.80)	4.57 (2.4-6.80)	5.28 (2.80-6.80)	5.07 (2.80-6.40)	3.73 (1.2-5.20)	0.16 (1.54)
NO_3	3.75^{b} (0.29–9.19)	4.74^{b} (0.16–11.77)	3.94^{b} (0.16–11.45)	6.85^{ab} (0.32–17.58)	6.95^{ab} (0.16–17.74)	9.87^{ab} (0.16–18.39)	7.91^{ab} (0.81–16.94)	8.06^{ab} (0.47–17.90)	12.53^{a} (0.32–18.06)	0.01 (2.78)
PO_4	5.04 (0.32–9.58)	4.90 (0.32–10.74)	5.83 (0.42–11.79)	4.94 (0.21–10.32)	4.83 (0.32–9.58)	5.28 (0.42–10.95)	5.46 (0.21–9.79)	6.79 (0.11–15.06)	7.99 (0.53–15.27)	0.47 (0.97)

Wat.T – Water Temperature (^{o}C); Sal. – Salinity (psu); EC – Electrical Conductivity (μScm^{-1}); Turb. – Turbidity (FTU); WD – Water Depth (m); DO – Dissolved Oxygen (mg L^{-1}); NO_3 – Nitrate ($\mu mol\ L^{-1}$); PO_4 – Phosphate ($\mu mol\ L^{-1}$).

St. 1 - Apa; St.2 – Gbaji; St. 3 – Badagry/Yovoyan jetty; St. 4 – Akarakumo; St. 5 – Ajido; St. 6 – Irewe; St. 7 – Igbolobi; St. 8 – Iyagbe; St. 9 – Ojo.

Means that do not share a letter are significantly different (P<0.05)

Station 3 (Badagry/Yovoyan jetty) was dominated by *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs (61.86%), *Actinoptychus undulatus* Bailey (26.06%) and *Coscinodiscus lineatus* Ehrenberg (5.44%). Dominant species at station 4 (Akarakumo) were *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs (52.00%), *Actinoptychus undulatus* Bailey (29.91%) and *Coscinodiscus nitidus* (8.73%). Station 5 (Ajido) samples were dominated by *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs (56.59%), *Actinoptychus undulatus* Bailey (29.87%) and *Amphiprora costata* Hustedt (6.75%). The prominent species at station 6 (Irewe) were *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs (43.24%), *Actinoptychus undulatus* Bailey (33.53%), *Amphiprora costata* Hustedt (10.59%) and *Surirella robusta* var. *splendida* (10.15%). *Actinoptychus undulatus* Bailey (46.60%) and *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs (36.82%) dominated samples collected at station 7 (Igbolobi). While station 8 (Iyagbe) had *Coscinodiscus centralis* Ehrenberg (18.02%), *Actinoptychus undulatus* Bailey (14.45%), *Coscinodiscus subtilis* Ehrenberg (13.72%), *Coscinodiscus lineatus* Ehrenberg (8.51%) and *Surirella robusta* var. *splendida* (8.24%) as its dominant species, station 9 (Ojo) was dominated by *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs (54.46%) and *Eudorina cylindrical* (33.87%).

All the six classes of phytoplankton recorded in this study were encountered at station 2 and 8 (Gbaji and Iyagbe) (Fig. 2a). Order Centrales of diatoms was more abundant (86.31%) in phytoplankton orders identified and well distributed among the stations while Mischococcales was the least (0.0003%) represented by *Goniochloris gigas*, and recorded only at station 1 (Apa). All the phytoplankton orders identified in the study were found in all stations with an exception of Oedogoniales, found only in station 9 (Ojo), Siphonocladales recorded at station 7 and 9 (Igbolobi and Ojo), Ulotrichales was seen only at station 2, 3 and 4 (Gbaji, Badagry/Yovoyan jetty and Akarakumo), Noctilucales was represented only at station 2 and 3 (Igbaji and Badagry/Yovoyan jetty), Tribonematales found only at station 6 (Irewe), Chromulinales was present at station 1, 2, 7, 8 and 9 (Apa, Gbaji, Igbolobi, Iyagbe and Ojo) and Mischococcales was recorded only at station 1 (Apa).

Diatoms were more frequent and dominated in both seasons with 92.82% (dry season) and 98.65% (rainy season) of total counts in each season. The phytoplankton recorded in order of dominance during dry season (Fig. 2a) included diatoms (92.82%), green algae (3.62%), blue-green algae (3.43%), chrysophytes (0.114%), euglenoids (0.013%) and dinoflagellates (0.001%). In rainy season, diatoms (98.65%), blue-green algae (0.85%), green algae (0.49%),

Table 2. Mean values of seasonal variation of abiotic factors of Badagry creek, Nigeria (Nov. 2011 – Sept. 2013) (Range values in parenthesis)

Parameters	Dry season	Rainy season	P value (F-value)
Water temperature (^{o}C)	29.71 (28 - 31)	29.19 (22 - 33)	0.16 (2.0)
pH	7.47 (6.20 – 8.45)	7.75 (7.23 – 8.52)	<0.001 (9.40)
Salinity (psu)	3.81 (0 – 14.5)	2.84 (0 - 14.2)	0.17 (1.96)
E. conductivity (µScm^{-1})	7155.43 (181 - 23000)	5165.87 (121 - 23000)	0.87 (0.03)
Turbidity(FTU)	30.15 (8 – 85.0)	26.83 (6 – 64.0)	0.23 (1.46)
Water Depth (m)	3.39 (0.45 – 9.05)	3.57 (0.95 – 9.52)	0.44 (0.60)
Dissolved Oxygen (mg L^{-1})	4.91 (2.8 – 7.60)	4.66 (1.2 – 8.0)	0.31 (1.04)
Nitrate (µmol L^{-1})	7.20 (0.16 – 17.42)	7.15 (0.16 – 18.39)	0.97 (0.00)
Phosphate (µmol/L)	6.54 (0.53 – 15.27)	4.80 (0.11 - 12.64)	0.02 (5.76)

euglenoid cells (0.018%), chrysophytes (0.001%) and dinoflagellates (0.001%) were obtained in order of dominance (Fig. 2b). All orders encountered were represented during dry season except Siphonocladales and Noctilucales, whereas during rainy months Oedogoniales, Dinokontae, Tribonematales and Mischococcales were not found. Both seasons were dominated by centrales order of diatoms while other orders were observed in smaller populations. In order of dominance, *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs, *Actinoptychus undulatus* Bailey, *Aulacoseira granulata* var. *angustissima* f. spiralis Müller, and *Microcystis aeruginosa* Kützing were the notable species encountered during dry season, whereas wet season notable taxa were dominated by *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs, *Actinoptychus undulatus* Bailey, *Coscinodiscus lineatus* Ehrenberg, *Surirella robusta* var. *splendida, Amphiprora costata* Hustedt and *Coscinodiscus nitidus.*

Table 4 shows overall spatial and seasonal variation of species and individuals recorded in the study. Highest and lowest species distribution was recorded in station 1 and 6, respectively. Individuals were highest in station 6 and least at station 8. Rainy season species distribution and individuals were higher than dry season species distribution and individuals (Table 4). Spatially, while the highest values of Simpson, Shannon and Evenness indexes of 0.896, 2.633 and 0.138, respectively were obtained for Iyagbe (Station 8), their corresponding lowest values of 0.589, 1.221 and 0.036 were recorded at Station 5 (Ajido) (Fig. 3a). Seasonally, the variation in the diversity indices of Badagry creek (Fig. 3b), revealed higher rainy season indexes. Simpson (1-D) index values of 0.512 and 0.699 were obtained for dry and rainy seasons, respectively. Shannon (H) index value of the rainy season (1.669) was higher than the dry season (1.167). Evenness index (e^H/S) values varied between 0.019 and 0.029, with higher value in the rainy season and lower value in dry season.

