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WATER QUALITY AND ZOOPLANKTON STRUCTURE OF FIRST ORDER RIVERS ALONG AGRICULTURAL LAND USE SITES IN EBONYI STATE, SOUTH-EASTERN NIGERIA

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Abstract. Small rivers provide important ecosystem services and harbour a rich biodiversity. Nevertheless, their ecology is still poorly understood in many parts of the world due to the paucity of studies. To this end, the water quality and zooplankton structure of several first order rivers in Ebonyi State, Nigeria were studied for the first time to assess the factors that influence the species diversity, abundance and biomass. Samples for water quality parameters and zooplankton analyses were collected for eighteen months using a standard procedure. The results showed a significant ($p < 0.05$) seasonal variation in mean air and water temperatures, conductivity, total dissolved solids, flow rate, and dissolved oxygen. Rotifera dominated zooplankton abundance and biomass and were the most diverse group. Cladocera contributed most to zooplankton species richness at the Ebyia and Idumayo rivers in the dry and rainy season, respectively. The dominance of *Brachionus* spp., *Filinia longiseta, Cyclops* spp. and nauplii indicated organic pollution at some of the rivers in the dry season. The Canonical Correspondence Analysis showed that temperature, water flow rate, transparency, conductivity, TDS, dissolved oxygen, and available phosphate were the major factors that affected zooplankton abundance, diversity, species richness and biomass in the rivers during the study.

INTRODUCTION

Rivers, whether small or large, are important sources of water for domestic, agricultural, industrial, and recreational purposes (Pongswat et al. 2000) and are a habitat for diversities of flora and fauna. Worldwide, river landscapes change frequently due to channelization, artificial waterways construction, damming and water abstraction for irrigation, municipal supply, and hydroelectric power generation. Often, rivers are recipients of point-source and diffuse pollution from residential areas, industrial clusters and agricultural ecosystems (Musingafi and Tom 2014). Pollutants frequently alter river ecology by changing water quality and composition and abundance of biota and increase vulnerability to climate changes and other adverse environmental conditions. Therefore, a proper understanding of the ecology of small rivers that are disturbed through human activities will enhance holistic management for improved ecological, economic and social benefits. Sustainable management of rivers can improve integrity, productivity, water quality, resilience and capacity to survive adverse environmental conditions and will protect the biological community. A proper management of rivers depends strongly on regular studies of this important ecological system in order to identify critical areas of need and proffer early solutions.

Small rivers in the tropics are sometimes overwhelmed by pollution from urban settlements and agricultural systems they support, which conspire with changes in pluviosity and high temperature to imperil these important ecosystems. Most unfortunately, they are often overlooked during ecological studies, although they contain diverse biological communities and are of immense economic importance as most are utilized by the riparian communities for domestic purposes and irrigation farming in the dry season (Pongswat et al. 2000; Nwonumara 2017). Unlike large rivers, small rivers sustain a high diversity and abundance of zooplankton community in the tropics, especially during the dry season when the flow rates attenuate significantly (Nwonumara 2017).

Common zooplankton groups found in freshwaters include Rotifera, Cladocera, and Copepoda (Wallace and Snell 1991), and they play a vital role in energy flow in the ecosystem, serving both as a consumer of microalgae, bacteria, and other microorganisms and as prey for larger fauna such as macro-crustaceans, insects, and juvenile fish (Infante and Abella 1985; Mathivanan et al. 2007).Zooplankton are considered good indicators of the trophic state and ecological integrity of water bodies due to their sensitivity and quick response to a wide range of environmental changes (Mathivanan et al. 2007). They play a major role in pollution monitoring by enhancing clear water phase production due to their filtering activities, which regulate algal and microbial productivities as well as nutrient cycling. Hence, they are important in restructuring the dynamics of aquatic environments (Dijk-Van and Zanten-Van1995).

Environmental factors such as temperature (Edmondson 1965), pH (Spirules 1975), conductivity (Mavuti 1990), hydrology (Moss 1994), food source (Ghadouani et al. 1998), size of water body (Patalas 1971), successional stage (Hutchinson1967), submerged aquatic vegetation (Lauridsen et al. 1998), inundation (Nwonumara and Okogwu 2013) have been reported to affect the species composition, abundance, biomass and diversity of zooplankton community in aquatic ecosystems. In the tropics, seasonality influences these factors and some zooplankton species thrive during the raining season (Aguigwo 1998; Kemdirim 2000; Davies et al. 2009; Arimoro and Oganah 2010; Imaobong 2013) while others proliferate during the dry season (Egborge et al. 1994; Onwudinjo and Egborge 1994). The ecological consequences of seasonality in aquatic ecosystems largely depend on the rate and magnitude of change in two critical environmental drivers, which are temperature and water level due to rainfall and run-off (Poff et al. 2002).These factors regulate the global climate and many ecological processes in aquatic ecosystems, either directly or indirectly, by affecting food availability, rate of production, succession and community dynamics, stability and ecological integrity of rivers.

In order to broaden understanding of the resilience of small rivers and their capacity to survive pressure from changing environmental factors, this baseline study was undertaken to assess the variation in water quality, zooplankton abundance, diversity and biomass of four small rivers for two seasons. So, we hypothesize that environmental factors may have seasonal influence on the water quality and zooplankton structure of the rivers.

