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Elliot Haruna Alhassan[a], Patrick Kwabena Ofori-Danson[b] & James Samman[c]

[a] Department of Fisheries & Aquatic Resources Management, University for Development Studies, P.O. Box TL 1882, Tamale, Ghana

[b] Department of Marine & Fisheries Sciences, University of Ghana, Legon, Ghana

[c] School of Applied Sciences, Central University College, Accra, Ghana

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[a]*Department of Fisheries & Aquatic Resources Management, University for Development Studies, P.O. Box TL 1882, Tamale, Ghana;* [b]*Department of Marine & Fisheries Sciences, University of Ghana, Legon, Ghana;* [c]*School of Applied Sciences, Central University College, Accra, Ghana*

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The current study was carried out to assess the ecological impact of impoundment using zooplankton as indicators. Sampling was conducted at two stations Bui and Bamboi that are located upstream and downstream of the dam, respectively. Sixteen species of zooplankton belonging to the order Cladocera (suborder Copepoda) were identified. Cladocerans were dominated by *Leptodora* sp. while copepods by *Cyclops* sp. Cladoceran densities increased from 29.67 ind./m^3 in the pre-impoundment period to 1179.4 ind./m^3 in the immediate post-impoundment period with a significant difference ($p < 0.05$) between these periods recorded. Hence, the abundance of Cladocerans varied following the Bui dam impoundment on the Black Volta River. The study into seasonal zooplankton distribution showed that zooplankton abundance reached the highest values during the wet season. Abundance of zooplankton groups at the upstream station was significantly higher ($p < 0.05$) than that at the downstream station, indicating the impact of impoundment on zooplankton ecology downstream. Since zooplankton was more abundant during the wet season, factors such as climatic changes and/or dam construction that modify the flooding pattern of the river will also alter zooplankton community structure in the newly created Bui reservoir and may have serious implications for fish production in the entire Black Volta ecosystem.

Šio tyrimo tikslas – įvertinti ekologinį užtvenkimo poveikį naudojant zooplanktoną kaip indikatorių. Mėginiai buvo imami aukščiau užtvankos (Bui) ir žemiau užtvankos (Bamboi) esančiose tyrimo vietose. Identifikuota 16 zooplanktono rūšių, priklausančių Cladocera būriui, Copepoda pobūriui. Iš šakotaūsių vėžiagyvių dominavo *Leptodora* sp., irklakojų vėžiagyvių – *Cyclops* sp. Šakotaūsių vėžiagyvių tankumas prieš užtvanką (29,67 ind./ m^3) ir žemiau jos (1179,4 ind./m^3) patikimai skyrėsi ($p < 0{,}05$), t.y., pastačius Bui užtvanką ant Black Volta upės, tankumas ženkliai išaugo. Užtvankos poveikį rodo ženkliai didesnis zooplanktono grupių gausumas aukščiau užtvankos esančioje stotyje. Nustatyta, kad zooplanktonas buvo gausiausias drėgnuoju sezonu. Tai reiškia, kad upės vandeningumą keičiantys veiksniai (klimato pokyčiai, užtvankos pastatymas) keičia ir zooplanktono bendrijos struktūrą naujajame Bui rezervuare. Tokie pokyčiai gali paveikti žuvų produkciją visoje Black Volta upės ekosistemoje.

Keywords: Black Volta; Bui dam; river impoundment; zooplankton and macroinvertebrates

Introduction

Dams are an inextricable element of our society and are built for many reasons such as irrigation, power generation, drinking water supply and flood control at an increasing cost (Collier, Webb, and Schmidt 1996). However, dams block or delay upstream fish migration, thus contributing to the decline and even extinction of species that depend on longitudinal movements along the stream continuum during certain phases of their life cycle. Mortality resulting from downstream passage through hydraulic turbines or over spillways can be significant. Although there are several reports on beneficial effects of river impoundment and great economic benefits of having hydropower schemes compared with cutting and selling of timber from catchments (Pandit 2000), it is equally well known that this leads to physicochemical and hydrobiological changes in the aquatic ecosystem.

The need for comprehensive pre- and post-impoundment studies of African man-made lakes has been clearly recognised (Adeniji 1981). Despite these studies, relatively few have been carried out and those that have been carried out tend to be descriptive accounts of the river system without making predictions about future conditions in the lake (Balon 1978; Bond et al. 1978; Egborge 1979). Therefore, one-size-fits-all prescriptions cannot substitute for local knowledge in developing prescriptions for dam structure and operation to protect local biodiversity (Power, Dietriich, and Finlay 1996).