Table 3. List of Phytoplankton recorded in Badagry creek, Nigeria (Nov. 2011 – Sept. 2013)

	Species
Division: Bacillariophyta (Diatomaceae)	
Class: Bacillariophyceae	
Order i: Centrales	
Family: Coscinodiscaceae	*Actinoptychus undulatus* (Bailey)
	Aulacoseira granulata var*. angustissima* (Ehr.) Ralfs
	Aulacoseira granulata var*. angustissima* f. spiralis Müller
	Aulacoseira granulata var*. Muzzanensis*
	Aulacoseira islandica
	Aulacoseira islandica subsp. helvetica O. Müller
	Aulacoseira italica var*. subarctica O.* Müller
	Aulacoseira italica var*. varida* Grun.
	Aulacoseira pusilla
	Aulacoseira undulata Ehrenberg
	Bacteriosira fragilis
	Coscinodiscus centralis Ehrenberg
	Coscinodiscus concinnus W. Smith
	Coscinodiscus curvulatus
	Coscinodiscus divisus Grunow
	Coscinodiscus lineatus Ehrenberg
	Coscinodiscus marginatus Ehrenberg
	Coscinodiscus nitidus Gregory
	Coscinodiscus oculus – iridis Ehrenberg
	Coscinodiscus radiatus Ehrenberg
	Coscinodiscus sub-bulliens
	Coscinodiscus subtilis Ehrenberg
	Cyclotella comta Kützing
	Cyclotella meneghiniana (Kütz) Grunow
	Cyclotella stelligera Cleve and Grunow
	Hyalodiscus sp.

	Species
	Melosira borreri (Grev.)
	Melosira nummuloides (Dillwyn) Agardh.
	Melosira moniliformis (Müller) Agardh.
	Stephanodiscus hantzschii Grunow
Family:Chaetoceraceae	*Chaetoceros atlanticum* Cleve
Family: Leptocylindraceae	*Leptocylindrus daniscus*
Family: Odontellaceae	*Climacodium frauenfeldianum* Grun.
	Odontella mobiliensis (Bailey) Grunow
	Odontella favus (Ehbg.) V. Heurck
	Odontella laevis
	Odontella vesiculosa
	Odontella regina W. Smith
	Terpsinoe musica (Ehr.) Hustedt
Family: Hemiaulaceae	*Hemiaulus membraceus*
Family: Thalassiosiraceae	*Thalassiosira hyalina*
	Skeletonema costatum (Grev.) Cleve
	Skeletonema marinoi-dorhnii
	Thalassiosira rotula
Family: Lithodesmiscaceae	*Ditylum brightwellii*
	Guinardia flaccid
Family: Rhizosoleniaceae	*Gossleriella tropica* Shütt
	Rhizoselenia hyaline
	Rhizosolenia delicatula Cleve
	Rhizosolenia stolterfothii Peragallo
Family: Achnanthaceae	*Achnanthes longipes* Agardh
	Cocconeis placentula
	Diploneis marginestriata Hust.
Order ii: Pennales	
Family: Fragilariaceae	*Asterionella formosa*
	Diatoma vulgaris
	Diatoma elongatum
	Fragilaria construens (Ehr.)
	Fragilaria crotonensis
	Fragilaria cylindrus Grun.
	Fragilaria islandica
	Fragilaria oceanica Cleve
	Synedra sp.
	Synedra acus
	Synedra affiinis
	Synedra capitata
	Synedra crystallina (Ag) Kützing
	Synedra ulna (Nitzsch) Ehrenberg
	Tabellaria fenestrate
	Tabellaria flocculosa (Roth) Kützing
	Thalassiothrix nitzschioides Grun.
	Thalassiothrix longissima
	Thalassiothrix frauenfeldii Grunow
Family: Naviculaceae	*Amphiprora costata* Hustedt
	Gyrosigma balticum
	Gyrosigma fasciola
	Gyrosigma scalproides
	Gyrosigma spenceri
	Mastogloia braunii Grunow
	Navicula menisculus
	Navicula mutica Kützing
	Navicula ancisa

	Species
	Navicula bacillum
	Navicula exigua
	Navicula riparia
	Navicula radiosa var. *Tenella*
	Navicula viridula (Kütz.) em. van Heurck
	Neidium grunowii
	Neidium javanicum
	Neidium affine (Ehr.)
	Neidium iridis var. *Amphigomphus*
	Neidium iridis var*. Subampliatum*
	Parabelius delognei (V.H.) E.J. Cox
	Pinnularia braunii var. *amphicephala*
	Pinnularia brevicosta
	Pinnularia cardinalis
	Pinnularia ruttneri
	Pinnularia major (Kütz) Rabh
	Pleurosigma angulatum
	Pleurosigma capense
	Pleurosigma elongatum
	Pleurosigma salinarium Reimer
	Pleurosigma strigosum (W. Smith)
	Stauroneis anceps
	Stenopterobia rautenbachiae
Family: Nitzschiaceae	*Bacillaria paradoxa* Gmel.
	Hantzschia sigma
	Nitzschia acicularis Smith
	Nitzschia bacata
	Nitzschia closterium
	Nitzschia delicatissima
	Nitzschia aequalis
	Nitzschia linearis
	Nitzschia seriata
	Nitzschia denticula Grunow
	Nitzschia ignorata Krasske
	Nitzschia obtuse
	Nitzschia intermedia
	Nitzschia punctate
	Nitzschia serrata f. elongata
	Nitzschia sigma Grunow
	Nitzschia sigmoidea Grunow
	Nitzschia subtilis f. tchadensis
	Nitzschia tryblionella var. *victoria*
	Nitzschia vivax
Family: Surirellaceae	*Campylodiscus clypeus var. bicostatus* (Ehr.) Kützing
	Cymatopleura elliptica Brébisson
	Surirella angusta
	Surirella linearis var. *constricta* (Ehr.) Grun.
	Surirella robusta var. *armata*
	Surirella robusta var. *splendida*
	Surirella tenera
Family: Cymbellaceae	*Amphora coffaeiformis* Agardh
	Cymbella prostata
Division: Chlorophyta	
Class: Chlorophyceae	
Order i: Chlorococcales	
Family: Chlorococcaceae	*Chlorococcum sp.*

