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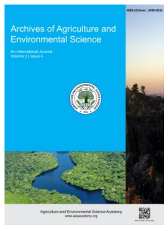

ORIGINAL RESEARCH ARTICLE

Assessment of zooplankton community in an anthropogenic-disturbance coastal creek, southwest Nigeria

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ABSTRACT

In order to assess the zooplankton community in an anthropogenic-disturbance Badagry creek, Zooplankton and water samples were collected and analyzed bi-monthly from November 2011 to September 2013 in nine stations representing its three different zones using standard methods. Zooplankton 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), Simpson (1-D) and Evenness (e^H/S) indices. Water samples were analysed for temperature, pH, salinity, conductivity, turbidity, dissolved oxygen, water depth and nitrate. Data were analysed using descriptive statistics, ANOVA, cluster and Canonical correspondence analysis (CCA) at $\alpha = 0.05$. A total of 56 species comprising 26 species of rotifers, 15 species of arthropoda, 4 species of ciliophora, 3 species of cnidaria, and 2 species of ctenophora, foraminifera, mollusca, protozoa each, with an array of meroplankton / juvenile stages of the order copepod of subphylum crustacea were recorded. Diversity indices were highest (H = 2.20; 1-D = 0.80; e^H/S = 0.27) at station 6 and lowest in station 8 (H = 1.20; 1-D = 0.56) and station 1(e^H/S = 0.14). Salinity/conductivity, nitrate and water depth were significantly different ($p < 0.05$) among the study stations. CCA revealed salinity/conductivity and nitrate were the most important abiotic factors co-related with the zooplankton abundance in Badagry creek. The moderately low zooplankton communities' diversity and abundance in Badagry creek point at different natural and anthropogenic factor impacts.

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INTRODUCTION

Coastal environments are the most diverse and productive habitats anywhere in the world. However, with the increasing rate of urbanisation and industrialization, landscapes are altered in a way that affects water body's biota and the entire biological context of the water body, causing it to diverge from integrity (Karr, 1999). Growing pressures mounted on coastal ecosystems, and the capacity to produce sustainable resources as a result of population growth, urbanisation trends, and increasing demand and competition for resources (Merkens *et al*., 2016). Thus, many human uses of coastal waters are potentially in conflict with the sustainable management of aquatic resources (Vinagre *et al*., 2004). An important ecological ramification of increasing population pressure, poor sewage system, industrialization and poor waste management in Nigerian's coastal area is that pollutants freely find their way unabated into our coastal waters through drains, canals, rivers, creeks and lagoons that act as conduits (Nwankwo, 2004).
Badagry creek with an estimated size of 1875ha is part of the Barrier Lagoon Coast (one of the four coastal geomorphic divisions in Nigeria). The creek shore is lined with communities

whose livelihood depends on the creek resources. The creek supports the artisanal fisheries, water transportations, and cultural heritages in the area. However, the water body has continued to receive increasing levels of anthropogenic activities such as indiscriminate direct discharge of faeces, sewage/ effluents and domestic waste and sand mining activities for land reclamation which could undermine the ecological integrity of the creek (Balogun, 2017; Agboola *et al*., 2008). Investigations of anthropogenic wastes and environmental modifications in the Lagos lagoon and adjoining water bodies in Nigeria, have revealed increased levels of pollution stress (Edokpayi and Nkwoji, 2007; Onyema *et al*., 2003).

Zooplankton plays a major role in energy transfer between the phytoplankton and the various economically important fish populations. Zooplankton are sensitive to changes in aquatic ecosystems. The change in species composition, abundance, and body size distribution is a reflection of the effects of environmental disturbances. Therefore, they are potential indicator species for water pollution (Jakhar, 2013). Zooplankton has short generation times and quick responses to diverse stressors, making them favourable candidates for a community indicator of ecosystem health (Cairns *et al*., 1993). Their abundance in time and space could affect fish production, abundance, distribution, and composition. Therefore the future of any fish stock would very much depend on the availability of zooplankton.

Although baseline data (Nwankwo, *et al*., 2008; Emmanuel and Onyema, 2007; Akpata *et al*., 1993) and recent studies (Abdul *et al*, 2016; Yakub *et al*, 2012) on zooplankton for Lagos coastal waters exist, frequent species monitoring in the face of increasing human impacts on the Badagry creek is essential. Furthermore, despite these previous studies, the effects of abiotic variables on zooplankton composition and abundance in Badagry creek in spite of its importance have not been investigated. The objectives of this study were to define composition and distribution pattern of zooplankton in an anthropogenic - disturbance Badagry creek, determine the spatial variations in the Abiotic variables of the creek, and assess the effect of the abiotic variables on zooplankton communities of Badagry creek, southwest Nigeria.

MATERIALS AND METHODS

Study area

The study was conducted in Badagry creek (E 2°42' - 3°23' and N 6°23' - 6°28') located in the upper part of the Barrier Lagoon Coast. The creek is fed mainly by River Ajara in the Republic of Benin and the Yewa River in Nigeria while it also links Ologe Lagoon (Figure 1). The creek provides the communities with numerous benefits. In addition to direct use, the creek replenishes the ground water table and influencing the climate of the city. The creek shore is lined with fishing communities whose livelihood depends on the creek resources. The climate is dominated by two distinct seasons: a rainy season which lasts from May to October (marked by two peaks in May to July, and September to October) and a dry season from November to April (Balogun, 2017). Vegetation is found over the low lying plains and marshes near the lagoons and creeks. The predominant vegetation is made up of woody plants, shrubs, coconut and oil palm trees in the sandy areas, while the marshy areas are covered by red mangrove (*Rhizophora sp.*).

Sampling design

Badagry creek was divided into 3 zones based on geographic locations and logistical characteristics, *viz*., upper, middle and lower zones. In the present study, three stations were randomly selected in each of the zones, and chosen as replicates based on the major community along the creek, thus giving a total of nine stations for the study within the creek. The sampling areas and sites are shown in Figure 1; indicated upper zone that stretches from station 1 (Apa) to station 3 (Badagry/Yovoyan jetty) is associated with residential, highway bridge, artisanal fishing, cage culture and agricultural activities. The middle zone that extends from station 4 (Akarakumo) to station 6 (Irewe) is influenced by human activities, including agricultural, artisanal fishing, settlement and sand mining activities. The lower zone which extends from station 7 (Igbolobi) to station 9 (Ojo) tends towards the sea (Lagos harbour) and is influenced by sea incursion, residential, agricultural activity and artisanal fishing. Some morphometric features of the nine (9) stations studied are shown in Table 1.