MATERIALS AND METHODS

Study area

The Idumayo, Oyilo-Adada, Mile 4, and Ebyia are small rivers located in various parts of Ebonyi State, Nigeria (Figure 1). The four rivers are within the Guinea savannah region with the average rainfall of 1,500 mm per annum (Ngele et al. 2014). The rivers retain water throughout the year but water flow is seasonal due to a reduced water level in the dry season. The area experiences distinct wet and dry seasons, which last from May to October and from November to April, respectively. The rivers receive surface run-off or saturated overland flow from surrounding farmlands and watersheds that make the benthic zones muddy and rich in decayed organic matter, especially in areas with a low flow rate or discharge. The depth of the rivers varied from 0.61 meter in the dry season to 4.57 meters in the rainy season, and could be above the recorded value during inundation. The rivers flow through long undulating channels to the Cross River system. Major activities within the study sites include cultivation of rice, yam, cassava, potato, and cocoyam as well as vegetable crops such as *Telfairia occidentalis* (fluted pumpkin) and *Solanum melongena* (African garden egg). The vegetable crops are cultivated mainly in the dry season when the rivers serve solely as the only water sources for irrigation. The rivers are also used for domestic purposes by the riparian population. Water and zooplankton samples were collected at and within 6°02'11.6" N 8°00'27.9" E; 6°00'25" N 8°5'13.1" E; 6°21'46" N, 8°4'17" E; and 6°21'40" N, 8°5'32" E in the Idumayo, Oyilo-Adada, Mile 4, and Ebyia rivers, respectively (Figure 1). The sampled locations were proximal to agricultural lands.

Sample collection and analysis

Air and water temperature, conductivity, total dissolved solids (TDS), and pH were measured *in situ* using Hanna instruments. Transparency was measured using a standard Secchi disc. The flow rate was measured with a buoy, a line and stop watch, while dissolved oxygen was determined using Winkler's method. Water samples were collected concurrently and analyzed in the laboratory for silicate (SiO_3), iron (Fe^{2+}), nitrate (NO_3^-N), and phosphate (PO_4-P) using standard methods according to APHA (2012). Samples were collected from each site monthly for eighteen (18) months.

Zooplankton samples were also collected from each site using a bucket to pool 20 L of water from 0.15 m depth. The pooled samples were filtered using a 45 µm mesh size plankton net attached to a sample container. The filtered samples were thereafter preserved in 4% formalin. Identification was carried out using an Olympus binocular microscope (model: XSZ-107E) at ×400 magnification in a bright field illumination with the keys and guides of Koste (1978) and Jeje and Fernando (1980).

Estimation of zooplankton diversity indices and biomass

Zooplankton were quantified by counting individuals of each species and presented as the number of individuals per litre ($indL^{-1}$) according to APHA/AWWA/WEF (2017). Zooplankton diversity, species richness, and evenness were calculated using the appropriate Shannon-Weiner diversity indices. The specific biomass of zooplankton was expressed as fresh weight (mgL^{-1}),

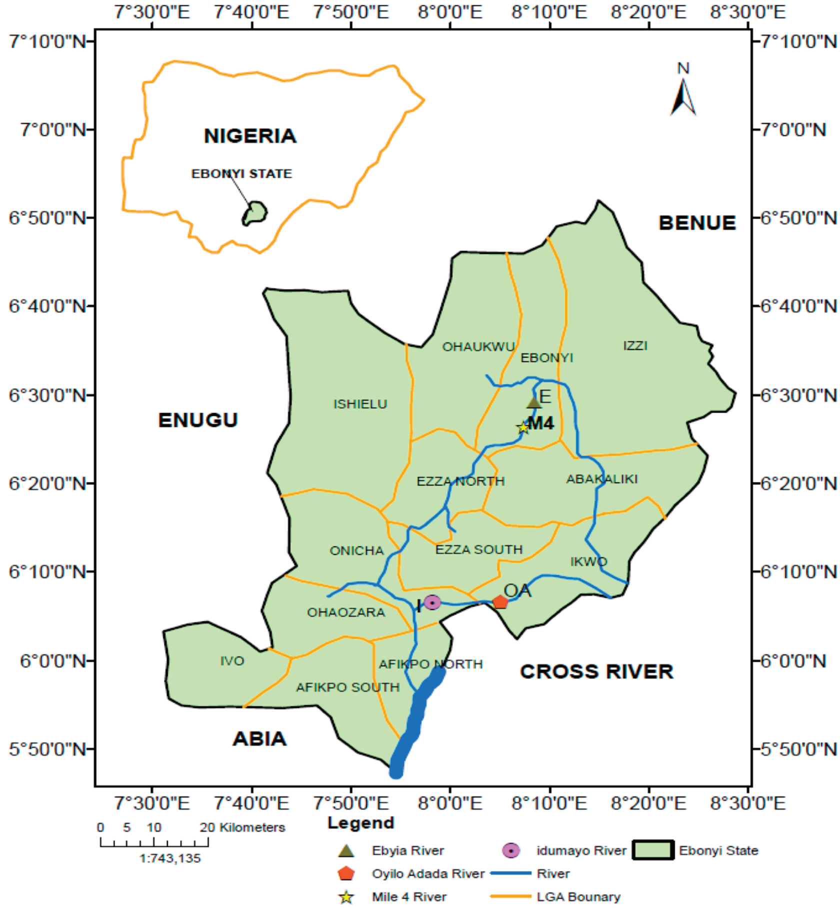

Figure 1. Map of Nigeria and Ebonyi State showing the study area. Source: Nwonumara and Okogwu 2021.

estimated from the product of abundance and the mean unit volume of each species (Hillebrand et al. 1999; Sun and Liu 2003), assuming a specific density of zooplankton cells is 1 g cm^{-3}.

Data analysis

Variations in water quality parameters and zooplankton data between the studied rivers at the different seasons were tested statistically using a two-way analysis of variance (ANOVA) after transforming the data and values were considered significant at $p < 0.05$. Water quality parameters and zooplankton data were also subjected to Canonical Correspondence Analysis (CCA) to pinpoint the factors that influenced zooplankton dynamics during the study. All statistical analyses were carried out using Paleontological Statistics (PAST), Statistical Package for Social Science (SPSS) software version 23, and PC-ORD 5.10.