Zooplankton abundance in rivers has been attributed to differences in flow, turbidity, dissolved oxygen concentration, conductivity, density of vegetation cover and seasons (Welcomme 1985). Under normal flow regimes, only low densities of zooplankton are present in the main channel of rivers. Distribution of zooplankton varies from place-to-place and year-to-year due to the dynamic nature of aquatic systems (FAO 2006). Zooplankton species succession and spatial distribution result from differences in ecological tolerance to abiotic

*Corresponding author. Email: aelliot@uds.edu.gh

and biotic factors (Marneffe, Comblin, and Thomé 1998); yet, bioindicator approaches, using responses of organisms to evaluate the trophic state, have often been neglected in favour of chemical and physical techniques. Despite, the considerable potential of zooplankton as effective indicators of environmental change and their fundamental importance in the transfer of energy and nutrient cycling in aquatic ecosystems, zooplankton communities have not been widely used as ecosystem indicators (Stemberger and Lazorchak 1994).

The aim of this study is, firstly, to analyse variations in abundance and diversity of zooplankton during the pre- and post-impoundment of the Black Volta River, and secondly, to give a comparative account of the same ecological characteristics upstream and downstream of the dam, with a view to identifying significant changes attributable to the river impoundment. This will generate preliminary information on the faunal characteristics in both periods of river impoundment. The hypothesis is that zooplankton abundance and diversity in the Black Volta River will change the impoundment by the Bui dam.

Methodology

The study was conducted in the Bui dam section of the Black Volta River (Figure 1). The study area stretched from the Bui reservoir (upstream) to Bamboi (downstream) within latitudes 8° 09′–8° 16′ N and longitudes 2° 01′–2° 15′ W covering a distance of about 37.5 km. It formed part of the Black Volta basin primarily located in north-western Ghana approximately 150 km upstream of Lake Volta. The basin covers parts of the Upper, Northern and Brong Ahafo Regions of Ghana. The basin embraces the total catchment area of 142,056 km^2 including areas outside Ghana. The part of the Black Volta in Ghana is estimated to be 650 km in length with the catchment area of 35,105 km^2 (Vanden Bossche and Bernacsek 1990).

The mean annual flow of the Black Volta at Lawra (a village in Ghana) is about 103.8 m^3/s, the percentage inflow of the Black Volta from outside Ghana to the total flow of the river is 42.6%, while the percentage of wet season and dry season flows to the flow of the river rise is 41.5% and 49.7%, respectively. Therefore, flows of the Black Volta from outside Ghana are very significant throughout all the seasons.

The morphometric characteristics of the Bui reservoir are as follows: full supply level (FSL) 183.0 m; reservoir area at FSL 444 km^2; storage volume at FSL 12.57×10^9 m^3; minimum operating level 168.0 m; and active storage 7.72×10^9 m^3.

There is considerable variation in local relief of the Black Volta basin. The northern areas ranged from 300 to 600 m above sea level. The basin is gently undulating from north to south. The major part of the Black Volta River falls into the Savanna zone, which is undulating with gentle slopes that promote overland flow. The low relief is also a cause for the poor surface drainage with subsequent flooding, which is characteristic of desertification prone areas during the wet season (Agorsah 2004).

Two sampling stations were chosen: the upstream station at Bui (08° 16′ 829″ N and 02° 15′ 470″ W) and the downstream station at Bamboi (08° 09′ 249″ N and 02° 01′ 940″ W).

The biodiversity of the upstream station at Bui includes living aquatic resources such as fish (both shell fishes e.g. *Etheria* sp. and fin fishes e.g. *Alestes* sp. and *Labeo* sp.) and some isolated populations of primates such as black and white colobus monkeys (*Colobus guereza*) and other large mammals such as the hippopotamus (*Hippopotamus amphibius*) and flood-tolerant plants such as *Panicum parvifolium, Hyparrhenia cyanescens* and *Acacia* sp. The substratum is composed of sand and decaying organic matter. Fishing is the major human activity at this station.

The downstream station is located at Bamboi. A bridge was constructed over the river at this station for vehicle transport. Some fish species at this station include *Hydrocynus* sp., *Labeo* sp., *Chrysichthys* sp., *Bagrus* sp. and *Synodontis* sp. The substratum is sandy with organic matter and silt. The major human activities here are sand winning, fishing, water supply for domestic activities, bathing, laundering and illegal small-scale mining ("galamsey").