Sampling and laboratory analyses

Zooplankton sample haul was carried out on each sampling trip from each station by towing a 55 µm mesh size standard plankton net held against the current of the ebbing tide at low speed (< 4 knots) below the water surface for 5 minutes from an outboard engine boat. Zooplankton samples were concentrated and transferred to a 500 ml well labelled plastic container with screw cap and preserved with 4% unbuffered formalin solution and stored in laboratory prior to microscopic analysis (APHA, 2005). In the laboratory, preserved zooplankton samples were concentrated to about 20 mL by decanting the supernatant aliquot. The 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 sample, at least 10 transects were thoroughly investigated with each transect at right angle to first. Zooplankton species were observed for adults and juvenile stages alike. Enumeration was done on natural unit count and reported in terms of abundance (organism mL^{-1}) (APHA, 2005). Identification of species was carried out according to Emi Yamaguchi and Caitlin Bell, (2007); Fernando, (2002); Waife and Frid, (2001); Newell and Newell, (1966).

Measurements of Abiotic variables were taken simultaneously with zooplankton sampling at each station. Water temperature was measured directly by mercury-in-glass thermometer, graduated to 0.1°C. pH, electrical conductivity and salinity were measured using a Multi-meter water checker (Horiba) Model U-10. Dissolved oxygen in water samples were estimated using modified iodometric Winkler's method (Stirling, 1999). Turbidity was measured directly in a smart–spectrophotometer at turbidity wavelength against distilled water as reference. Water depth (m) profile was determined by means of a cylindrical rod calibrated along its length in centimetres. Nitrate and phosphate were analysed using standard pink azo-dye and molybdenum-blue methods, respectively according to Parsons *et al.* (1984).

Data and statistical analysis

The level of community structure was assessed according to the diversity index (H), Simpson index (1 - D), Pielou's evenness index (e^H/S) and Berger - parker dominance. These indexes were calculated from the abundance data (species and individual total number) using the software package 'PAST' (Hammer *et al.*, 2001). Data generated were subjected to both descriptive and inferential statistics using SPSS 16.0 for windows evaluation version. One-way analysis of variance (ANOVA) ($P \leq 0.05$) was used to determine significant differences among stations. When significant differences were obtained, mean values were separated using post-hoc Tukey's (HSD) test. Prior to the ANOVA tests, the normality of all variables was checked by means of the Shapiro–Wilk test. Homogeneity of variance of variables among stations was assessed using Levene's test. Spearman rank correlation (r) was used to determine associations between overall abiotics 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 variables, taxa and station data to define relationships between them and to identify abiotic variable that best explained taxa distribution patterns at study areas. To reduce the effect of rare species, taxa whose occurrence frequency was less than 0.09% and juvenile stages organisms were arbitrarily excluded from the CCA analysis (Ter Braak, 1986). A Monte Carlo randomization test (1000 permutations) was run to assess probability of observed pattern being due to chance (Crowley, 1992).

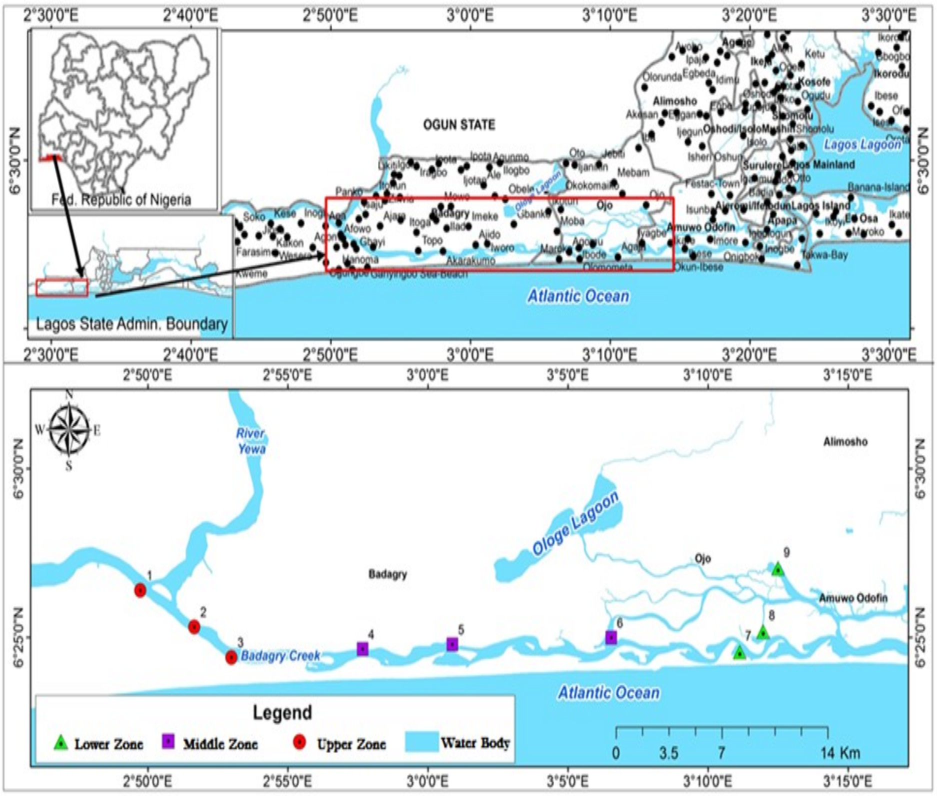

Figure 1. *Map of Badagry creek and its environs showing the sampling stations [Stations 1(Apa), 2(Gbaji), 3 (Badagry/Yovoyan jetty), 4(Akarakunmo), 5(Ajido), 6(Irewe), 7(Igbolobi), 8(Iyagbe), 9(Ojo)].*

Table 1. Some Morphometric features of the studied stations.