RESULTS

Water quality parameters

Air and water temperatures, conductivity, TDS, water flow rate and dissolved oxygen varied significantly ($p < 0.05$) between seasons only (Table 1). Higher conductivity values were recorded during the dry compared to rainy season. The highest value (474 µScm^{-1}) was recorded at the Ebyia River during the dry season, while the minimum value (26 µScm^{-1}) was recorded at the Oyilo-Adada River during the rainy season. Dissolved oxygen was significantly higher during the rainy season than the dry season and the highest value (9 mgL^{-1}) was recorded in the Ebyia River. Phosphate varied significantly between rivers and seasons with the highest (3.83 mgL^{-1}) and lowest (0.06 mgL^{-1}) values recorded in the Mile 4 River in the dry season.

Zooplankton species composition, abundance, diversity and biomass

The three major zooplankton taxa identified during the study were Cladocera (581 indL^{-1}; 28 species), Rotifera (770 indL^{-1}; 105 species) and Copepoda (704 indL^{-1}; 14 species) as shown in Table 2. Overall, Rotifera were the most abundant zooplankton taxa and were most abundant at the Oyilo-Adada River(436 indL^{-1}). Copepoda was dominant at the Idumayo (347 indL^{-1}) and Ebyia (91 indL^{-1}) rivers, and Cladocera at the Mile 4 River (127 indL-^{1}). The most frequently encountered species among the rotifera belonged to the genera

Table 1. Mean with standard deviation, minimum and maximum values of water quality parameters measured during the study period.

Parameters	Rainy season				Dry season				P values (for seasonal variation)
	Idumayo River	Oyilo-Adada River	Mile 4 River	Ebyia River	Idumayo River	Oyilo-Adada River	Mile 4 River	Ebyia River	
Air temperature, °C	$30.49^{a} \pm 3.11$ 26.50–35.60	$28.74^{a} \pm 1.26$ 27.00–30.60	$27.98^{a} \pm 1.30$ 26.00–30.00	$28.21^{a} \pm 1.21$ 26.20–29.50	$32.98^{b} \pm 4.20$ 26.20–39.60	$32.20^{b} \pm 4.45$ 25.50–40.50	$28.97^{b} \pm 3.31$ 24.00–36.70	$29.30^{b} \pm 2.96$ 26.30–36.50	0.04
Water temperature, °C	$29.33^{a} \pm 3.03$ 25.50 – 35.50	$28.48^{a} \pm 1.10$ 27.00–30.00	$28.54^{a} \pm 1.14$ 27.20–30.60	$28.43^{a} \pm 0.92$ 27.20–30.20	$30.17^{b} \pm 9.88$ 26.40–34.40	$30.32^{b} \pm 3.34$ 22.60–33.60	$29.09^{b} \pm 9.78$ 24.40–34.90	$29.63^{b} \pm 2.60$ 26.4–33.60	0.02
Conductivity, µScm^{-1}	$74.88^{a} \pm 29.15$ 50.00–126.00	$57.13^{a} \pm 18.60$ 26.00–78.00	$57.13^{a} \pm 19.44$ 45.00–97.00	$59.38^{a} \pm 12.01$ 44.00–76.00	$199.11^{b} \pm 118.70$ 82.00–443.00	$183.80^{b} \pm 87.78$ 84.00–356.00	$169.56^{b} \pm 90.43$ 0.00–304.00	$197.60^{b} \pm 118.08$ 61.00–474.00	0.0001
TDS, mgL^{-1}	$35.88^{a} \pm 14.41$ 18.00–62.00	$27.13^{a} \pm 9.16$ 13.00–40.00	$37.38^{a} \pm 7.96$ 28.00–48.00	$28.75^{a} \pm 5.34$ 20.00–39.00	$99.22^{b} \pm 58.05$ 54.00–220.00	$97.40^{b} \pm 45.20$ 40.00–179.00	$90.00^{b} \pm 44.68$ 50.00–152.00	$102.60^{b} \pm 57.11$ 33.00–236.00	0.0008
Transparency, m	$0.13^{a} \pm 0.08$ 0.08–0.15	$0.12^{a} \pm 0.03$ 0.06–0.16	$0.14^{a} \pm 0.03$ 0.09–0.15	$0.13^{a} \pm 0.03$ 0.07–0.17	$0.08^{a} \pm 0.06$ 0.02–0.14	$0.12^{a} \pm 0.03$ 0.08–0.18	$0.10^{a} \pm 0.06$ 0.03–0.17	$0.14^{a} \pm 0.03$ 0.08–0.20	0.26
pH	$6.80^{a} \pm 0.15$ 6.60–7.00	$6.66^{a} \pm 0.22$ 6.20–6.90	$6.76^{a} \pm 0.37$ 6.20–7.30	$6.86^{a} \pm 0.28$ 6.40–7.20	$7.18^{a} \pm 2.32$ 6.50–7.90	$7.19^{a} \pm 0.40$ 6.60–7.70	$6.96^{a} \pm 5.47$ 6.50–7.90	$6.96^{a} \pm 0.28$ 6.70–7.50	0.06
Flow rate, ms^{-1}	$0.04^{a} \pm 0.03$ 0.00–0.06	$0.04^{a} \pm 0.01$ 0.02–0.07	$0.05^{a} \pm 0.00$ 0.03–0.07	$0.07^{a} \pm 0.01$ 0.05–0.08	$0.01^{b} \pm 0.00$ 0.00–0.03	$0.01^{b} \pm 0.00$ 0.00–0.03	$0.01^{b} \pm 0.00$ 0.00–0.04	$0.01^{b} \pm 0.00$ 0.00–0.03	0.01
Dissolved oxygen, mgL^{-1}	$5.69^{a} \pm 1.92$ 3.80–8.50	$5.86^{a} \pm 1.93$ 4.00–8.70	$6.00^{a} \pm 1.97$ 4.00 –.80	$6.15^{a} \pm 1.88$ 4.40–9.00	$3.78^{b} \pm 1.42$ 2.60–5.20	$3.76^{b} \pm 1.13$ 2.50–5.50	$2.98^{b} \pm 1.36$ 1.50–4.50	$3.34^{b} \pm 0.89$ 2.20–4.8	0.002
Silicate, mgL^{-1}	$4.07^{a} \pm 3.09$ 0.59–8.58	$2.31^{a} \pm 1.70$ 0.90–5.78	$2.05^{a} \pm 1.15$ 0.60–3.52	$3.04^{a} \pm 2.32$ 0.83–6.97	$2.08^{a} \pm 1.81$ 0.43–5.10	$2.31^{a} \pm 1.70$ 0.11–5.58	$2.18^{a} \pm 1.75$ 0.37–7.71	$2.44^{a} \pm 1.90$ 0.37–5.56	0.29
Iron, mgL^{-1}	$0.29^{a} \pm 0.24$ 0.06–0.81	$0.17^{a} \pm 0.10$ 0.07–0.33	$0.16^{a} \pm 0.11$ 0.00–0.33	$0.16^{a} \pm 0.12$ 0.05–0.36	$0.46^{a} \pm 0.38$ 0.09–1.01	$1.04^{a} \pm 0.51$ 0.08–3.89	$0.74^{a} \pm 0.43$ 0.12–3.37	$0.41^{a} \pm 0.39$ 0.00–1.19	0.06
Nitrate, mgL^{-1}	$1.56^{a} \pm 1.02$ 0.27–3.17	$1.16^{a} \pm 0.68$ 0.41–2.27	$0.71^{a} \pm 0.39$ 0.29–1.35	$1.25^{a} \pm 0.82$ 0.48–2.28	$1.13^{a} \pm 0.56$ 0.35–1.85	$1.49^{a} \pm 1.18$ 0.27–3.33	$1.70^{a} \pm 1.27$ 0.33–8.57	$1.18^{a} \pm 1.07$ 0.22–4.05	0.54
Phosphate, mgL^{-1}	$0.55^{a} \pm 0.40$ 0.14–1.23	$0.50^{b} \pm 0.31$ 0.10–0.96	$0.70^{c} \pm 0.55$ 0.14–1.56	$0.44^{d} \pm 0.42$ 0.08–1.36	$0.71^{e} \pm 0.50$ 0.08–1.35	$0.55^{a} \pm 0.34$ 0.13–1.24	$0.93^{f} \pm 0.58$ 0.06–3.83	$0.52^{g} \pm 0.40$ 0.09–1.33	0.04