Sampling design

In order to provide an all-year picture of the hydrobiology of the study area, a three-level stratified random sampling approach was adopted. The first stratum, which was characterised by the four designated hydrological seasons in the study area, included dry season (January–March); pre-wet season (April–June); wet season (July–September); and post-wet season (October–December) (Abban, Kwarfo-Apegyah, and Amedome 2000). The second stratum, which was characterised by the three impoundment periods in the study area, included: pre-impoundment (March–May 2011); immediate post-impoundment (June–December 2011); and late post-impoundment (January–December 2012). The third stratum, on the other hand, which was formed to improve sampling for accuracy included upstream of the dam site or reservoir area with sampling station at Bui (old town currently submerged); and downstream of the dam site area with sampling station at Bamboi.

Collection and identification of zooplankton samples

Zooplankton samples were collected monthly using a 55 µm mesh size zooplankton net with the mouth surface area of 0.25 m^2. Sampling was conducted for 22 months (March 2011–December 2012) between 0600 and 0700 GMT from a non-motorised canoe within a distance of

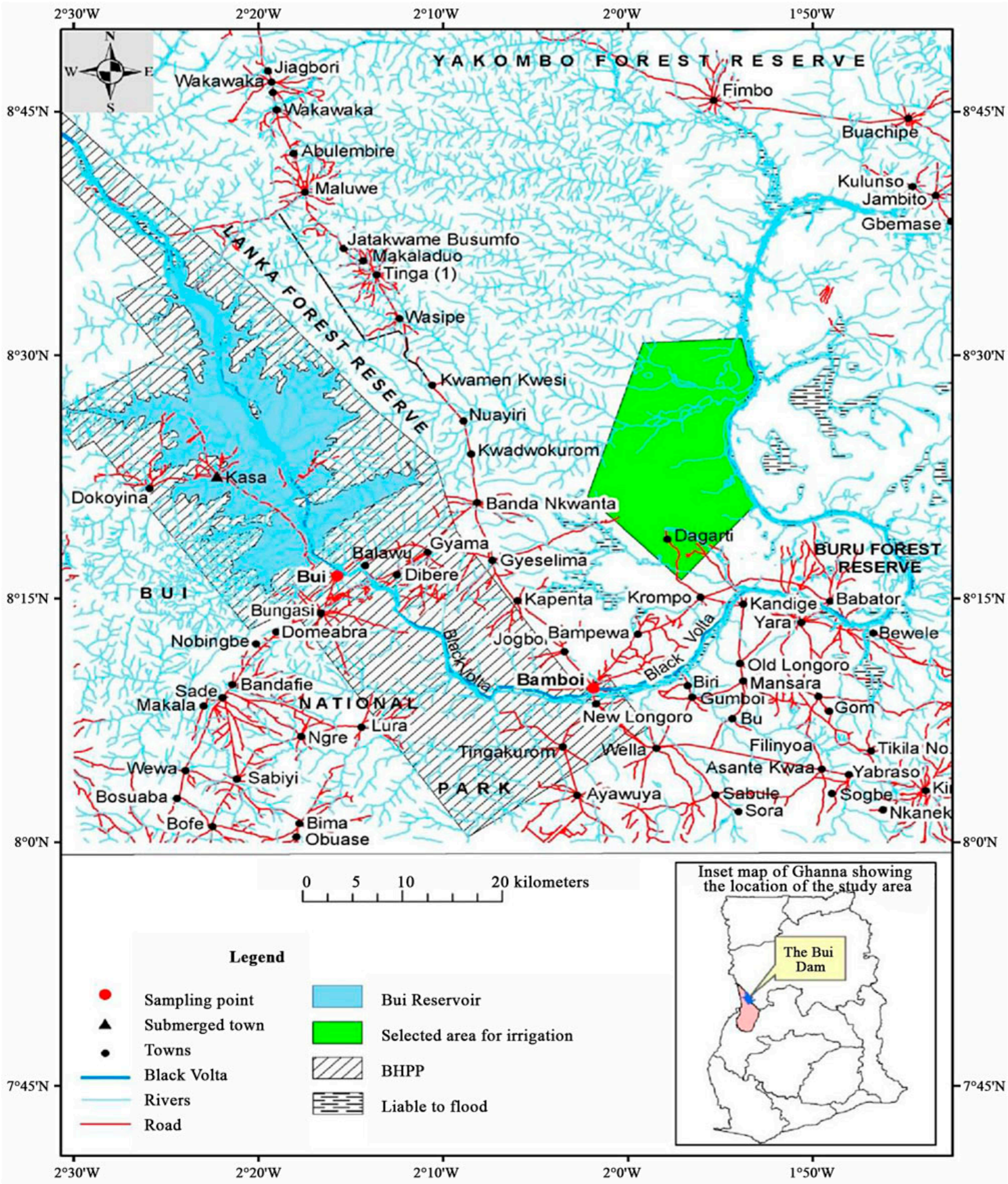

Figure 1. Map of the study area showing location of sampling stations (after Ofori-Danson et al. 2012).

100 m. Collected zooplankton samples were preserved in 4% formaldehyde solution in 50 ml sampling bottles.

For enumeration of zooplankton, a 5 ml subsample was taken from the water sample. Zooplankton counts were carried out in Sedgewick-Rafter counting chambers under an inverted microscope (Nikon Eclipse TE-200) as recommended by Downing and Rigler (1984). Zooplankton densities were expressed as ind./m^3 from the average count of three aliquots of 5 ml each. Zooplankton species identification was done to the genus level in accordance with descriptions from Edmondson (1969), Jeje and Fernando (1986) and Fernando (2002).

Data analysis