	Species
Family: Oocystaceae	*Ankistrodesmus falcatus Ralfs* var. *setiformis Nygaard f. brevis* Nygaard
	Ankistrodesmus falcatus Ralfs var. *mirabilis West f. dulcis (Playfair)* Nygaard
	Ankistrodesmus falcatus Ralfs var. *setiformis f. elongata* Nygaard
	Palmellococcus minutus (Kütz.) Chodat
	Treubaria crassipina G. M. Smith
	Palmellococcus protothecoides (Kruger) Chodat
Family: Micractiniaceae	*Acanthosphaera zachariasi* Lemm.
Family: Dictyosphaeriaceae	*Westella botryoides* Wildemann
Family: Mesotaeniaceae	*Gonatozygon kinahanii*
Family: Hydrodictyaceae	*Pediastrum boryanum* var. *longicorne* Meneghini
	Pediastrum clathratum (A.Brawn) Lengerth
	Pediastrum duplex
	Pediastrum simplex
	Pediastrum simplex var. *duodenarium* Bailey
	Pediastrum tetras
	Pedistrum duplex var. *subgranulatum*
	Hydrodictyon reticulatum
Family: Coccomycaceae	*Elakatothrix gelatinosa* Wille
Family: Scenedesmaceae	*Actinastrum hantzschii* var. *fluviatile*
	Coelastrum microporum Nägeli
	Crucigenia tetrapedia
	Scenedesmus acuminatus var. *elongatus*
	Scenedesmus armatus var. *bicaudatus*
	Scenedesmus brasiliensis
	Scenedesmus carinatus
	Scenedesmus circumfusus var. *bicaudatus*
	Scenedesmus nygaardii
	Scenedesmus opoliensis var. *mononensis*
	Scenedesmus protuberans
	Scenedesmus quadricauda
	Scenedesmus quadricauda var. *longispina*
Order ii: Volvocales	
Family: Volvocaceae	*Eudorina cylindrical*
	Volvox globator
	Pandorina morum
Order iii: Zygnematales (Conjugales)	
Family: Desmidiaceae	*Arthrodesmus incus Hassall var. extensus* Andersson
	Closterium cornu var. javanicum
	Closterium dianae var. *brevius*
	Closterium acutum
	Closterium eboracense
	Closterium subulatum
	Closterium gracile Brébisson
	Closterium kuetzingii var. *vittatum*
	Closterium limneticum f. *elongatum*
	Closterium lineatum Ehrenberg
	Closterium setaceum f. *sigmoideum* (Irenee-Marie)
	Hyalotheca dissiliens
	Hyalotheca undulatus
	Micrasterias radiosa f. *Minuta*
	Staurastrum sebaldii var. *ornatum* f. *Minus*
	Spondylosium planum

	Species
	Staurastrum caledonense
	Staurastrum leptocladum
	Staurastrum paradoxum Meyen
Family: Zygnemataceae	*Spirogyra africana* Fritsch Cruda
Order: Oedogoniales	
Family: Oedogoniaceae	*Oedogonium sp.*
Order iii: Siphonocladales	
Family: Cladophoraceae	*Cladophora sp.*
Order iv: Ulotrichales	
Family: Ulotrichaceae	*Stichococcus bacillaris* Nageli
Division: Cyanophyta	
Class: Cyanophyceae	
Order i: Chroococcales	
Family: Chroococcaceae	*Chroococcus disperses*
	Chroococcus cohaerens (Breb.) Naegeli
	Chroococcus prescotti Dr. and Daily
	Chroococcus turgidus (Kütz.) Lemm.
	Coelosphaerium kuetzingianum Nag
	Merismopedia punctata (Meyen)
	Merismopedia glauca (Ehr.)
	Merismopedia teniussima (Lemm.)
	Gomphosphaeria aponina
	Microcystis aeruginosa f. flos-aquae
	Microcystis aeruginosa Kützing
	Microcystis incerta (Lemmermann) Prescott
Order ii: Nostocales	
Family: Nostocaceae	*Anabaena constricta* Geitler
	Anabaena spiroides Klebahn var. *minima* Nygaard
	Anabaena spiroides Klebahn var. *tumida* Nygaard
	Nostoc commune Vaucher
	Nodularia spumigena Mertens
Order iii: Oscillatoriales	
Family: Oscillatoriaceae	*Dactyliosolen tenius*
	Lyngbya martesiana Meneghiniana
	Oscillatoria curviceps Agardh
	Oscillatoria acutissima Kufferath
	Oscillatoria lacustris Geitler
	Oscillatoria rubiscence
	Oscillatoria tenius Agardh
	Oscillatoria articulata Gardner
	Phormidium retzii Gomont
	Spirulina major
Division: Euglenophyta	
Class: Euglenophyceae	
Order: Euglenales	
Family: Euglenaceae	*Euglena acus*
	Euglena ehrenberghii
	Euglena oxyuris f. charkowiensis
	Euglena rostrifera
	Phacus glaber
	Phacus orbicularis
	Phacus longicauda
	Phacus longicauda var. *rotundus*
	Phacus pleuronectes
	Strombomonas fluviatilis (Lemmermann) Deflandre

	Species
	Strombomonas treubii
	Trachelomonas armata f. longicollis
	Trachelomonas hispida
	Trachelomonas conica var. *granulate*
	Trachelomonas planctonica var. *oblonga*
	Trachelomonas superb
	Trachelomonas verrucosa
Division: Dinophyta	
Class: Dinophyceae	
Order: Noctilucales	
Family: Noctilucaceae	*Noctiluca scintillans*
Order: Gonyaulacales	
Family: Gonyaulacaceae	*Gonyaulax fragilis*
Order: Peridiniales	
Family: Peridiniaceae	*Peridinium cinctum*
Division: Chrysophyta	
Class: Xanthophyceae	
Order: Tribonematales	
Family: Tribonemataceae	*Tribonema monochloron*
Order: Chromulinales	
Family: Chrysocapsaceae	*Tetrasporopsis perforata*
Order: Mischococcales	
Family: Pleurochloridaceae	*Goniochloris gigas*

Dendrogram displays the information in form of a tree diagram (Fig. 4). Cluster analysis of overall species abundance produced four clusters. Stations 1, 7 and 8 make up the first cluster with closer relationships between stations 7 and 8 in lower zone. Station 9 and 2 were distinct and make up second and fourth clusters respectively. Third cluster included station 3 and all the stations in creek middle zone with close link between stations 3 and 4; and stations 5 and 6.

3.3 Species Assemblage and Abiotic Factors

Table 5 shows specifically correlation (Spearman) between abiotic variables and species abundance and distribution. Water depth positively correlated to abundance of *Synedra acus* (P<0.001), *Thalassiothrix nitzschioides* Grun. (P = 0.001), *Melosira borreri* Grev. (P = 0.001), *Coscinodiscus lineatus* Ehrenberg (P = 0.03), *Aulacoseira granulata var. angustissima* f. spiralis Müller (P = 0.01), *Closterium kuetzingii* var. *vittatum* (P = 0.03), and negatively correlated to abundance distribution of *Microcystis aeruginosa* f. flos-aquae (P<0.001), *Coscinodiscus radiatus* (P = 0.03) and *Coscinodiscus subtilis* Ehrenberg (P = 0.04). Water temperature positively correlated with abundance distribution of *Amphiprora costata* Hustedt (P = 0.04), *Skeletonema costatum* (Grev) Cleve (P = 0.02), *Oscillatoria tenius* Agardh (P = 0.02) and inversely correlated with *Thalassiothrix nitzschioides* Grun. (P = 0.04). Phosphate positively correlated to *Westella botryoides* Wildemann (P = 0.02), *Coscinodiscus subtilis* Ehrenberg (P = 0.05) and negatively correlated with *Phormidium retzii* Gomont (P = 0.02). E conductivity negatively correlated to abundance of *Synedra acus* (P<0.001), *Coscinodiscus lineatus* Ehrenberg (P = 0.01), *Melosira borreri* Grev. (P<0.001), *Thalassiothrix nitzschioides* Grun. (P = 0.04), *Coscinodiscus nitidus* (P = 0.04) and positively correlated with *Westella botryoides* Wildemann (P = 0.02) and *Microcystis aeruginosa* f. flos-aquae (P = 0.03). Dissolved oxygen positively correlated with *Coscinodiscus nitidus* (P = 0.05). Turbidity negatively correlated to *Coscinodiscus nitidus* (P = 0.01). pH positively correlated to *Coscinodiscus lineatus* Ehrenberg (P = 0.04) and *Synedra acus* (P = 0.05).