NB: Means with the same superscript on the same row are not significant ($p > 0.05$).

Table 2. Zooplankton species composition, total abundance (indL^{-1}) and biomass (µgL^{-1}) per study sites.

Zooplankton taxa (abundance/biomass)	Study sites			
	Idumayo River	Oyilo-Adada River	Mile 4 River	Ebyia River
Cladocera (582 indL^{-1}; 24.15µgL^{-1})	197 indL^{-1} (10.61 µgL^{-1})	107 indL^{-1} (4.58 µgL^{-1})	229 indL^{-1} (7.37 µgL^{-1})	49 indL^{-1} (1.59 µgL^{-1})
Alona rectangular rectangularr Sars, 1862	**	*	*	*
Alona veruccosa Sars, 1901	*	**		**
Alonella excisa excisa Fischer, 1854	*	**	*	*
Ceriodaphnia cornuta Sars, 1888	***	*	*	*
Chydorus eurynotus Sars, 1901	*	**	*	*
Diaphanosoma excisum Sars, 1885	***	***	***	***
Diaphanosoma sarsi Richard, 1895	*	*	**	*
Echinisca capensis Sars, 1916	**	*	*	**
Echinisca capensis capensis Sars, 1916	**	**	*	**
Echinisca rosea Liévin, 1848	**	**	*	*
Echinisca triseralis Brady, 1886	**	*	*	*
Grimaldina brazzai Richard, 1892	**	*	*	*
Karualona muelleri King, 1893	*	**	*	*
Leydigia leydigi Schoedler, 1863	*	*	*	**
Macrothrix goeldi Richard, 1897	**	*	*	*
Macrothrix spinosa King, 1853	*	**	*	*
Moina micrura Kruz, 1874	***	***	***	***
Moina reticulate Daddy, 1905	**	*	*	*
Moinodaphnia macleayi King, 1853	***	*	***	***
Ovalona glabra Guerne and Richard, 1893	**	*	*	*
Oxyurella ciliate Bergamin, 1939	**	**	**	**
Pleuroxus hamatus hamatus Birge, 1879	**	**	**	**
Pleuroxus laevis Sars, 1862	**	*	*	*
Pleuroxus similis Vavra, 1900	**	**	**	**
Pseudochydorus globosus Baird, 1843	**	*	*	*
Pseudosida bidentata Herrick, 1884	***	***	**	**
Scapholeberis kingi Sars, 1903	**	**	**	**
Simocephalus vetulus Muller, 1776	***	***	***	**
Rotifera (864 indL^{-1}; 85.05 µgL^{-1})	239 indL^{-1} (13.20 µgL^{-1})	436 indL^{-1} (29.88 µgL^{-1})	106 indL^{-1} (25.45 µgL^{-1})	83 indL^{-1} (16.52 µgL^{-1})
Anuraeopsis coelata coelata de Beauchamp, 1932	**	*	**	*
Anuraeopsis fissa Gosse, 1851	**	*	*	*
Anuraeopsis fissa f. urawensis Sudzuki, 1957	*	*	*	**
Anuraeopsis racenesi Berzins, 1962	*	**	*	**
Ascomorpha saltans Bartsch, 1870	*	*	**	*
Brachionus jirovci Bartos, 1942	**	*	*	*
Brachionus bidentata Anderson,1889	*	**	***	**
Brachionus bidentata f.*crassispineus*Hauer, 1963	**	*	*	*
Brachionus bidentata f. *inermis* Rousselet 1906	**	**	**	**
Brachionus bidentata f. *jirovci* Bartos 1947	*	*	*	**
Brachionus bidentata f. *testudinarius* Jakubsky, 1912	*	*	*	**
Brachionus calyciflorus f. *amphiceros* Ehrenberg, 1838	**	**	*	*
Brachionus caudatus f. *majusculus* Ahlstrom, 1940	*	**	*	*
Brachionus caudatus var vulgatus Ahlstrom, 1940	**	*	*	*
Brachionus falcatus Zacharias, 1898	*	*	*	***
Brachionus leydigi f. tridentatus Ankara (G) 1949	**	*	*	*
Brachionus melhemi Barrois and Daday, 1894	**	*	*	*
Brachionus patulus patulus Muller, 1786	**	*	*	**
Brachionus quadridentatus Hermann, 1783	*	*	**	*
Brachionus quadridentatus mirabilis Daday, 1897	**	*	*	*