Zooplankton abundance during the three periods of impoundment was analysed using one way analysis of variance (ANOVA) of SPSS v. 16 on log $(x + 1)$ transformed data. Fixed effect ANOVAs were performed using dates as replicates. Zooplankton analysis at the two sampling stations, on the other hand, was done using the student *t*-test. Given significant differences ($p < 0.05$) among means, the Duncan's multiple range test was used to compare the treatment means.

The data on diversity of zooplankton species during each hydrological season were estimated using the PRIMER software version 6.1.6 (Clarke and Gorley 2006). Species diversity was estimated using the Shannon–Wiener index (H') (Shannon and Weaver 1963) from the density data (bits/ind.) and was expressed as:

$$H' = -\sum pi \log Pi,$$

where Pi is the proportion of individuals in the ith species (Dahlberg and Odum 1970).

Results

Zooplankton composition, density and diversity

Table 1 shows the checklist of zooplankton species identified during the pre- and post-impoundment periods. Figure 2 shows the species composition and abundance of zooplankton in 2011 and 2012, while Figure 3 shows seasonal variations in density and diversity of zooplankton in 2011 and 2012. In both 2011 and 2012 sampling years, 16 species of zooplankton belonging to two taxonomic groups – Subclass Copepoda and Order Cladocera – were recorded.

Table 1. Checklist of zooplankton species identified during pre- and post-impoundment periods.

Genus	PI	IPI	LPI
Cladocera			
Alonella sp.	−	+	+
Bosmina sp.	+	−	+
Ceriodaphnia sp.	+	+	+
Daphnia sp.	+	−	+
Diaphanosoma sp.	+	−	+
Leptodora sp.	+	+	+
Macrothrix sp.	+	−	+
Moina sp.	+	−	+
Polyphemus sp.	+	+	+
Sida sp.	−	+	+
Copepoda			
Canthocamptus sp.	+	−	+
Cyclops sp.	+	+	+
Cypridopsis sp.	+	+	+
Diaptomus sp.	+	+	+
Eubranchanpus sp.	+	−	+
Limnocalanus sp.	+	−	+

Note: +: present; −: absent. PI – pre-impoundment; IPI – immediate post-impoundment; LPI – late post-impoundment.

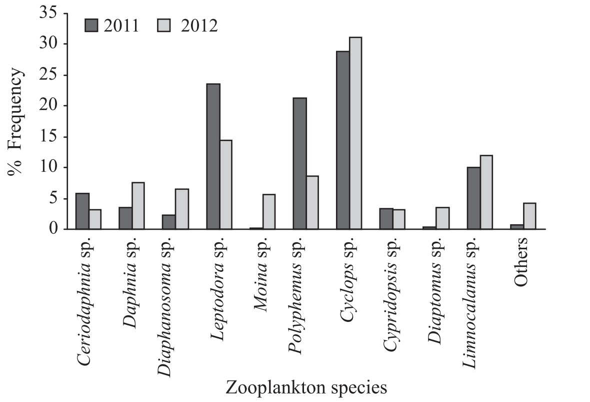

Figure 2. Percentage species composition and abundance of zooplankton in the Bui dam area of the Black Volta in 2011 and 2012.