Zone	Station	Co-ordinates	Maximum depth (m)	Mean depth (m)	Elevation
Upper	1 (Apa)	6°26'21.0''N 2°49'44.7''E	4.65	2.98	3.4 m
	2 (Igbaji)	6°25'14.6''N 2°51'37.9''E	9.52	6.72	7.7 m
	3 (Badagry/Yovoyan jetty)	6°24'22.0''N 2°53'04.0''E	8.84	6.52	9.2 m
Middle	4 (Akarakumo)	6°24'37.0''N 2°57'40.9''E	5.4	4.08	9.9 m
	5 (Ajido)	6°24'48.6''N 3°00'30.0''E	3.31	2.37	6.6 m
	6 (Irewe)	6°25'16.9''N 3°08'38.4''E	4.70	3.33	9.2 m
Lower	7 (Igbolobi)	6°24'35.7''N 3°11'07.4''E	2.95	1.38	5.3 m
	8 (Iyagbe)	6°25'09.5''N 3°11'56.1''E	4.12	2.32	2.5 m
	9 (Ojo)	6°27'02.9''N 3°12'30.6''E	4.25	1.64	8.2 m

RESULTS AND DISCUSSION

Abiotic variables

The physical and chemical parameters (Abiotic variables) of Badagry creek measured during the study period are presented in Table 2. The physical variables of the creek throughout the study duration were fairly stable except for depth, turbidity, and salinity. The slight variation in water temperature among the stations were not significant ($p>0.05$). The high and fairly stable distribution of water temperature conditions in the Badagry creek is characteristic of the entire coastal waters of south-western, Nigeria. The minimal variation in temperature spatially was attributed to their exposure to the same climatic elements (Ogamba *et al.*, 2004). On the other hand, the differences in conductivity, salinity, water depth, and turbidity among the sampling stations were statistically significant ($p<0.05$). In the case of pH, the difference among stations was not significant ($p>0.05$) but differences were seasonally significant ($p>0.05$). 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 month's average DO value (4.91 mg L^{-1}) was slightly higher than rainy months (4.66 mg L^{-1}). However, Dissolved oxygen means values among the stations and months did not differ significantly ($p>0.05$). Dissolved oxygen is one of the best indicators of the water's health. DO levels below 3 mg/L are usually of concern and waters with DO less than 1 mg/L are considered hypoxic. The decline in oxygen level in station 9 towards the harbour/sea could be attributed to anthropogenic factors such as runoff from the sewage treatment plant, oil waste, domestic and industrial effluents in the creek catchment. Nitrate levels increased significantly from upper to lower zone during the study period. Seasonally, the nitrate dry month mean value was higher than the rainy months, but the difference was not significant ($p>0.05$). The addition of nutrients through anthropogenic activities has impacts on aquatic systems, leading to eutrophication, occasionally.

Zooplankton composition, distribution and abundance

The checklist of zooplankton identified in Badagry creek, Nigeria from November 2011 to September 2013 is presented in Table 3. The zooplankton diversity observed in this study comprised a mixture of freshwater and marine species. The heterogeneity of this assemblage could be as a result of mixing of zooplankton from adjoining water bodies with distinct communities. A total of 56 zooplankton species were recorded, completely dominated by Tintinnid ciliates (*Acanthostomella norvegica* (Daday) Jörgensen) for the study, with juvenile stages of the order copepod of sub-phylum Crustacea dominating in terms of abundance. The zooplankton phylum in the creek comprised of Cnidaria, Ctenophora, Foraminifera, Arthropoda, Rotifera, Ciliophora, Mollusca, Protozoa, and an array of Juvenile stages (Figure 2). In the study, rotifers (26 species) were the richest group of species among the zooplankton recorded. The dominance of rotifers may be related to their short generation time compared to the larger crustacean

Table 2. Spatial variation of measured Abiotic variables in Badagry creek, southwest Nigeria.

	Water Temperature (°C)	pH	Salinity (PSU)	Conductivity (µScm^{-1})	Turbidity (FTU)	Water depth (m)	Dissolved Oxygen (mgL^{-1})	Nitrate (µmolL^{-1})	Phosphate (µmolL^{-1})
St. 1	29.63± 1.69	7.70±0.40	1.27± 2.42^{b}	2674.33 ± 4801.83^{b}	29.92 ±11.41	2.98 ± 1.33^{bcd}	4.58 ± 1.10	3.75 ± 3.26^{b}	5.04 ± 3.24
St. 2	29.04± 2.54	7.63±0.58	1.12± 2.01^{b}	2259.33 ± 3715.03^{b}	24.00 ±15.59	6.72 ± 2.06^{a}	5.07 ± 1.39	4.74 ± 4.00^{b}	4.90 ± 3.29
St. 3	29.38± 2.47	7.66±0.55	1.59± 3.05^{b}	2855.00 ± 4822.43^{b}	34.33 ±17.76	6.52 ± 1.25^{a}	4.88 ± 1.32	3.94 ± 3.87^{b}	5.83 ± 3.51
St. 4	29.42± 2.20	7.67±0.54	1.64± 3.43^{b}	2838.25 ± 5034.20^{b}	19.75 ± 9.33	4.08 ± 1.26^{b}	5.13 ± 1.57	6.85 ± 6.25^{ab}	4.94 ± 3.07
St. 5	29.75± 1.50	7.65±0.47	1.68± 3.14^{b}	3141.58 ± 5333.72^{b}	35.58 ±12.01	2.37 ±0.60^{cde}	4.73 ± 1.14	6.95 ± 5.50^{ab}	4.83 ± 2.98
St. 6	29.54± 1.88	7.45±0.41	3.40± 3.47^{ab}	7288.75± 5898.57^{ab}	33.00 ±21.01	3.33 ±0.79^{bc}	4.57 ± 1.33	9.87 ± 7.04^{ab}	5.28 ± 3.65
St. 7	29.58± 1.33	7.61±0.28	4.61± 3.19^{ab}	8629.67 ±5771.10^{ab}	19.67 ±11.30	1.38 ±0.65^{e}	5.28 ± 1.19	7.91 ± 6.67^{ab}	5.46 ± 3.24
St. 8	29.13± 1.26	7.56±0.46	6.80± 4.64^{a}	12116.92±7970.46^{a}	24.17 ±10.61	2.32 ± 1.01^{cde}	5.07 ± 1.06	8.06 ± 6.82^{ab}	6.79 ± 5.23
St. 9	29.58± 1.58	7.57±0.54	7.83± 5.06^{a}	13642.00±8457.93^{a}	36.00 ±13.62	1.64 ± 1.16^{de}	3.73 ± 1.08	12.53 ±6.69^{a}	7.99 ± 4.64

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*).