The relative importance of measured abiotic factors to phytoplankton species abundance is shown in Fig. 5, as evaluated by Canonical correspondence analysis. The result of 1000 permutation test concludes that stations/species data are not linearly related to stations/variables data with 5% significance level. However, CCA revealed that the first two axes explained 68.95% of the variation in species– abiotic factors relationships. The first axis explained 44.94% and second axis explained 24.00% of total variation (Table 6). Phosphate and water temperature have higher correlation ordination axis, closely followed by conductivity (salinity), water depth and dissolved oxygen. CCA map revealed that *Skeletonema costatum* (Grev.) Cleve and *Amphiprora costata* Hustedt abundance were associated with a high-water temperature and a low water depth. *Westella botryoides* Wildemann and *Microcystis aeruginosa* f. flos-aquae seems to be more sensitive to elevated phosphate. Species such as *Melosira borreri* (Grev.), *Aulacoseira granulata* var. *angustissima* (Ehrenberg) Ralfs, *Coscinodiscus lineatus* Ehrenberg, *Synedra acus* and *Thalassiothrix nitzschioides* Grunow preferred higher water depth levels and more likely lower levels of temperature. Water temperature had a strong positive correlation with Axis 2. Phosphate had a strong negative correlation with Axis 1. Dissolved oxygen had a strong positive correlation with Axis 1. Water depth had a strong negative correlation with Axis 2. Acronyms used in CCA graphs are listed in Correlation (Spearman) of species abundance with abiotic variables (Table 5).

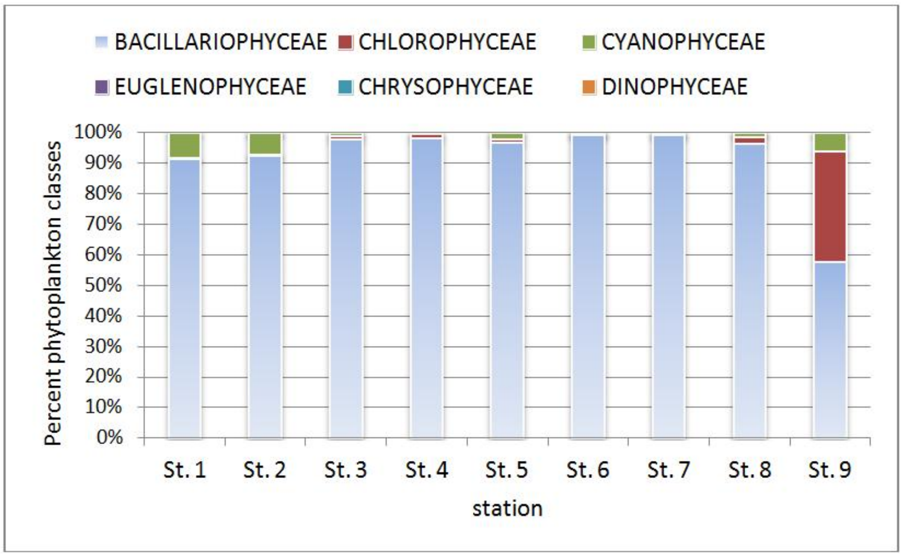

Fig. 2a. Spatial composition of phytoplankton classes of Badagry creek, Nigeria (Nov. 2011 – Sept. 2013)

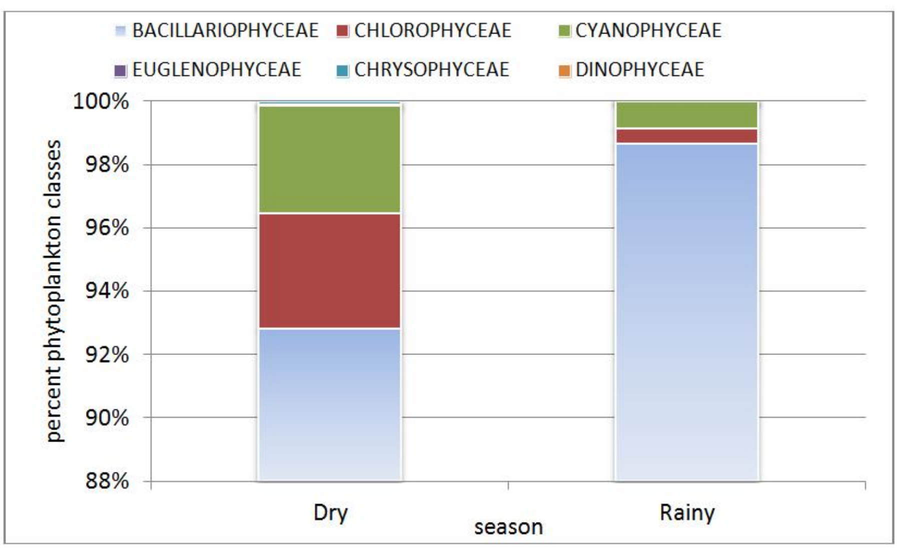

Fig. 2b. Seasonal composition of phytoplankton classes of Badagry creek, Nigeria (Nov. 2011 – Sept. 2013)

Table 4. Spatial and seasonal variation of species and individuals recorded of Badagry creek, Nigeria (Nov. 2011 – Sept. 2013)

	Station sampling									DS	RS
	1	2	3	4	5	6	7	8	9		
Taxa_S	112	96	100	92	94	76	95	101	97	174	184
Individual	40148	128274	134711	124792	109823	161101	48951	6332	38138	446516	541655

St. 1 - Apa; St. 2 – Gbaji; St. 3 – Badagry/Yovoyan jetty; St. 4 – Akarakumo; St. 5 – Ajido; St. 6 – Irewe; St. 7 – Igbolobi; St. 8 – Iyagbe; St. 9 – Ojo. DS – Dry season; RS – Rainy season

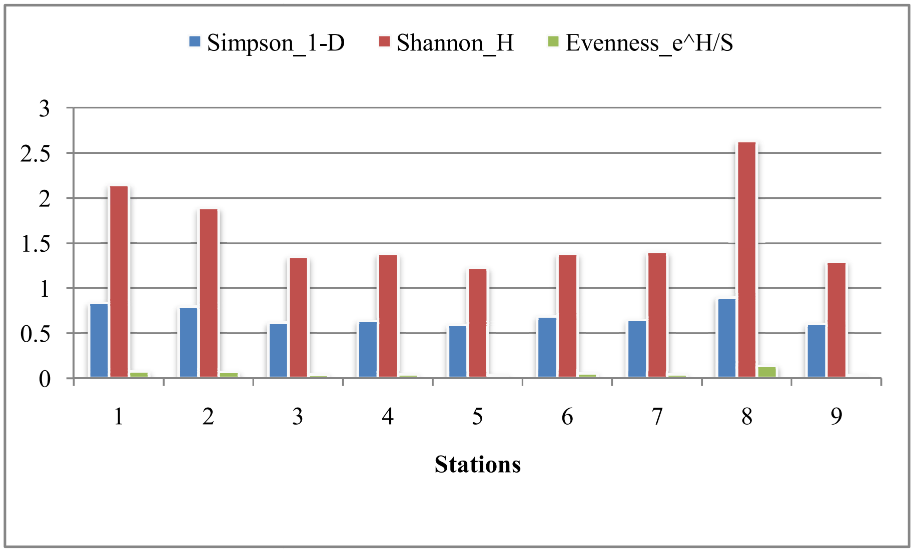

Fig. 3a. Spatial variation in diversity indices of phytoplankton in Badagry creek, Nigeria (Nov. 2011 – Sept. 2013)