Zooplankton taxa (abundance/biomass)	Study sites			
	Idumayo River	Oyilo-Adada River	Mile 4 River	Ebyia River
Brachionus quadridentatus varmelheni Barrois and Daday, 1894	*	**	*	*
Brachionus rhenanus Lauterborn, 1893	**	*	*	*
Brachionus urceolaris f. sericus Rousselet, 1907	*	**	*	*
Brachionus zahniseri Thomasson, 1954	*	**	*	**
Brachionus zahniseri f geseneri Hauer, 1956	*	**	*	*
Brachionus zahniseri f. reductus Hauer, 1956	**	*	*	*
Bryceella tenella Bryce, 1897	*	*	**	*
Cephalodella globata (Gosse, 1887)	*	*	**	*
Cephalodella hyalina Myers, 1924	*	*	**	*
Cephalodella nana Myers, 1924	*	**	*	*
Cephalodella tenuiseta Harring & Myers, 1924	*	*	*	**
Collotheca bulbosa Berzins, 1951	*	**	*	*
Colurella colurus f. compressa Lucks, 1912	*	**	*	*
Colurella dicentra Gosse, 1887	**	*	*	*
Colurella geophila f. *hallensis* Althaus, 1957	*	*	*	**
Colurella geophila f. *limnetica* Althaus, 1957	*	**	*	*
Colurella hindenburgi Steinecke, 191	*	*	*	**
Colurella hinderburgi f. *gastracantina* Hauer, 1924	**	**	*	*
Colurella monodactylos Althaus, 1957	*	*	*	**
Colurella obtusa obtuse Gosse, 1886	*	**	*	*
Colurella uncinata Müller, 1773	*	**	*	*
Conochilus coenobasis Skorikov, 1914	**	*	**	**
Conochilus natans Seligo, 1900	*	*	*	**
Conochilus unicornis Rousselet, 1892	*	*	*	*
Encentrum incisum Wulfert, 1936	*	**	*	*
Erignatha clastopis Gosse, 1886	*	**	*	*
Euchlanis dilatata f. *lucksiana* Hauer 1832	**	*	*	*
Euchlanis meneta Myers, 1930	*	**	*	*
Filinia longiseta varsaltator Gosse, 1886	**	**	**	**
Filinia longiseta Ehrenberg, 1834	**	**	*	**
Filinia maior Carlin, 1943	**	**	*	*
Filinia opoliensis Zacharias, 1898	**	**	*	*
Filinia pejleri Hutchinson, 1964	**	**	**	*
Filinia terminalis Plate, 1886	**	**	**	**
Floscularia melicerta Ehrenberg, 1832	**	*	*	*
Keratella americana Carlin, 1943	*	*	*	**
Keratella hiemalis Carlin, 1943	*	*	**	*
Lecane candida Harring & Myers, 1926	*	**	*	*
Lecane chankensis Bogoslovsky, 1958	**	*	*	*
Lecanec repidacrepida Harring, 1914	*	**	*	*
Lecane curvicornis Murray, 1913	**	**	*	*
Lecane elsa Hauer, 1931	**	*	*	*
Lecane flexilis Gosse, 1886	**	*	*	*
Lecane hastata Murray, 1913	v	*	*	**
Lecane hornemanni Ehrenberg, 1834	*	*	**	**
Lecane (H) inopinata Harring & Myers, 1926	**	*	*	*
Lecane imbricata Carlin, 1939	**	**	*	**
Lecane pustulosa Myers, 1938	**	*	v	*
Lecane stichaea Harring, 1913	*	**	*	*
Lecane stichaea f. intrasinuata Olofsson, 1917	*	*	**	*
Lecane rhacois Harring & Myers, 1926	*	**	**	*