Table 3. Checklist of Zooplankton taxa recorded in Badagry Creek, Nigeria (-; Absent; +: Rare; ++: Occasional; +++: Common; ++++: Abundant).

Taxa	Codes	St. 1	St.2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8	St. 9
Phylum: Cnidaria										
Cunina octonaria McCrady	*Coc*	-	-	-	+	+	+	+	-	-
Lensia fowleri	*Lfo*	-	+	+	+	-	-	-	-	+
Muggiaea sp.	*Msp*	+	-	+	+	-	-	+	-	+
Phylum: Ctenophora										
Beröe cumis	*Bcu*	-	-	-	-	-	+	+	+	-
Beroid Ctenophore	*Bct*	-	-	+	+	+	+	+	-	+
Phylum: Foraminifera										
Globorotalia inflata d'Orbigny	*Gid*	++	+	+	-	-	-	-	-	++
Discorbis sp.	*Dsp*	-	-	-	-	-	+	-	-	+
Phylum: Arthropoda										
Neochetina eichhorniae Warner	*Nei*	-	-	-	+	-	-	-	-	-
Subphylum: Crustacea										
Acartia longiremis (Lillejeborg)	*Alo*	+	++++	+	++	++	++	+	-	++
Acartia tonsa Dana	*Ato*	-	+	-	-	-	-	-	-	-
Paracalanus aculeatus	*Pac*	+	-	+	-	-	++	+	+	-
Paracalanus parvus Claus	*Ppa*	-	+	+	+	-	-	-	+	+
Temora turbinata Dana	*Ttu*	+	-	-	+	+	++	++	+	+
Cyclopina longicornis Boeck	*Clo*	+	-	-	+	+	-	-	+	+
Oithona colcarva	*Oco*	+	-	-	-	-	-	-	-	-
Oithona nana	*Ona*	+++	+	+	+	-	+++	+	+++	+
Euterpina acutifrons Dana	*Eac*	-	+	++	-	-	-	-	-	-
Microsetella norvegica	*Mno*	-	+	+	-	-	-	-	-	+
Bosmina longirostris	*Blo*	+	-	+	+	+	-	-	+	+
Penilia avirostris Dana	*Pav*	-	-	-	-	-	-	-	+	-
Camptocercus rectirostris	*Cre*	-	-	-	+	-	-	-	-	-
Moina macropa	*Mma*	+	-	-	-	-	-	-	-	-
Phylum: Rotifera										
Asplanchna priodonta Gosse	*Apr*	-	-	+	-	+	+	+	+	-
Notommata aurita Müller	*Nau*	+	+	++	+	++	++	++	+	+
Brachionus angularis Gosse	*Ban*	-	-	+	-	+	+	+	+	-
Brachionus falcatus Zacharias	*Bfa*	+	-	-	-	-	-	-	-	-
Brachionus calyciflorus Pallas	*Bca*	-	-	-	-	+	-	-	+	-
Brachionus urceolaris	*Bur*	-	-	-	-	-	-	-	+	-
Keratella cochlearis Gosse	*Kco*	+	-	-	-	+	+	+	+	+
Keratella valga Ehrenberg	*Kva*	+	+	+	+	-	+	+	+	-
Keratella cochlearis F. Tecta	*Kcof*	-	-	-	-	-	-	-	+	-
Platyias sp.	*Psp*	+	-	+	+	+	+	+	-	+
Horaella sp.	*Hsp*	-	-	+	-	+	+	++	++++	+++
Filinia opoliensis	*Fop*	-	-	-	+	+	-	-	-	-
Filinia terminalis Plate	*Fte*	-	+	-	-	-	-	-	-	+
Euchlanis lyra Hudson	*Ely*	-	-	-	-	-	-	+	+	-
Dipleuchlanis propatula Gosse	*Dpr*	-	-	-	-	-	+	-	-	-
Lecane bulla Gosse	*Lbu*	-	-	+	+	-	+	+	+	-
Lecane closterocerca Schmarda	*Lcl*	-	-	+	+	+	+	+	-	-
Lecane curvicornis	*Lcu*	-	+	+	-	+	+	+	-	-
Lecane eutarsa Harring and Myers	*Leu*	-	-	-	-	+	-	-	-	-
Lecane lunaris	*Llu*	-	-	-	+	-	+	+	-	-
Lecane sylviae	*Lsy*	-	-	+	-	-	+	+	-	-
Monostyla hamata Cushing	*Mha*	+	-	-	-	-	-	-	-	+
Trichocerca longiseta Schrank	*Tlo*	-	-	+	-	+	+	+	+	-
Trichocerca pusilla Jennings	*Tpu*	-	-	-	+	-	+	+	-	-
Trichocerca sp.	*Tsp*	-	-	-	+	+	+	+	+	-
Ascomorpha ovalis Bergendahl	*Aov*	-	-	-	+	+	+	-	-	+