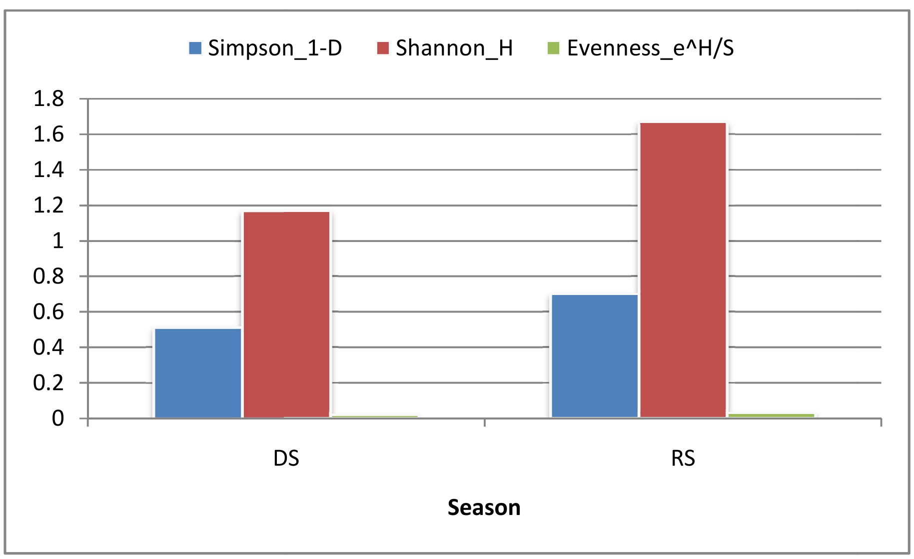

Fig. 3b. Seasonal variation in diversity indices of Phytoplankton in Badagry creek, Nigeria (Nov. 2011 – Sept. 2013)

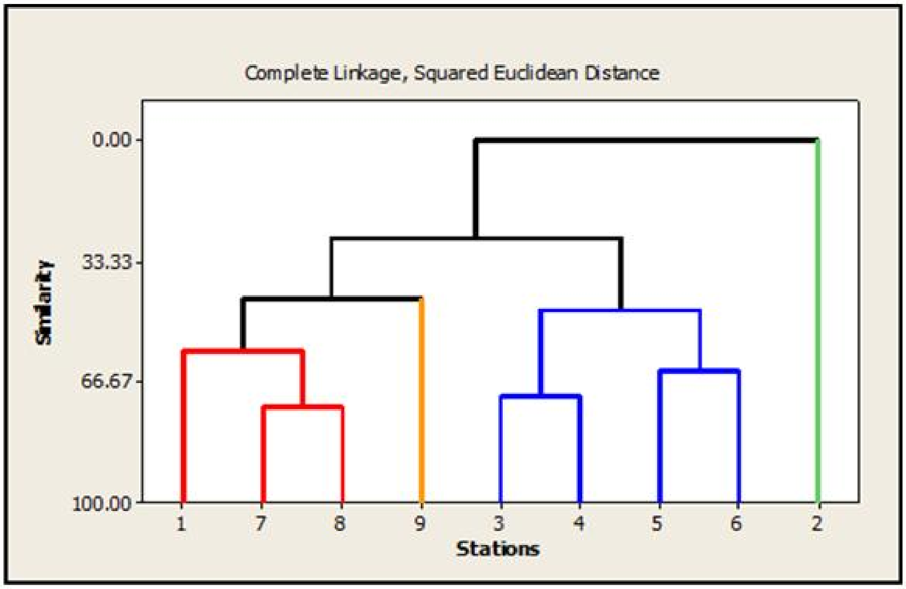

Fig. 4. Dendrogram produced, representing stations cluster based on species abundance of Badagry creek, Nigeria (Nov. 2011 – Sept. 2013)

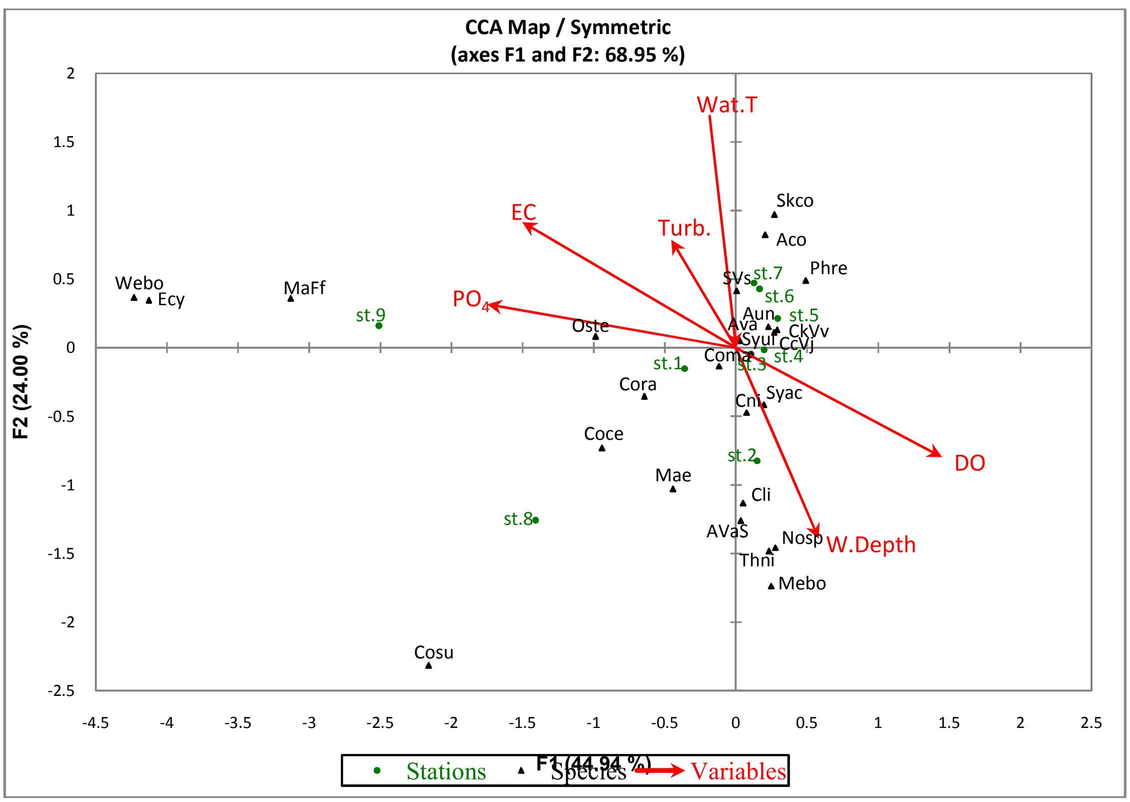

Fig. 5. Two-dimensional canonical correspondence analysis (CCA) of Badagry creek, Nigeria dominant phytoplankton species abundance with abiotic variables and stations

Wat.T – Water Temperature; Turb – Turbidity; EC – Electrical Conductivity; PO_4 – Phosphate; W.Depth – Water Depth; DO – Dissolved Oxygen.
Refer to Table 5 for an explanation of the species codes

Table 5. Correlation (Spearman) coefficients between Phytoplankton abundance and Abiotic factors investigated in Badagry creek (Nov. 2011 – Sept. 2013)