Zooplankton taxa (abundance/biomass)	Study sites			
	Idumayo River	Oyilo-Adada River	Mile 4 River	Ebyia River
Lecane rhenana Hauer, 1929	*	**	*	**
Lecane ungulata Gosse, 1887	*	**	*	*
Lepadella patella f. *similis* Lucks, 1912	*	*	**	*
Lindia euchromatica europaea Koch-Althaus, 1962	*	**	**	*
Lophocharis gracilis Dvorakova, 1960	*	*	*	**
Macrochaetus sericus Thorpe, 1893	*	*	*	**
Notholca bipalium Müller, 1786	***	***	***	**
Notholca liepetterseni GodskeBjorklund, 1972	*	*	*	**
Notholca psammarina Buchholz and Ruhmann, 1956	**	*	*	*
Polyarthra aptera-reducta Hood, 1893	*	*	**	*
Polyarthra euryptera Wierzejski, 1891	**	**	*	**
Polyarthra major Burckhardt, 1900	*	**	**	**
Polyarthra minor Voigt, 1904	**	**	*	*
Polyarthra remata Skonkov, 1846	**	***	**	**
Polyarthra vulgaris Carlin, 1943	*	**	*	*
Polyarthra vulgaris vardis simulans Nipkow, 1952	*	**	*	*
Pleosoma (s. str.) *africana* Herrick, 185	*	*	**	*
Ptygura elsteri elsteri Koste, 1972	*	**	*	*
Ptygura melicerta Ehrenberg, 1832	*	**	*	*
Ptygura libera Myers, 1934	**	*	*	*
Ptygura pedunculata Edmondson, 1939	*	*	**	*
Sinantherina socialis Linne, 1758	*	**	*	*
Stephanoceros fimbriatus fimbriatus Goldfusz, 1820	*	*	**	*
Synchaeta oblonga Ehrenberg, 1832	*	**	*	*
Taphrocampa selenura Gosse, 1851	**	*	*	*
Testudinella parva f. *bidentata* Myers, 1931	*	*	**	*
Trichocerca elongata Gosse, 1886	***	*	*	**
Trichocerca (s. str.) *bicristatavar mucosa* Stokes, 1896	*	*	*	**
Trichocerca (s. str.) *lata* Jennings, 1894	**	*	*	*
Trichocerca (s. str.) *longiseta* Schrank, 1802	*	*	**	*
Trichocerca (s. str.) *ornate* Myers, 1934	*	*	**	*
Weirzejskiella velox Wiszniewski, 1932	**	*	*	*
Xenolepadella branchicola Hauer, 1926	*	**	*	*
Copepoda (704 $indL^{-1}$; 14.39μgL^{-1})	347 $indL^{-1}$ (6.37 μgL^{-1})	134 $indL^{-1}$ (2.27 μgL^{-1})	132 $indL^{-1}$ (2.19 μgL^{-1})	91 $indL^{-1}$ (3.56 μgL^{-1})
Bryocamptus bristeini Borutxkii, 1940	***	***	***	***
Cryptocyclops bicolor Sars, 1863	***	**	*	*
Ectocyclops phaleratus Koch,1838	**	**	**	*
Eucyclops serrulatus Fischer, 1860	**	**	**	*
Eucycyclops speratus Lilljeborg, 1901	*	**	**	*
Halicyclops troglodytes Kiefer, 1954	**	**	*	*
Mesocyclops leuckarti Claus, 1857	*	*	**	*
Metacyclops minutus Claus, 1863	***	***	***	***
Microcyclpos rubellus Lilljeborg, 1901	**	*	*	*
Microcyclops varicans Sars, 1863	***	***	***	***
Thermocyclops neglectus Sars, 1901	**	**	*	*
Thermocyclops oithonoides Sars, 1863	***	***	***	***
Tropocyclops prasinus Fischer,1860	**	**	*	*
Thermodiaptomus yabensis Wright and Tressler, 1928	**	*	*	*
Nauplii	**	**	**	***

NB: * absent, ** present, *** abundant. NB: Means with the same superscript on the same row are not significant ($p > 0.05$).

Brachionus>Lecane>Colurella>Filinia>Polyarthra>Trichocerca>Anuraeopsis>Cephalodella>Echinisca>Ptygura>Conochilus>Notholca. *Simocephalus vetulus* and *Diaphanosoma excisum* were the most dominant cladocera in the rivers.

Rotifera was the most diverse taxon and its highest diversity (4.26) was recorded at the Ebyia River, while Copepoda was the least diverse with its lowest diversity (1.41) at the Idumayo River. Cladocera contributed most (10.61 μgL^{-1}) to the zooplankton biomass of the study sites at the Idumayo, and least (1.59 mgL^{-1}) at the Ebyia River (Table 2). Meanwhile, Rotifera had the highest biomass with 13.20 μgL^{-1}, 29.88 μgL^{-1}, 25.45 μgL^{-1}, and 16.52 μgL^{-1}at the Idumayo, Oyilo-Adada, Mile 4, and Ebyia rivers, respectively. This represented 44.48%, 81.50%, 72.69%, and 76.25% of the total zooplankton biomass at the Idumayo, Oyilo-Adada, Mile 4, and Ebyia rivers, respectively, during the study. Only the difference in the abundance of Copepoda ($p = 0.03$) was significant between the studied rivers.

Seasonal diversity indices and biomass of zooplankton

The three zooplankton taxa identified showed higher abundance, diversity, and biomass in the dry season (except Rotifera at the Idumayo River) than in the rainy season (Table 3). Rotifera was the most diverse (H′ = 4.26) group among the three zooplankton taxa with the highest diversity recorded at the Ebyia River in the dry season (Table 3). On the other hand, Cladocera was the most diverse group (H′ =3.82; d= 1.25) in the rainy season and at the Idumayo River. ANOVA result showed that variation in the abundance of Cladocera and Copepoda were significant ($p < 0.05$) between seasons at the rivers; however, the difference in the diversity and species richness of the three taxa were not significant ($p > 0.05$). The biomass contribution of Rotifera was the highest among the zooplankton taxa identified, with the highest mean biomass (2.40 μgL^{-1}) recorded at the Oyilo-Adada River in the dry season. Copepoda, on the other hand, contributed least to the zooplankton biomass of the study sites. Seasonal variations in the biomass of Cladocera ($p = 0.02$) and Copepoda ($p = 0.007$) were significant (Table 3).

Zooplankton–environment relation

The Canonical Correspondence Analysis (CCA) showed that the zooplankton–environment correlation was significant for Axis 1 ($r = 0.84$, $p < 0.001$) and Axis 2 ($r = 0.61$, $p < 0.001$). These axes accounted for 26.60% of the zooplankton–environment association (Figure 2). Transparency (0.81), conductivity (–0.64),