Table 3. *Contd...*

Phylum: Ciliophora										
Tintinnopsis tubulosoides	*Ttu*	-	-	-	-	-	-	-	-	+
Ptychocyclis arctica	*Par*	-	-	++	-	+	-	+	+	-
Acanthostomella norvegica (Daday) Jörgensen	*Ano*	+++	++	++++	++	+++	++++	++++	+	++++
Paramecium caudatum	*Pca*	-	-	-	+	+	+	-	+	-
Phylum: Mollusca										
Oxygyrus keraudreni Lesueur	*Oke*	+	+	++	+	+	++	++	+++	++
Creseis acicula	*Cac*	-	-	-	-	-	-	-	-	+
Phylum: Protozoa										
Arcella vulgaris Ehr.	*Avu*	-	+	-	-	+	-	+	+	-
Arcella gibbosa Penard	*Agi*	-	-	-	+	+	+	-	+	-
Meroplankton / Juvenile stages										
Acartia nauplius		+++	+++	+++	++	++	++	++++	+++	++++
Acartia metanauplius		+	-	++	+	-	++	+	+	-
Arachnactis larva		-	-	-	-	+	-	-	-	+
Balanus balanoides cypris		+	+	+	+	+	+	+++	++++	++
Balanus balanoides nauplius da Costa (5th stage)		+	+	-	-	-	++++	+	-	+
Balanus balanoides nauplius da Costa (below 5th stage)		+	+	+	-	-	-	-	-	-
Cyclopina longicornis metanauplius		+	+	+	+	-	+	-	+	-
Cyclopina longicornis nauplius		+	+	+	+	+	+	-	+	-
Zoeae larva		+	-	-	-	-	-	-	-	-
Megalops larva		-	-	-	-	-	-	-	-	+
Oithona nana nauplius		-	-	-	-	-	-	++	++	+
Polinoid larva of Nereis diversicolor		-	-	+	+	-	+	-	-	-
Temora turbinata nauplius		+	++	++	++	++	+++	++	++	+
Typhloscolex mulleri		-	-	+	-	-	-	-	-	-

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.

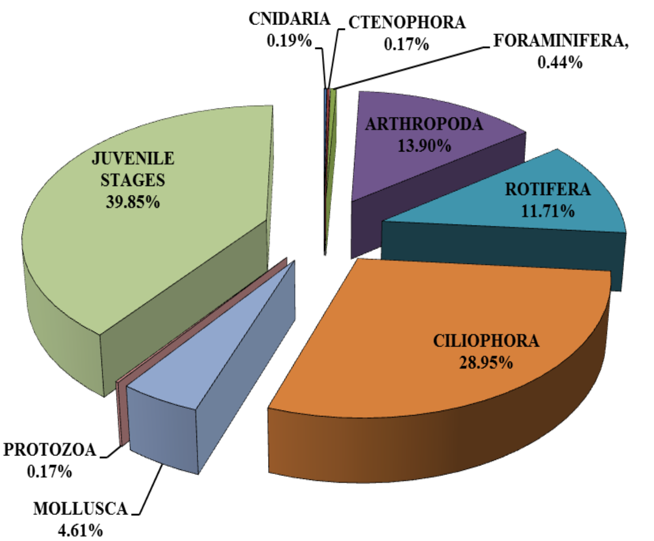

Figure 2. *Percentage composition of zooplankton groups in Badagry creek, Southwest Nigeria.*

zooplankton (Van Dijk and Zanten, 1995) and to the near eutrophication water condition affecting the zooplankton composition, changing the dominant large crustacean species to smaller rotifer species (Mola, 2011). According to Margoński *et al.* 2006, rotifers play a very important role in estuarine environments. The prevalent of Rotifers is typical of tropical waters. The predominance of rotifer species such as Keratella, Filinia and Brachionus has been associated with eutrophic condition (Dirican *et al.* 2009). Other phylum recorded in order of dominance included Arthropoda with fifteen species, Ciliophora (four species), Cnidaria accounted for three species, Ctenophora, Foraminifers, Mollusca, and Protozoa were represented by two species each. Copepods had been reported as dominant zooplankton in the findings of some earlier workers (Abdul *et al*, 2016; Emmanuel and Onyema, 2007, Akpata *et al*, 1993). The presence of an array of Meroplankton / juvenile stages in the study more than the numbers reported by Emmanuel and Onyema, 2007 and Onyema *et al.*, 2003, may reflect that Badagry creek serves as nursery / breeding ground for zooplankton. Most of the zooplankton species recorded in this study were similar to that previously reported for Southwest Nigerian waters (Abdul *et al*, 2016; Nwankwo, *et al.*, 2008; Onyema *et al.*, 2003; Akpata *et al.*, 1993). Pollution sensitive group Cladocera was observed to be less species-rich with only three species representing the whole group. Among the planktonic juvenile stages identified, Acartia nauplius of order Copepoda was predominant while Megalops larva and *Typhloscolex mulleri* (Polychaete) were least in abundance. The significant species recorded in terms of frequency of occurrence and abundance in order of dominance included *Acanthostomella*

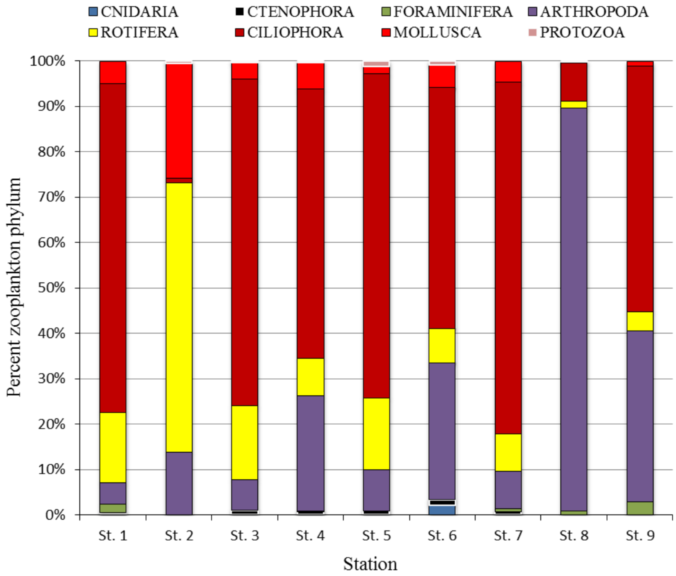

Figure 3. *Spatial composition of zooplankton phylum of Badagry creek, Southwest Nigeria (St. 1 - Apa; St.2 – Gbaji; St. 3 – Badagry/Yovoyan jetty; St. 4 – Akarakumo; St. 5 – Ajido; St. 6 – Irewe; St. 7 – Igbolobi; St. 8 – Iyagbe; St. 9 – Ojo).*