Order Cladocera

Ten Cladoceran species were recorded in 2011 and 2012. They were dominated by *Leptodora* sp. The density of Cladocerans in 2011 decreased from 2085.3 ind./m^3 in the wet season to 0.0 ind./m^3 (absent) in the post-wet season. There were significant differences ($p < 0.05$) found between the wet and post-wet seasons. Cladoceran densities decreased from 145.3 ind./m^3 in the wet season to 11 ind./m^3 in the post-wet season with a significant difference ($p < 0.05$) between these seasons in 2012. Significant differences ($p < 0.05$) were found in cladoceran densities at the upstream and downstream stations in both 2011 and 2012. Cladoceran densities also increased from 29.67 ind./m^3 in the pre-impoundment period to 1179.4 ind./m^3 during the immediate post-impoundment period (Table 2). Significant differences ($p < 0.05$) were recorded between cladoceran densities during the pre- and immediate post-impoundment periods. Hence, the abundance of zooplankton species belonging to the Order Cladocera changed following the impoundment of the Black Volta River by the Bui dam.

Subclass Copepoda

Six species of the Subclass Copepoda were recorded. They were dominated by *Cyclops* sp. in 2011 and 2012.

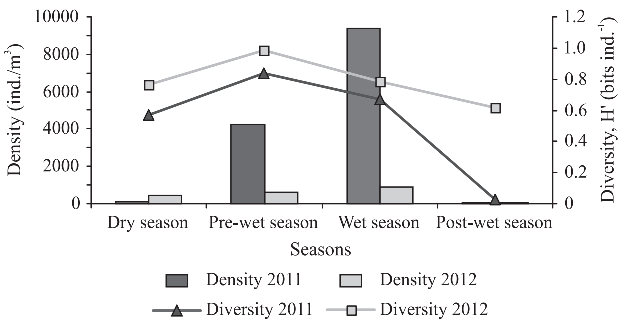

Figure 3. Zooplankton seasonal variations in density and diversity of zooplankton in the Bui dam area of the Black Volta in 2011 and 2012.

Table 2. Mean zooplankton abundance during pre- and post-impoundment periods (mean ± standard error).

Taxa (ind./m^3)	PI	IPI	LPI	*p* value
Cladocera	29.7^a ± 5.8	1179.4^b ± 86.9	423.9^a ± 28.6	0.20
Copepoda	130.3^a ± 26.2	731.4^a ± 47.9	86.4^a ± 12.8	0.18
Total zooplankton	160.0^a ± 2.8	1910.9^b ± 13.4	168.2^a ± 4.5	0.19

Notes: Figures on the same row with different superscript letters are significantly different ($p < 0.05$).
PI – pre-impoundment; IPI – immediate post-impoundment; LPI – late post-impoundment.

In 2011, copepod densities decreased from 1043.7 ind./m^3 in the wet season to 24.7 ind./m^3 during the post-wet season with a significant difference ($p < 0.05$) recorded between these seasons. Mean seasonal densities also declined from 157.3 ind./m^3 in the wet season to 16 ind./m^3 in the post-wet season in 2012. There was a significant difference ($p < 0.05$) recorded between the wet and post-wet seasons. A significant difference was also found in Copepoda densities at the upstream and downstream stations both in 2011 and 2012 (Table 3). Copepoda densities decreased from 731.43 ind./m^3 during the immediate post-impoundment period to 86.42 ind./m^3 during the late post-impoundment period. However, differences between densities in the above mentioned periods were not significant ($p > 0.05$). Hence, the abundance of zooplankton species belonging to the Subclass Copepoda did not change following the impoundment of the Black Volta River by the Bui dam.

Discussion

Zooplankton organisms are important components of the aquatic ecosystem and are considered to be indicators of water quality (Pinto-Coetuo et al. 2005) and fisheries health because they are a food source for organisms at higher trophic levels (Davies, Tawari, and Abowei 2009). The nature of species composition, diversity and seasonal abundance of zooplankton differ in water bodies (FAO 2006). A total of 16 species belonging to the Subclass Copepoda and Order Cladocera were recorded in the Bui dam area of the Black Volta River. The low zooplankton densities recorded in this study corroborate with the findings of Nilssen (1984), who reported that zooplankton communities are usually simplified, with low densities in tropical freshwaters. The dominance of Cladocera during the entire study period compares favourably with the findings of other researchers (Yakubu, Sikoki, and Horsfal 1998; Tackx et al. 2004). Most of the zooplankton encountered in the study area appeared to be normal inhabitants of natural lakes, rivers and artificial impoundments in the tropics and subtropics (Jeje and Fernando 1986; Aneni and Hassan 2003; Ayodele and Adeniyi 2005; Okogwu and Ugwumba 2006).