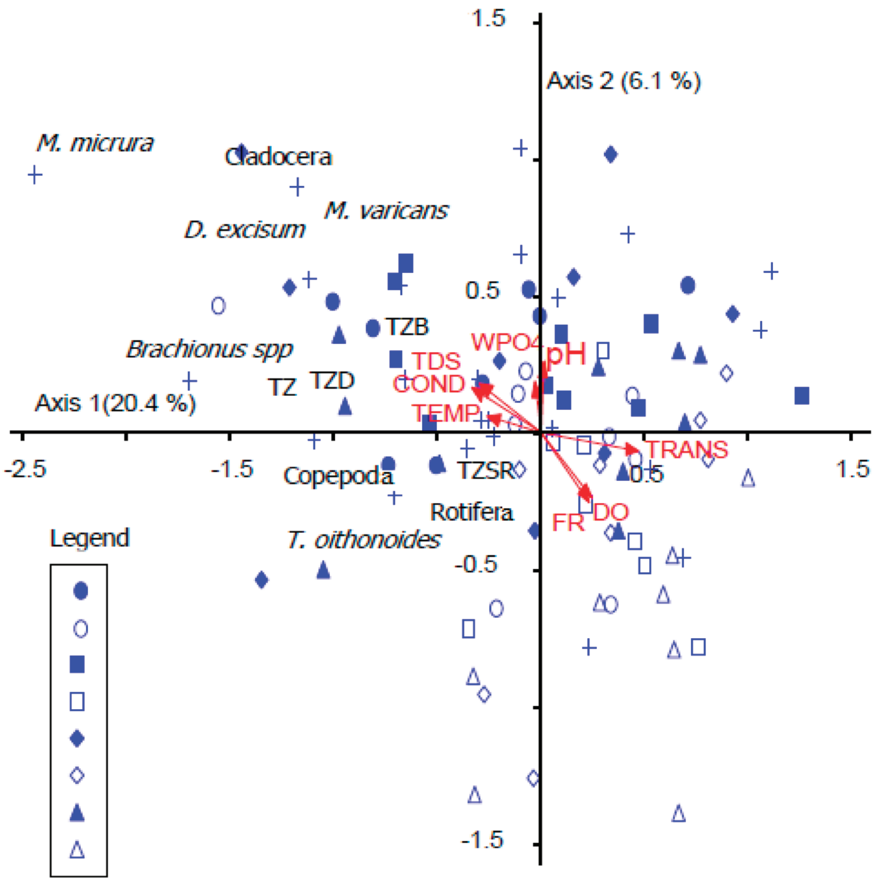

Figure 2. Canonical Correspondence Analysis (CCA) of zooplankton–environment relationship.

Table 3. Seasonal diversity indices of zooplankton taxa.

Zooplankton taxa	Diversity indices	Rainy season				Dry season				P-values (for seasonal variation)
		Idumayo River	Oyilo-Adada River	Mile 4 River	Ebyia River	Idumayo River	Oyilo-Adada River	Mile 4 River	Ebyia River	
Cladocera	Mean abundance	34.00^a	25.00^a	15.00^a	10.00^a	179.00^b	85.00^b	220.00^b	79.00^b	0.008
	Number of species	9.00	10.00	6.00	7.00	12.00	5.00	5.00	3.00	
	Shannon-Weiner diversity index, H′	3.82^a	3.71^a	2.60^a	3.59^a	2.89^a	3.34^a	2.39^a	2.35^a	0.07
	Margalef's index	1.25^a	0.96^a	0.63^a	0.91^a	0.93^a	1.16^a	0.65^a	0.91^a	0.86
	Mean biomass (μgL^{-1})	0.18^a	0.09^a	0.01^a	0.03^a	0.93^b	0.45^b	0.21^b	1.54^b	0.02
Rotifera	Mean abundance	193.00^c	58.00^c	19.00^c	30.00^c	100.00^c	391.00c	90.00^c	64.00^c	0.21
	Number of species	33.00	30.00	14.00	21.00	30.00	36.00	21.00	19.00	
	Shannon-Weiner diversity index, H′	1.78^c	2.33^c	2.92^c	3.67^c	3.51^c	3.68^c	2.44^c	4.26^c	0.23
	Margalef's index	0.68^d	0.82^d	0.60^d	0.91^d	1.01^d	0.85^d	1.18^d	1.08^d	0.10
	Mean biomass (μgL^{-1})	1.32^d	0.73^d	0.98^d	0.02^d	0.84^d	1.84^d	0.12^d	0.25^d	0.07
Copepoda	Mean abundance	30.00^e	10.00^f	5.00^g	5.00^h	321.00^i	128.00^j	128.00^k	88.00^l	0.0007
	Number of species	6.00	3.00	3.00	2.00	12.00	13.00	9.00	8.00	
	Shannon-Weiner diversity index, H′	3.14^g	3.70^g	2.39^g	2.39^g	1.41^g	3.53^g	2.04^g	3.20^g	0.49
	Margalef's index	0.73^h	1.09^h	0.54^h	0.84^h	0.74^h	0.98^h	0.98^h	0.89^h	0.43
	Mean biomass (μgL^{-1})	0.06^i	0.05^i	0.02^i	0.02^i	0.97^j	0.18^j	0.32^j	0.21^j	0.007

NB: Values with the same superscript on the same row are not significant.

TDS (–0.60), dissolved oxygen (0.54), water velocity (0.52) and temperature (0.46) explained variability in Axis 1, while pH (–0.57) and dissolved phosphate (0.38) explained most of the variations in Axis 2. A Monte Carlo test performed along with CCA showed that Axis 1 was significant (eigenvalue = 0.15, p = 0.001) and the axis was mainly related to hydrophysical factors, while Axis 2 was attributed to eutrophication factors (high phosphate).

Closed circle – dry season (Idumayo River), open circle – rainy season (Idumayo River), closed square – dry season (Oyilo-Adada River), open square – rainy season (Oyilo-Adada River), closed prism – dry season (Mile 4 River), open prism – rainy season (Mile 4 River), closed triangle – dry season (Ebyia River), open triangle – rainy season (Ebyia River), TZ – total zooplankton, TZB – total zooplankton biomass, TZD – total zooplankton density, TZSR – total zooplankton species richness.