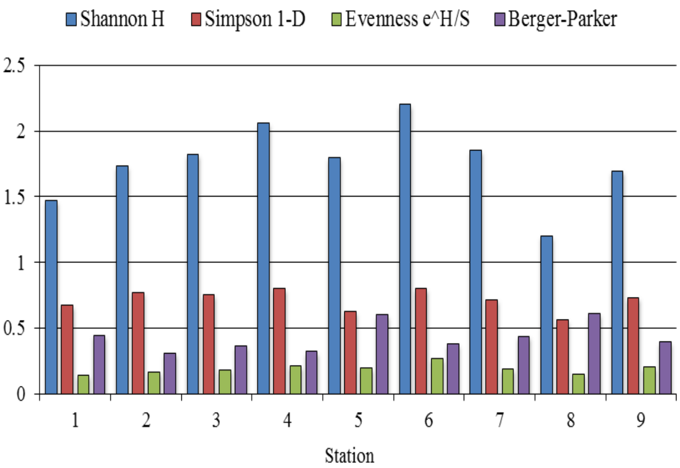

Figure 4. *Spatial variation in diversity indices of zooplankton in Badagry creek, Southwest Nigeria (St. 1 - Apa; St.2 – Gbaji; St. 3 – Badagry/Yovoyan jetty; St. 4 – Akarakumo; St. 5 – Ajido; St. 6 – Irewe; St. 7 – Igbolobi; St. 8 – Iyagbe; St. 9 – Ojo).*

norvegica (Daday) Jörgensen, *Horaella species* and *Acartia longiremis*. Tintinnid ciliates (grazers) played an important role, consuming approximately 30% of the primary annual production of phytoplankton, a value equivalent to that of copepods in the pelagial trophic chain (Capriulo and Carpenter, 1983). Spatially, the diversity varied between 22 species in station 8 and 37 species in station 4 in this study, with the least total individual (Abundance) of 461 organism/ml at station 6 and highest Abundance of 3,492 organism/ml at station 2. All the Zooplankton phylum reported in the study including the planktonic juvenile stages were identified in all stations except Cnidaria in station 2, Ctenophora at station 8 and 9, Foraminifera in station 2, 3, 5 and 6, and Protozoa at stations 1, 7 and 9.

Rotifers were most abundant (1,118 organisms per ml) at station 2 and least (17 organisms per ml) at station 8. Ciliophora was highest with 1,412 organisms per ml at station 1 and lowest (18 organisms per ml) at station 2, Arthropoda was highest with 1,003 organisms per ml at station 9 and minimum of 40 organisms per ml at station 5. Planktonic juvenile stages varied from 71 organisms per ml (lowest count) at station 5 to 1,607 organisms per ml (highest count) at station 2. Mollusca highest (479 organisms per ml) and least abundant (2 organisms per ml) were obtained at stations 2 and 8, respectively. Foraminifera ranged from 0 organisms per ml at station 2, 3, 5 and 6 to 36 organisms per ml at station 1. Cnidaria was between zero at station 2 and 7 organisms per ml at stations 1 and 6. Ctenophora was highest (9 organisms per ml) at station 3 while station 8 and 9 recorded zero organisms per ml. Protozoan was observed to have maximum abundance of 8 organisms per ml at station 2 and minimum (0 organisms per ml) at station 7 and 9 (Figure 3).

The notable organisms encountered during dry months in order of dominance were *Oxygyrus keraudreni* Lesueur, *Notommata aurita* Müller and *Temora turbinata* Dana whereas *Acanthostomella norvegica* (Daday) Jörgensen, *Horaella* spp., and *Acartia longiremis* (Lillejeborg) were the prominent organisms in order of dominance during the wet months. Among the juvenile stages, *Temora turbinata* nauplius dominated in terms of abundance during dry months while Acartia nauplius was more frequent in the rainy months.

The zooplankton community structure parameters (bio-indices) in Badary creek are presented in Figure 4. Highest Shannon - wiener (2.199) and Simpson (0.800) diversity indexes were recorded at station 6 while their corresponding lowest values of 1.200 and 0.563 were obtained at station 8. Pielou's evenness index ranged from 0.140 in station 1 to 0.265 in station 6. Berger parker index was highest (0.608) at station 8 and lowest (0.310) at station 2. Cluster analysis of overall taxa abundance (Figure 5), produced four clusters. Stations 1, 2 and 8 were distinct and make up the first, third and fourth cluster, respectively. Second cluster included station 3, 4, 5, 6, 7 and 9 with closer relationships between stations 3 and 4, and close link between stations 5 and 6, and station 7 and 9. The fairly distributed zooplankton diversity indices values across stations in the study compared favourably with the baseline report by earlier author (Olaniyan, 1975). However, other researchers (Obot *et al*, 2020; Abdul *et al*., 2016; Nwankwo, *et al*., 2008; Emmanuel and Onyema, 2007) pertaining to the zooplankton species diversity carried out in coastal waters of Nigeria, reported lesser diversity values due to the lower values of population density and less species number than that of the present 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 diversity value decreases with environmental degradation (Magurran, 1988). The cluster analysis revealed a certain degree of zooplankton differentiation on spatial scale and separated them into four major groups. The zooplankton clusters formed, comprising combination of stations could possibly 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.

Table 4. Correlation (Spearman) coefficients between abiotic factors and Zooplankton abundance in Badagry creek.