There were seasonal variations recorded in zooplankton groups during the two years of sampling. The mean values in the wet season were found to be high compared with those of post-wet and dry seasons. This was in contrast with the findings of Egborge (1994), Onyema (2007), Nkwoji, Onyema, and Igbo (2010), Okogwu (2010), who reported that the seasonal pattern of zooplankton densities in Nigerian freshwaters is characterised by a peak in the dry season. However, in agreement with findings of this investigation, Muylaert et al. (2003) and Arimoro and Oganah (2010) reported that zooplankton abundance usually reaches its peak during the wet season. This may be ascribed to rains bringing in allochthonous nutrients from the drainage basin that accelerate primary production resulting in higher zooplankton production and abundance (Evans, Townsend, and Crowl 1993; Okogwu and Ugwumba 2006). The high population density of zooplankton during the wet season in this study was also traced to high population of phytoplankton, which was abundant during the pre-wet season (Alhassan 2013). According to Rocha et al. (1999), an increase in phytoplankton abundance tends to be followed by an increase in zooplankton densities.

There was also relatively low zooplankton abundance observed during the post-wet and dry seasons of the study period and most especially during 2011. Low availability of food source could be responsible for the decline in zooplankton during post-wet and dry seasons (Achenbach and Lampert 1997). Oxygen at levels below 2.5 mg/l is known to exert a negative impact on zooplankton (Aka et al. 2000). In response to low oxygen concentration, most zooplankton including Cladocerans

Table 3. Mean zooplankton abundance in 2011 and 2012 at the two sampling stations (mean ± standard error).

	2011		2012	
Taxa (ind./m^3)	Bamboi	Bui	Bamboi	Bui
Cladocera	723.7^a ± 16.1	6569.0^b ± 49.3	81.7^a ± 9.0	3146.4^b ± 24.8
Copepoda	397.7^a ± 3.1	2345.4^b ± 18.5	86.1^a ± 12.8	1371.6^b ± 9.4
Total zooplankton	1121.4^a ± 19.2	7915.4^b ± 67.8	168.2^a ± 20.5	4518.4^b ± 34.2

Note: Figures on the same row with different superscript letters within the same year are significantly different ($p < 0.05$).

increase haemoglobin synthesis to enhance their oxygen extraction efficiency and survival rate (Hanazato and Dodson 1995). This probably explains the absence of cladoceran population during the post-wet season of the 2011 sampling year when the mean dissolved oxygen concentration was low (1.77 mg/l) (Alhassan 2013).

With the exception of the post-wet season, the biotic indices of Shannon–Wiener diversity (*H′*) were fairly distributed in the first three seasons of 2011. This was attributed to the fact that the post-wet season of 2011 lasted from three to six months after the impoundment of the Black Volta River and that the reservoir had not yet stabilised hydro-biologically. The higher variability in the biotic indices that was observed in the wet and post-wet seasons could also be a reflection of community instability in these seasons. This fact confirms changes in species composition, density and diversity caused by the river impoundment. There was, however, a fair distribution of these diversity indices during the 2012 sampling year indicating that 8–20 months after the impoundment, zooplankton community structure in the four hydrological seasons began to stabilise.

The study showed that the total abundance of zooplankton was significantly higher in the reservoir than at the downstream station indicating the impact of the impoundment on the downstream ecology. Ecological implications should always be considered when impounding a river for hydroelectric power generation. Since, the most abundant zooplankton species identified in the study area was *Cyclops* sp., a vector of Guinea worm, which can contribute to an outbreak of the Guinea worm disease among communities along the Black Volta basin, studies on the nematode (*Dracunculus medinensis*), which infests *Cyclops* sp., should be conducted by scientists from the School of Public Health and other Health Research Centers in the country in order to help prevent and eradicate this disease in the area. This is because the Guinea worm disease is mainly endemic in 13 countries (all in Sub-Saharan Africa), except for a few remote villages in the Rajasthan desert of India and in Yemen.

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