DISCUSSION

The abundance, diversity, species richness and biomass production of organisms in aquatic ecosystems depend largely on the ecological status, prevailing environmental factors, and the extent and nature of human activities in and around the ecosystem. This study evaluated the effects of some environmental factors on the abundance, diversity, species richness and biomass of zooplankton taxa recorded at the study sites. Three major zooplankton taxa were recorded during the study: Cladocera, Rotifera, and Copepoda.

Among the three taxa, Rotifera was recorded as the most abundant zooplankton taxa, while Cladocera was the least. This result agreed with the reports of Mwebaza-Nadwula et al. (2005), Imoobe and Akoma (2009), Imoobe (2011), and Ekpo (2013) that recorded rotifera as the most abundant zooplankton taxa in some tropical waters. The dominance of Rotifera could be due to their preference for warm water according to Segers (2003) cited in Bhat et al. (2015). It could also be due to high nitrate and phosphate, as the dominant species were *Brachionus* which are associated with nutrient-rich waters as recorded mainly in the dry season at the rivers (Bhat et al. 2015).

Higher zooplankton abundance, diversity, and biomass were recorded in the dry season compared to the rainy season. This could be attributed to a lower water flow which reduced the flush out of zooplankton biomass and increased nutrient concentration, which in turn promoted phytoplankton productivity that served as a suitable diet for the zooplankton. This is in line with the findings of Onwudinjo and Egborge (1994) and Egborge et al. (1994) and depicted the reason for the negative correlation between total zooplankton abundance and rainy season. Low zooplankton abundance, diversity and, biomass recorded in the rainy season was also in line with the observation of Anyanwu et al. (2013) who adjudged that it is a unique characteristic of fast-flowing rivers, which does not allow for stable development of zooplankton community due to a narrow width and high flow rate according to Arimoro and Oganah (2010).

Rotifera were the most abundant in the dry season, while Cladocera were the least. This agreed with the report of Okogwu et al. (2009) that recorded a higher abundance of rotifera in the dry season and attributed the low density in the rainy season to the washing off by water current due to floods. Akin-Oriola (2003) and Imoobe and Adeyinka (2010) attributed the higher abundance of rotifera they observed in the dry season to their parthenogenetic reproductive pattern, short development rate under favourable conditions, and a short life cycle with a peak reproductive period of 12 days at 20°C and 5 days at 25°C. Similarly, Arimoro and Oganah (2010) concluded that the dominance of Rotifera could be due to their ability to undergo vertical migration, which reduced competition via niche exploitation and food utilization.

Higher diversity and species richness of Rotifera recorded in the dry season could be attributed to availability of food which supported their productivity and lesser predation (Imoobe and Adeyinka 2010). Overland flow from riparian farmlands may have added to the nutrient level of the rivers which increased in concentration as the water level decreased in the dry season, hence supported the growth of Rotifera. This is buttressed by the report of Bhat et al. (2015) that the dominance of Rotifera species in a water body indicates nutrient enrichment from direct inflow of untreated domestic sewage. Therefore, a high frequency of *Brachionus* species and *Filinia longiseta* (both Rotifera) recorded in this study could be due to increased nutrient concentration (Bhat et al. 2015) that leached into the rivers in diluted form from riparian rice farms. In the same vein, increased nutrient levels in the rivers in the dry season may have been responsible for the dominance of *Cyclops* spp. and nauplii among Copepoda. Verma et al. (1984) and Ahmad et al. (2011)have reported that *Cyclops* spp. and nauplii correlate positively with high nutrients and are indicators of pollution.

The diversity and species richness of Cladocera recorded was, on the other hand, higher in the rainy season compared to the dry season and could be attributed to lower water temperatures which enhance the hatching of resting Cladocera eggs lying dormant in the soil in the pre-rainy season as reported by Okogwu (2010).

Rotifera had a higher biomass in the dry season and this could be attributed to the favourable environmental conditions that supported their productivity. However, Cladocera and Copepoda had a lower biomass, which could be due to higher predation by planktivorous fishes. It could also be related to their lower abundance, since biomass accumulation could be enhanced by similar factors that favour abundance.

The major factors that influenced the abundance, biomass, species richness, and diversity of zooplankton at the study sites were transparency, conductivity, TDS, dissolved oxygen, water flow rate, temperature, pH and water phosphate. Dissolved oxygen, flow rate, and transparency were the dominant factors in the rainy season, while water temperature, conductivity, TDS, pH, and, phosphate level were the major regulating factors in the dry season. The significance of Axis 2 to eutrophication factors (high phosphate) depicted by the Monte Carlo test performed with CCA explained the occurrence of *Brachionus* spp. which are indicators of pollution mainly in the dry season. The dry season could reduce river flow rate, consequently increasing water residence time and nutrient accumulation (Bukaveckas et al. 2011) with a resultant increase in phytoplankton abundance and biomass (Kiss et al. 1994). This condition can support zooplankton proliferation in the dry season although the species may be those that thrive in a nutrient-rich ecosystem, such as the *Brachionus* species. Hence, the study revealed that water temperature, conductivity, TDS, and phosphate influenced the total zooplankton abundance, diversity and biomass of the rivers during the study.

CONCLUSION

Some of the zooplankton taxa (Cladocera and Copepoda) recorded at the rivers during the study showed a significant variation ($p < 0.05$) in abundance and biomass. The three taxa were higher in abundance in the dry season, except Rotifera that was more abundant at the Idumayo River in the rainy season. Cladocera was more diverse in the rainy season, Rotifera in the dry season, except at the Mile 4 River, and Copepoda in the rainy season, except at the Ebyia River. Cladocera and Copepoda had a higher biomass in the dry season. The major factors that influenced zooplankton abundance, diversity, species richness and biomass of the rivers were temperature, water flow and nutrient (phosphate) level of the rivers. *Brachionus* species, *Filinia longiseta,* Copepoda and nauplii recorded indicated organic pollution in the rivers during the study. So, frequent monitoring will be necessary to regulate nutrient input through anthropogenic sources.

Conflict of Interest: The authors have no conflict of interest to declare.

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