	Codes	Wat T	pH	EC	DO	Salinity	Wat D	Turb.	NO_3	PO_4
Acanthostomella norvegica (Daday) Jörgensen	Anj	0.44	0.72*	-0.20	-0.03	-0.22	-0.03	0.03	-0.50	0.10
Horaella sp.	Hsp	-0.20	0.52	-0.82**	0.25	-0.87**	0.61	-0.40	-0.79*	-0.43
Acartia longiremis (Lillejeborg)	Alo	0.06	-0.13	0.17	-0.23	0.20	-0.07	0.10	0.13	0.12
Oithona nana	Ona	-0.45	-0.07	0.07	0.23	0.10	0.06	-0.23	0.16	0.33
Oxygyrus keraudreni Lesueur	Okl	-0.23	0.62	-0.85**	0.23	-0.83**	0.65	-0.43	-0.73*	-0.42
Notommata aurita Müller	Nau	0.26	0.51	0.03	0.26	0.00	-0.07	0.18	-0.27	-0.02
Temora turbinata Dana	Ttd	-0.15	0.67*	-0.72*	-0.10	-0.74*	0.82**	0.08	-0.69*	-0.33
Ptychocyclis arctica	Par	0.17	0.13	-0.07	0.43	-0.15	-0.09	-0.13	-0.22	-0.27
Globorotalia inflata d'Orbigny	Gid	0.33	-0.02	0.37	-0.26	0.37	-0.64	0.07	0.13	0.53
Keratella valga Ehrenberg	Kva	-0.50	0.02	-0.01	0.27	0.04	0.25	-0.21	0.13	0.22
Paracalanus aculeatus	Pac	-0.31	0.25	-0.19	0.64	-0.13	0.16	-0.57	-0.12	-0.05
Euterpina acutifrons Dana	Eac	-0.10	-0.39	0.50	0.60	0.50	-0.64	-0.55	0.30	0.39
Platyias sp.	Psp	0.62	0.18	0.30	-0.16	0.26	-0.53	0.13	0.05	0.38
Bosmina longirostris	Blo	0.76*	0.13	-0.04	-0.59	-0.04	-0.33	0.41	0.00	-0.23
Keratella cochlearis Gosse	Kco	-0.15	0.67*	-0.55	0.12	-0.53	0.62	0.13	-0.51	-0.40
Trichocerca sp.	Tsp	-0.04	0.30	-0.40	0.10	-0.36	0.59	0.07	-0.20	-0.60
Paracalanus parvus Claus	Ppa	-0.27	-0.33	0.09	0.39	0.09	-0.29	-0.60	0.04	0.16
Lecane closterocerca Schmarda	Lco	0.39	0.19	0.03	0.35	0.03	-0.11	-0.07	-0.05	-0.36
Beroid Ctenophore	BCt	0.11	0.29	-0.24	0.00	-0.28	0.38	0.04	-0.29	-0.14
Brachionus angularis Gosse	Ban	0.08	0.31	-0.18	0.61	-0.21	0.04	-0.28	-0.31	-0.33
Lecane bulla Gosse	Lbu	-0.28	0.03	-0.20	0.50	-0.15	0.32	-0.57	-0.04	-0.15
Arcella gibbosa Penard	Agi	-0.28	0.08	-0.56	0.18	-0.47	0.62	-0.24	-0.12	-0.77*
Lecane curvicornis	Lcu	-0.17	0.01	0.28	0.62	0.28	-0.24*	-0.27	0.02	0.14
Asplanchna priodonta Gosse	Apr	-0.19	0.46	-0.33	0.64	-0.35	0.33	-0.33	-0.45	-0.23
Cyclopina longicornis Boeck	Cyl	0.40	-0.16	0.04	-0.81**	0.04	-0.06	0.62	0.26	-0.11
Muggiaea sp.	Msp	0.44	-0.03	0.29	-0.60	0.23	-0.35	0.40	0.13	0.55
Trichocerca longiseta Schrank	Tlo	0.08	0.36	-0.22	0.54	-0.27	0.13	-0.17	-0.36	-0.37
Ascomorpha ovalis Bergendahl	Aov	0.54	0.39	-0.31	-0.16	-0.22	0.14	0.12	-0.16	-0.69*
Microsetella norvegica	Mno	0.10	-0.10	0.28	0.43	0.28	-0.61	-0.53	0.01	0.31
Cunina octonaria McCrady	Coc	0.21	0.20	-0.26	-0.28	-0.26	0.43	0.28	-0.15	-0.36
Penilia avirostris Dana	Pav	-0.55	0.00	-0.55	0.21	-0.55	0.55	-0.27	-0.27	-0.41
Arcella vulgaris Ehr.	Avu	-0.36	0.06	-0.08	0.12	-0.19	0.30	0.28	-0.28	-0.03
Lensia fowleri	Lfo	0.23	-0.15	0.11	-0.04	0.11	-0.37	-0.30	0.00	0.19
Beröe cumis	Bcu	-0.61	0.47	-0.64	0.46	-0.60	0.78*	-0.37	-0.50	-0.35
Lecane lunaris	Llu	-0.29	0.23	-0.24	0.12	-0.22	0.55	-0.08	-0.17	-0.04

Wat T: Water Temperature (0C); EC: Electrical Conductivity (µScm-1); DO: Dissolved Oxygen (mgL-1); Wat D: Water Depth (m); Turb.: Turbidity (FTU); NO3: Nitrate (µmolL-1); PO4: Phosphate (µmolL-1). (*p < 0.05, **p < 0.01).

Table 5. CCA eigenvector analysis of dominant zooplankton species (abundance) versus abiotic variables and stations of Badagry creek, Southwest Nigeria.

	Axis order			
	F1	F2	F3	F4
Eigenvalue	0.604	0.392	0.148	0.057
Constrained inertia (%)	48.86	31.65	11.97	4.58
Cumulative % (Species–environment relation (%))	48.86	80.51	92.48	97.06

Taxa assemblage composition and abiotic variables

Correlation (Spearman) between abiotic variables and species abundance are shown in Table 4 while the relative importance of measured abiotic variables to zooplankton species abundance is presented in Figure 6, as evaluated by Canonical Correspondence Analysis. This study has demonstrated that zooplankton species abundance could possibly be explained by the measured abiotic variables. This is shown by both the positive and negative correlation between individual species and investigated environmental parameters.

Generally, the survival of many zooplankton species tends to decrease at temperatures greater than 25°C. The low zooplankton abundance and species diversity in this study and other reported studies in Nigerian coastal waters could be a result of the impact of elevated water temperature. In this study, Badagry creek demonstrated spatial variations in low salinity values, increasing towards the sea. The salinity variation had an impact on zooplankton abundance and species richness. A noticeable decrease in species richness of zooplankton was observed with relatively high salinity spatially during the dry months. Salinity gradient was the most important factor influencing zooplankton assemblages and has an effect on physiological processes, as a result, species have adapted for certain salinity (Harris and Vinobaba, 2012). The inverse correlation between turbidity and overall zooplankton abundance in this study is a clear sign that the higher the turbidity of this creek water, the lower the zooplankton abundance. The degree to which turbidity will persist in a lagoon is largely dependent upon

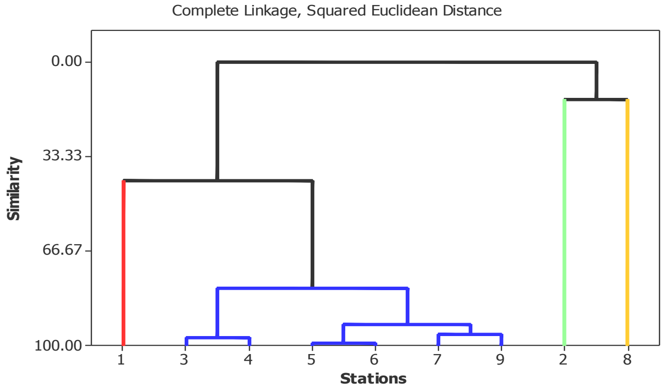

Figure 5. Dendrogram produced, representing stations cluster based on species abundance of Badagry creek, Southwest Nigeria (*St. 1 - Apa; St.2 – Gbaji; St. 3 – Badagry/Yovoyan jetty; St. 4 – Akarakumo; St. 5 – Ajido; St. 6 – Irewe; St. 7 – Igbolobi; St. 8 – Iyagbe; St. 9 – Ojo*).