Species name	codes	W.T	pH	EC	Turb	Sal.	DO	W.D	NO_3	PO_4
Aulacoseira granulata var. *angustissima* (Ehr.) Ralfs	Ava	-0.13	0.12	-0.27	0.27	-0.30	-0.13	0.62	-0.12	-0.25
Actinoptychus undulatus	Aun	-0.13	0.13	-0.42	-0.12	-0.40	0.13	0.62	-0.20	-0.50
Coscinodiscus lineatus	Cli	-0.48	0.67*	-0.78**	-0.27	-0.82**	0.37	0.68*	-0.87**	-0.33
Surirella robusta var. *splendida*	SVs	0.42	0.25	-0.30	-0.15	-0.25	-0.08	0.13	-0.22	-0.43
Amphiprora costata Hustedt	Aco	0.66*	-0.37	0.42	0.23	0.40	-0.34	-0.53	0.38	-0.02
Coscinodiscus nitidus	Cni	-0.13	0.63	-0.67*	-0.77**	-0.57	0.65*	.27	-0.63	-0.53
Aulacoseira granulata var. *angustissima* f. spiralis Müller	AVaS	-0.61	-0.02	-0.47	0.15	-0.55	-0.29	.75 *	-0.35	0.02
Eudorina cylindrical	Ecy	-0.39	0.00	0.30	0.02	0.33	0.20	-.08	0.22	0.47
Microcystis aeruginosa	Mae	-0.16	0.03	-0.30	0.18	-0.38	-0.40	.27	-0.27	0.13
Nodularia spumigena Mertens	Nosp	-0.16	0.28	-0.42	0.04	-0.40	0.21	.49	-0.22	-0.57
Coscinodiscus centralis	Coce	0.32	-0.34	0.33	-0.01	0.33	-0.30	-.54	0.25	0.27
Coscinodiscus marginatus	Coma	0.23	0.09	0.31	-0.50	0.43	0.42	-.55	0.19	0.20
Skeletonema costatum	Skco	0.74*	-0.03	0.16	-0.08	0.19	-0.06	-.42	0.18	-0.22
Oscillatoria tenius Agardh	Oste	0.74*	0.34	0.03	0.13	0.13	-0.33	-.40	0.05	-0.13
Synedra acus	Syac	-0.36	0.65*	-0.85**	-0.28	-0.83**	0.27	.89**	-0.75*	-0.52
Closterium cornu var. *javanicum*	CcVj	0.01	0.42	-0.52	0.18	-0.53	0.03	0.63	-0.45	-0.63
Synedra ulna (Nitzsch)	Syul	0.03	0.62	-0.53	-0.20	-0.55	0.19	0.50	-0.63	-0.25
Closterium kuetzingii var. *vittatum*	CkVv	-0.19	0.30	-0.40	0.28	-0.43	-0.03	0.68*	-0.35	-0.42
Phormidium retzii Gomont	Phre	0.19	0.26	-0.30	-0.34	-0.22	0.52	0.04	-0.15	-0.75*
Coscinodiscus subtilis	Cosu	-0.04	-0.54	0.61	-0.16	0.64	-0.07	-0.67*	0.54	0.65*
Thalassiothrix nitzschioides	Thni	-0.69*	.039	-0.66*	-0.25	-0.68*	0.37	0.84**	-0.55	-0.29
Microcystis aeruginosa f. flos-aquae	MaFf	0.62	-0.39	0.71*	0.45	0.69*	-0.37	-0.86**	0.56	0.33
Melosira borreri (Grev.)	Mebo	-0.51	0.64	-0.86**	-0.35	-0.84**	0.33	0.84**	-0.75*	-0.42
Westella botryoides	Webo	-0.10	-0.50	0.73*	0.37	0.73*	-0.32	-0.53	0.64	0.73*
Coscinodiscus radiatus	Cora	0.58	-0.08	0.34	-0.09	0.34	-0.08	-0.70*	0.11	0.19

W.T – Water Temperature (^oC); EC – Electrical Conductivity (μScm^{-1}); Turb – Turbidity (FTU); Sal. – Salinity (psu); DO – Dissolved Oxygen ($mg\ L^{-1}$); W.D – Water Depth (m); NO_3 – Nitrate ($\mu mol\ L^{-1}$); PO_4 – Phosphate ($\mu mol\ L^{-1}$).

** significant at P < 0.05.*

*** significant at P < 0.01*

Table 6. CCA eigenvector analysis of dominant phytoplankton species (abundance) versus abiotic variables and stations of Badagry creek, Nigeria (Nov. 2011 – Sept. 2013)

	Axis order			
	F1	F2	F3	F4
Eigenvalue	0.352	0.188	0.104	0.064
Constrained inertia (%)	44.95	24.00	13.28	8.13
Cumulative % (Species–environment relation (%))	44.95	68.95	82.23	90.37

4. DISCUSSION

The 242-phytoplankton species from six major classes and 17 orders recorded in present study, were similar with other background studies in barrier-lagoon complex, south-west Nigeria [5,7]. The dominance of diatoms in phytoplankton assemblages agrees with reports by earlier workers in barrier-lagoon complex, south-west Nigeria [5,7,9]. The predominance of Bacillariophyceae is typical of most tropical coastal waters. Matsuoka et al. [24] reported that phytoplankton type diatoms have been associated with more eutrophic conditions. Therefore, diatoms dominating in this study are straightforward evidence that the area was tending towards eutrophic condition. Furthermore, predominance of phytoplankton community of study area (rainy and dry seasons) by diatoms against the pollution tolerant blue-green and green algae, could be attributed to a relatively low level of human anthropogenic activities in creek, which promotes diatoms growth. It may also be an indication that, diatoms due to their wholly planktonic and neritic nature are able to live in a wide range of environmental conditions.

The prevalence in most samples of pennate forms might indicate their recruitment from phytobenthos community [8,10]. Most of the notable species recorded in this study have been reported in background and recent studies in Nigeria's inland and coastal waters [5,8,9,25,26,27]. The occurrence of *Aulacoseira granulata var. angustissima* Ehrenberg Ralfs as predominant species in the study had been reported by earlier researcher [7]. The author deduced that species prominence was associated with water bodies of low salinity values. This '*Aulacoseira granulata var. angustissima* Ehrenberg Ralfs community' has also been reported by Onyema [11] for Iyagbe lagoon. These species could be regarded as possible indicators of fresh water or very low salinity conditions in this habitat.

The lower algae population density (excluding diatoms) during rainy season may be due to combined effect of environmental variables such as heavy rainfall causing flushing of population by floods, reduced salinity, nutrients and temperature experienced in creek. Environmental conditions such as low temperature, light and nutrients (nitrate and phosphate) are usually unfavourable for other algae classes. However, the relatively higher overall phytoplankton abundance recorded in rainy season agrees with Olaniyan [5] finding in Lagos lagoon and Abowei et al. [27] from Sombreiro River.

The presence of both freshwater and marine phytoplankton species in investigated ecosystem could possibly be an indication that the species were introduced from adjoining river and adjacent sea respectively. According to Onyema [11], the presence of *Chaetoceros, Thalassionema, Odontella*, *Skeletonema and Rhizosolennia* spp. probably points to their source of recruitment because they are known marine forms in the zone and these species are commonly found in sea conditions at coastal waters of Nigeria in dry season. Similar observations have been reported in Lagos lagoon [28,9].

The dominant cyano-bacteria (*Microcystis aureginosa* and *Microcystis aeruginosa* f. flos-aquae) recorded had been previously reported in south-western Nigeria [29,11]. Occurrence of species such as *Oscillatoria and Microcystis* (blue-green algae) is an indicator of pollution. This is evidence that places where above-mentioned, phytoplankton which maintain constant high densities were considered polluted. Furthermore, Euglenoids prevalence may be a further indication of organic contamination. The probable reason for *Cyclotella spp.* observation, in both rainy and dry season, shows not only their tolerance, but also their resilient ability to withstand varied abiotic factors. Most important nutrients are phosphates and nitrates, which favour phytoplankton growth mainly in surface light layers. The occurrence of higher phytoplankton density during rainy season coincided with lower nutrients (nitrates and phosphates) concentration. This may be attributed to nutrients utilization by phytoplankton. Similar observation was reported by Ananthan [30] from Pondicherry coastal environs.