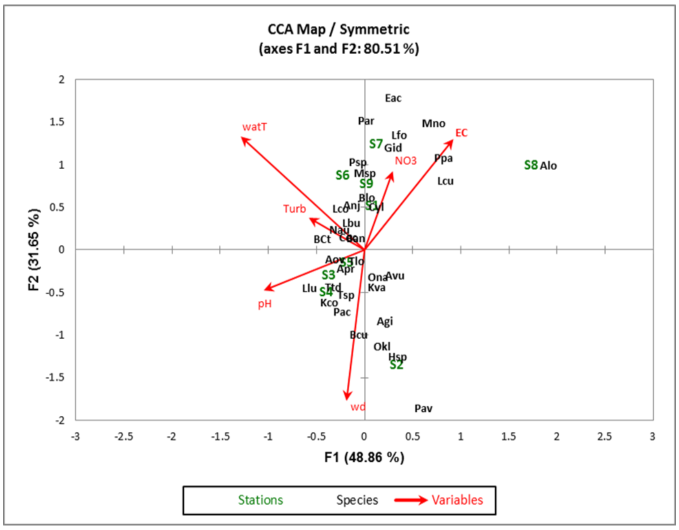

Figure 6. *Two-dimensional canonical correspondence analysis (CCA) of Badagry creek, Southwest Nigeria dominant zooplankton species abundance with abiotic variables and stations (WatT – Water Temperature; Turb – Turbidity; EC – Electrical Conductivity; NO_3 – Nitrate; Wd– Water depth. Refer to Table 2 for an explanation of the species code).*

the velocity and turbulence of the lagoon (Harris and Vinobaba, 2012). The overall zooplankton abundance in this study was also inversely correlated with nitrate and phosphate. Nevertheless, the levels of nitrate and phosphate recorded suggested nutrient enrichment required by plankton for growth and reproduction (Nybakken, 1988). The nutrients load reported is a reflection of the quantity of organic matter reaching the creek through the discharged wastewaters and land runoff.

Canonical Correspondence Analysis was performed for thirty-five (35) taxa and six (6) abiotic factors. Among the abiotic variables investigated (Table 2), salinity was not included in the analysed dataset in CCA since it was strongly correlated with electrical conductivity selected (Table 4). As revealed by the CCA (Figure 6), the response of the species to abiotic variables tested was primarily explained by the first two axes (80.51%). The first and second axis explained 48.86% and 31.65% of total variation, respectively (Table 5). The correlation between species and abiotic variables was low (r ~ 0.5), indicating an insignificant relationship between species and abiotic variables used in the analysis. The result of 1000 permutation test concludes that stations / species data are not linearly related to stations/variables data with 5% significance level. Furthermore, taxa such as *Microsetella norvegica* (Mno), *Acartia longiremis* (Alo), *Paracalanus parvus* (Ppa) and *Lecane curvicornis* (Lcu) abundance were associated with high conductivity/salinity and a low pH. *Globorotalia inflata* d'Orbigny (Gid), *Lensia fowleri* (Lfo), *Muggiaea* sp. (Msp) were sensitive to elevated nitrate and lower water depth. Abiotic variables such as Nitrate had a strong positive correlation with Axis 2. Water depth had a strong negative correlation with Axis 2. pH had a negative correlation with Axis 1 (Figure 6). The variation in taxa – abiotic factors relationship as explained by first two axes in CCA (80.51%) implies that two-dimensional Canonical Correspondence Analysis map was enough to analyse the relationships between stations, taxa 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 conductivity/salinity, water temperature and depth were the important abiotic factors in zooplankton assemblages. This finding is consistent with previous research suggesting salinity played a key role in zooplankton composition assemblages (Harris and Vinobaba, 2012). Salinity has been considered an important influence on the composition and dynamics of aquatic ecosystems (Greenwald and Hurlbert, 1993). However, the insignificant canonical axes in CCA, shows that zooplankton species abundance pattern cannot be fully explained at least, for the studied period, by the abiotic variables evaluated. Nevertheless, the concentration of species at the centre of the plot far from the abiotic variable arrows may be an indication that more than one variable or other variables unmeasured were likely to have been drivers of taxonomic abundance during the study period.

Conclusion

The present study provided valuable information on zooplankton assemblage structure of Badagry creek, Nigeria. Rotifers were the predominant group of species among the zooplankton phylum recorded with Meroplankton / juvenile stages of the order copepod of sub-phylum Crustacea dominating in terms of abundance during the study in Badagry creek. The results of Canonical Correspondence Analysis to some extent, showed that salinity / conductivity and nitrate were the most important abiotic factors co-related with the zooplankton abundance, but did not show the best predictor of zooplankton abundance and distribution in Badagry creek for the study period. Nevertheless, the dominance of Tintinnid ciliates (*Acanthostomella norvegica* (Daday) Jörgensen), a marine (grazers) species in this study also confirm the influence of salinity gradients on the zooplankton assemblage structure of Badagry creek, Nigeria. Furthermore, this study covered a period of two years, long- term data would have given more information on the zooplankton assemblage structure in Nigeria's coastal waters, as well as clearer picture of zooplankton in response to environmental changes in anthropogenic-disturbance Badagry creek. The findings from this study have contributed in understanding to some extent the Barrier Lagoon coast waters. Continuous monitoring of this section / region of the Barrier Lagoon coast waters is recommended.

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