The moderately high values of community structure indices obtained in the study (spatially and seasonally), were a consequence of species diversity and population density recorded. These indices values were higher than values reported by Kadiri [9] and Onyema [11] in some coastal waters, south-western Nigeria. The difference recorded is due to higher numbers of species and individuals recorded in this study. High indices values are an indication that species numbers are more evenly distributed while low values of the diversity index indicate dominance by one or two species.

The clusters formed, comprising combination of stations could be an indication that stations in a cluster had similar habitats conditions and hence, more or less same species composition and abundance, depending on similarity degree. The isolation of station 9 (Ojo) at the extreme end of lower zone, and station 2 (Gbaji) in the upper zone, independently (clusters 2 and 4) from other station groups may be attributed to distinct ecological conditions at these stations because of stress gradient. Elements respond differently to gradient imposed by ecological controllers in these stations [31]. The abiotic factors analysed, suggests the main cause of gradient to be conductivity (salinity). Stations 9 (Ojo) and 2 (Gbaji) were more influenced by seawater incursion (tidal) and freshwater inflow, respectively. With these findings, tidal influence and freshwater inflow may be factors determining phytoplankton distribution in Badagry creek.

The analyses of the study revealed that species abundance could probably be explained by abiotic variables considered. This is shown by both positive and negative association between individual species abundance and investigated abiotic factors in Badagry creek. The significant positive influence of water temperature on *Amphiprora costata*, *Skeletonema costatum* and *Oscillatoria tenius* suggests preference of warmer temperatures for these species. Temperature exerts a major influence on the biological activities and growth. Rajkumar et al. [32], opined that growth of phytoplankton composition is governed by temperature. The uniformity of water temperature in the study could be attributed to creek shallowness and regular tidal motions, which ensured complete water mixing. While significant negative influence of conductivity on abundance of *Synedra acus*, *Coscinodiscus lineatus*, *Melosira borreri*, *Thalassiothrix nitzschioides* and *Coscinodiscus nitidus* in Badagry creek was an indication that these species performed better in moderately low conductivity waters, the significant positive association of conductivity with *Westella botryoides* and *Microcystis aeruginosa* f. flos-aquae indicates preference of these species for high conductivity. Conductivity significantly varied spatially with values drastically reduced from lower end having communication with sea water via Lagos harbour to upper end of creek where freshwater inflow was present. The alkaline and stable pH recorded across stations in this study may be due to buffering effects of seawater incursion and effective flushing. The pH value is very important for plankton growth [33]. The pH values obtained in the study may be responsible for phytoplankton growth. According to Umavathi et al. [34], pH in range of 5 to 8.5 was best for plankton growth but harmful when it increases to 8.8. A significant positive correlation of pH with abundance distribution of *Coscinodiscus lineatus* and *Synedra acus* is an indication that abundance of these species increases with high pH values.

The relatively constant shallow water of creek, elevated temperature and nutrients availability resulted in good growth of phytoplankton in this habitat. The significant positive relationship of water depth with abundance distribution of *Synedra acus*, *Thalassiothrix nitzschioides*, *Melosira borreri*, *Coscinodiscus lineatus*, *Aulacoseira granulata var. angustissima* f. spiralis and *Closterium kuetzingii* var. *vittatum* suggests that as the water depth increases so these species abundance increases. The significant negative influence of water depth on *Microcystis aeruginosa* f. flos-aquae, *Coscinodiscus radiatus* and *Coscinodiscus subtilis* abundance distribution is indicating that as water depth increases, there will be a resultant decrease in species abundance.

Nutrients are considered as one of the most important parameters in aquatic ecosystem influencing growth, reproduction and metabolic activities of biotic components. Increases in nitrogen and phosphorus have been associated with specific taxonomic classes growth or individual species of phytoplankton [35,36]. The level of nitrate and phosphate concentrations coupled with favourable temperature could explain the abundance of algae recorded in the study. Phosphate significant positive correlation with *Westella botryoides* and *Coscinodiscus subtilis* is suggesting that high phosphate values are responsible for abundance increase in these species. The higher mean value of phosphate during dry months may be attributed to weathering of rocks and sand mining activities liberating soluble alkali phosphate coupled with inputs of domestic sewage and industrial effluents. However, nitrate and phosphate level recorded during the study period suggested nutrient enrichment required by plankton for growth and reproduction [37].

Variation in species – abiotic factors relationship as explained by first two axes in CCA (68.95%) allows that two-dimensional Canonical Correspondence Analysis map is enough to analyse the relationships between stations, species and abiotic factors. The relative length of the vectors (abiotic factors) in CCA plot (the longer the vector, the greater the influence of variables on species abundance) indicates phosphate and water temperature were the most important abiotic factors in phytoplankton assemblages. This finding is consistent with previous research suggesting phosphates and temperature played a key role in diatom composition assemblages in China [38], and in Zimbabwe [39], respectively. However, the insignificant canonical axes in CCA, show that phytoplankton species abundance pattern cannot be fully explained by evaluated abiotic factors, probably for studied period.

Turbidity is the detrimental factor which limits phytoplankton growth [40]. In CCA plot, turbidity was the weakest variable to influence species composition and abundance in Badagry creek. However, highly significant negative association between turbidity and *Coscinodiscus nitidus* suggests the species preference for non-turbid waters. According to Sharma et al. [41], less turbid water enhances photosynthesis resulting in high Bacillariophyceae growth.

Stations that associated with other stations are probably because of same component phytoplankton presence and abundance. Stations 3 (Badagry/ Yovoyan jetty), 4 (Akarakumo), 5 (Ajido) and 6 (Irewe) had conducive ecosystems for good growth of *Aulacoseira granulata* var. *angustissima* Ehrenberg Ralfs and *Actinoptychus undulatus*. This observation could be attributed to the fact that these cosmopolitan species amongst the Bacillariophyceae are tolerant to wide range of environmental conditions / factors which are less suitable for other algae groups [43]. Station 2 (Gbaji) had good habitats for *Aulacoseira granulata* var. *angustissima* f. spiralis and *Coscinodiscus lineatus* growth. Species such as *Microcystis aeruginosa* f. flos-aquae, *Westella botryoides* Wildemann and *Eudorina cylindrical* exhibited a preference for station 9 (Ojo). The presence of high abundance of microcystis (Cyanophyceae) and Chlorophyceae have been reported to indicate high pollution load and nutrient rich site condition [42]. The high abundance of species *Actinoptychus undulatus* in all stations, with an exception of station 9 (Ojo) in Badagry creek, suggests that station 9 (most impacted by human activities) characterized by highest nutrients content, salinity, turbidity and lowest dissolved oxygen, had relatively poor habitat conditions for the species.

5. CONCLUSIONS

The abiotic factors values were within the permissible limit for aquatic life. Diatom species was main contributor to phytoplankton assemblages, spatially and seasonally. Creek conditions show a tendency towards eutrophication. The correlations between species and variables, suggests the importance of abiotic factors in determining phytoplankton distribution and abundance. The CCA clarified to some extent phytoplankton dominant species response to abiotic factors, but did not reveal best predictor of phytoplankton species abundance distribution in Badagry creek for study period.

6. RECOMMENDATIONS

This study recommends further long-term research in creek to provide gaps as phytoplankton assemblages can change quickly.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Balogun KJ. Effects of abiotic and biotic factors on fish productivity in Badagry creek, Nigeria. Ph.D Thesis, University of Ibadan, Nigeria. 2015;249.
2. Russell-Hunter WD. Aquatic productivity. Macmillan, New York. 1970;306.

3. Rey PA, Taylor JC, Laas A, Hensburg L, Vosloo A. Determining the possible application value of diatoms as indicators of general water quality a comparison with SASS 5, Water S.A. 2004;30:325-332.
4. Edward M, Reid P, Planque B. Long-term and regional variability of phytoplankton biomass in the Northeast Atlantic (1960 – 1995), Journal of Marine Science. 2001;58(1):39-49.
5. Olaniyan CIO. The seasonal variation in the hydrology and total plankton of the lagoons of South West-Nigeria. Nigerian Journal of Science. 1969;3(2):101-119.
6. Nwankwo DI. Seasonal changes of phytoplankton of Lagos lagoon and the adjacent sea in relation to environmental factors. PhD. Thesis. University of Lagos. 1984;447.
7. Nwankwo DI. A preliminary checklist of planktonic algae in Lagos lagoon Nigeria. Nigeria Journal of Botanical Applied Sciences. 1988;2:73-85.
8. Nwankwo DI, Akinsoji A. Periphyton algae of a eutrophic creek and their possible use as indicator. Nigerian Journal of Botany. 1988;1:47-54.
9. Kadiri, MO. Phytoplankton distribution in some coastal waters of Nigeria. Nigeria Journal of Botany 1999;12(1):51-62.
10. Onyema IC. The phytoplankton composition, abundance and temporal variation of a polluted estuarine creek in Lagos, Nigeria. Turkish Journal of Fisheries and Aquatic Sciences. 2007;7: 89-96.
11. Onyema IC. A checklist of phytoplankton species of the Iyagbe lagoon, Lagos. Journal of Fisheries and Aquatic Sciences. 2008;3(3):167-175.
12. Adesalu TA, Nwankwo DI. A checklist of Lekki lagoon diatoms. International Journal of Botany 2009;5(2):126-134.
13. Balogun KJ, Ladigbolu IA. Nutrients and Phytoplankton Production Dynamics of a Tropical Harbor in Relation to Water Quality Indices. Journal of America science. 2010;6(9):261-275.
14. Ajani EK, Balogun KJ. Variability in levels of heavy metals in water and fish (*Chrysichthys nigrodigitatus*) tissues from Badagry creek, Nigeria. Journal of Biol. & Life Science. 2015;6(2):193–207.
15. APHA (American Public Health Association). Standard methods for examination of water and wastewater. 15th edn. Byrdpas spring field. Washington, D.C.; 1989.
16. Wimpenny RS. The plankton of the Sea. Faber and Faber Limited, London. 1966;426.
17. Raymont JEG. Plankton and productivity in the oceans. Vol. 1. Phytoplankton. 2nd ed. Pergamon Press, Oxford. 1980;489.
18. Tomas CR. Identifying marine phytoplankton. Academic press, Harcourt Brace and Company, Toronto. 1997;858.
19. Stirling HP. Chemical and biological methods of water analysis for aquaculture. Pisces press Ltd, Scotland. 1999;44-47.
20. Parsons TR, Maita Y, Lalli CM. A manual of chemical and biological methods for seawater analysis. Pergamon Press. 1984;173.
21. Hammer Ø, Harper DAT, Ryan PD. Past: Palaeontogical Statistics Software packages for education and data analysis. Palaeontologia Electronica. 2001;4(1):9.
22. Ter Braak CJF. Canonical Correspondence Analysis: A new eigenvector technique for multivariate direct gradient analysis. Ecology. 1986;67(5):1167-1179.
23. Crowley PH. Resampling methods for computation-intensive data analysis in ecology and evolution. Annual Review of Ecology and Systematics. 1992;23:405-447.
24. Matsouka K, Joyce LB, Kotani Y, Matsuyama Y. Modern dinoflagellate cysts in hypertrophic coastal waters of Tokyo Bay, Japan. Journal of Plankton Research. 2003;25:1461-1470.
25. Emmanuel BE, Onyema IC. The plankton and fishes of a tropical creek in south-western Nigeria. Turkish Journal of Fisheries and Aquatic Sciences. 2007;7:105-114.
26. Nwankwo DI, Owoseni TI, Usilo DA, Obinyan I, Uche AC, Onyema IC. Hydrochemistry and plankton dynamics of Kuramo lagoon. Life Science Journal. 2008;5(3):50-55.
27. Abowei JFN, Davies OA, Tawari CC. Phytoplankton in the lower Sombreiro river, Niger Delta, Nigeria Research Journal of Biological Sciences. 2008;3(12):1430-1436.
28. Nwankwo DI. A First list of Dinoflagellates (Pyrrophyta) From Nigerian Coastal Waters (Creeks, Estuaries, Lagoons). Polskie Archiwum Hydrobilogii. 1997;44(3): 313–321.

29. Nwankwo DI, Onyema IC, Adesalu TA. A survey of harmful algae in coastal waters of south-western Nigeria. Journal of Nigerian Environmental Society. 2003;1(2): 241–246.
30. Ananthan G. Plankton ecology and heavy metal studies in the marine environments of Pondicherry, India. PhD. Thesis. Annamalai University, India. 1994;125.
31. Vasconcellos RM, Araújo FG, Santos JNS, Silva MA. Short term dynamics in fish assemblage structure on a sheltered sandy beach in Guanabara Bay, South-eastern Brazil. Marine Ecology. 2010;31:506-519.
32. Rajkumar MP, Perumal AV, Prabu NV, Perumal KT, Rajeskar. Phytoplankton diversity in Pichavaram mangrove waters from South–East coast of India. J. Environ. Biol. 2009;30:489–498.
33. Chisty N. Studies on biodiversity of fresh water zooplankton in relation to toxicity of selected heavy metals. PhD. Thesis. Mohanlal Sukhadia University, Udaipur, India; 2002.
34. Umavathi S, Longankumar K, Subhashini. Studies on the nutrient content of Sulur pond in Coimbator, Tamil Nadu. Journal of Ecology, Environment and Conservation 2007;13(5):501-504.
35. Piehler MF, Twomey LJ, Hall NS, Paerl HW. Impacts of inorganic nutrient enrichment on the phytoplankton community structure and function in Pamlico Sound, NC USA. Estuar Coast Shelf Sci. 2004;61:197-207.
36. Domingues RB, Anselmo TP, Barbosa AB. Nutrient limitation of phytoplankton in the freshwater tidal zone of a turbid, Mediterranean estuary. Est. Coast. Shelf Sci. 2011b;91:282–297.
37. Nybakken JW. Marine biology: An ecological approach 2nd ed. Harper and Row Publishers, New York. 1988;514.
38. Wu N, Cai Q, Fohrer N. Contribution of microspatial factors to benthic diatom communities. Hydrobiologia. 2014;732:49-60
39. Bere T, Phiri C, Kadye WT, Utete B. Benthic diatom assemblages in mountain streams: community structure in relation to environmental and human pressures. African Journal of Ecology. 2013;51:625–634.
40. Sharma A, Sharma RC, Anthwal A. Monitoring phytoplankton diversity in the hill stream Chandrabhaga in Garhwal Himalayas. Life Sci. J. 2007;4:80–84.
41. Sharma RC, Neetu S, Anita C. The influence of physico-chemical parameters on phytoplankton distribution in a head water stream of Garhwal Himalayas: A case study Egyptian Journal of Aquatic Research. 2016;42:11–21.
42. Kadiri MO. Notes on Harmful algae from Nigerian coastal waters. Acta. Botanica, Hungarica. 2011;53(1-2):137-143.
43. Ganai AH, Parveen S. Effect of physico-chemical conditions on the structure and composition of the phytoplankton community in Wular Lake at Lankrishipora, Kashmir Int. J. Biodivers. Conserv. 2014;6(1):71-84.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/21115