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Water quality and planktonic community of Owalla Reservoir, Osun State, Southwest Nigeria

Qualidade da água e comunidade planctônica do reservatório Owalla, Estado de Osun, sudoeste da Nigéria

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Abstract: Aim: Owalla Reservoir, one of the largest and oldest man-made lakes in Osun State supplies potable water to many towns in the state including the state capital, Osogbo. Active fishing activities also takes place in the lake. Inspite of the importance of the reservoir, information on the planktonic community and physico-chemical water quality are scarce. Therefore, this study investigated the water quality and plankton composition of Owalla Reservoir, Osun State, Nigeria, from October 2012 to November 2013 with a view to providing baseline information on limnology of the reservoir. **Methods:** Seven sampling stations (designated Stations 1-7) were established as representatives of the zones and regions of the reservoir and sampling was conducted quarterly. At Stations 1 and 3, only surface water samples were collected while water samples were collected from the surface, mid-depth and close to the bottom at other stations. Samples for total plankton and physico-chemical water quality were analyzed using standard methods. **Results:** The result of the study showed that mean dissolved oxygen ($P<0.001$), biochemical oxygen demand, conductivity, pH ($P<0.001$), and alkalinity were higher at the surface of the reservoir. As regards seasonal variation, alkalinity, biochemical oxygen demand had the higher mean values during the rainy season. Also, acidity, dissolved oxygen, and pH showed significantly ($P<0.001$) higher values during the rainy season. One hundred and thirty-seven (137) taxa of phytoplankton and 39 taxa of zooplankton were recorded from the reservoir. The horizontal pattern of variation showed an increase in the mean abundance of most of phytoplankton groups from inflow to the dam area while vertical variation showed a decrease in mean abundance from surface to the bottom of the reservoir. Most of the phytoplankton and zooplankton taxa were more abundant during the dry season than in the rainy season. **Conclusions:** The study concluded that all the monitored physico-chemical water quality parameters were within the guide level range as of the World Health Organisation (WHO) for drinking water, Owalla Reservoir is qualitatively rich in both phytoplankton and zooplankton and the reservoir can support a viable aquatic community and sustainable fishery production.

Keywords: physicochemical; phytoplankton; zooplankton; spatial; temporal.

Resumo: Objetivo: O reservatório Owalla, um dos maiores e mais antigos lagos artificiais do estado de Osun, fornece água potável para muitas cidades, incluindo a capital do Estado, Osogbo. Atividades de pesca também ocorrem no lago. Apesar da importância do reservatório, as informações sobre a comunidade planctônica e a qualidade físico-química da água são escassas. Portanto, este estudo investigou a qualidade da água e a composição do plâncton do Reservatório Owalla, Estado de Osun, Nigéria, de outubro de 2012 a novembro de 2013, com o objetivo de fornecer informações das características Limnológicas do reservatório. **Métodos:** Sete estações de amostragem (designadas Estações 1-7) foram estabelecidas como representantes das zonas e regiões do reservatório e a amostragem foi realizada trimestralmente. Nas Estações 1 e 3, foram coletadas apenas amostras de água superficial, enquanto para as demais estações, foram coletadas amostra de água na superfície, em meia profundidade e próximo ao fundo. Amostras de plâncton total e qualidade físico-química da água foram analisadas usando métodos padrões. **Resultados:** O resultado do estudo mostrou que as concentrações médias do oxigênio dissolvido ($P < 0{,}001$), a demanda bioquímica de oxigênio, a condutividade elétrica, o pH ($P < 0{,}001$) e a alcalinidade foram maiores na superfície do reservatório. Com relação à variação sazonal, a alcalinidade e a demanda bioquímica de oxigênio apresentaram os maiores valores médios durante o período chuvoso. Além disso, acidez, oxigênio dissolvido e pH apresentaram valores significativamente ($P < 0{,}001$) maiores durante a estação chuvosa. Cento e trinta e sete (137) taxa de fitoplâncton e 39 taxa de zooplâncton foram registradas no reservatório. O padrão horizontal de variação mostrou um aumento na abundância média da maioria dos grupos de fitoplâncton da entrada para a área da barragem, enquanto a variação vertical mostrou uma diminuição na abundância média da superfície para o fundo do reservatório. Os taxas de fitoplâncton e zooplâncton foram mais abundantes durante a estação seca do que na estação chuvosa. **Conclusões:** O estudo concluiu que todas as variáveis físico-químicas monitoradas de qualidade da água estavam dentro da faixa de nível de referência da Organização Mundial da Saúde (OMS) para água potável. O Reservatório Owalla é qualitativamente rico em fitoplâncton e zooplâncton e o reservatório pode suportar uma comunidade aquática viável e uma produção pesqueira sustentável.

Palavras-chave: físico-químico; fitoplâncton, zooplâncton; espacial; temporal.

1. Introduction

The plankton community of a natural waterbody typically comprises the phytoplankton flora and the zooplankton fauna. The phytoplankton, being primary producers, constitutes the basis of the food chain in natural aquatic ecosystems. The number and type of phytoplankton can be used to determine the quality of a waterbody (Bahura, 2001). On the other hand, zooplankton serves as link between the lower trophic level comprising of phytoplankton which are primary producers and the macroinvertebrates and fishes, which occupy a higher trophic level of the ecosystem (Akindele & Adeniyi, 2013).

The phytoplankton and zooplankton are good indicators for changes in nutrient pollution over time because they respond quickly to changes in nutrient input to the reservoir. The biological analysis of inland waters, especially the phytoplankton analysis will describe clearly about the pollutant materials impact on the aquatic life and a decrease in biological diversity. Furthermore, Biological analyses may identify possible changes in the quality of water, as well as the time patterns expressed in environmental variations and aquatic organism composition (Gökçe, 2016). Hydrological characteristics (e.g. depth, clarity and reservoir capacity) can drive their limnological patterns (e.g. electrical conductivity, pH and dissolved oxygen) and further affect other processes (e.g. precipitation, wind and land use), alter these communities and their landscape diversity (De Paggi & Paggi 2008).

Paucity of information on the plankton community especially their biodiversity, population dynamics and the primary productivity of Owalla Reservoir is a setback to a proper understanding of the life process of the limnology of this important reservoir, hence the need for this study. Therefore, the objectives of this study were to determine the taxonomic composition of the plankton biota (both phytoplankton and zooplankton) of Owalla Reservoir in Osun State, Nigeria, determine the spatial (horizontal and vertical) and seasonal variations in the composition, abundance and community structure of the plankton community of the reservoir as well as determining the influence of some selected physico-chemical water characteristics on the planktonic biota of the reservoir.

2. Materials and Methods

2.1. Area of study

Owalla Reservoir (Figure 1) is the largest reservoir in Osun State, Nigeria and indeed, one of the largest water bodies in South West Nigeria (Adediji & Ajibade, 2008). The reservoir is bordered by Odo-Otin, Ifelodun and Orolu Local Government Areas of Osun State at the northern, eastern western and southern parts respectively (Aduwo & Adeniyi, 2018) and lies roughly within Latitudes $07^{o}53^{1}$ N – $07^{o}60^{1}$ N and

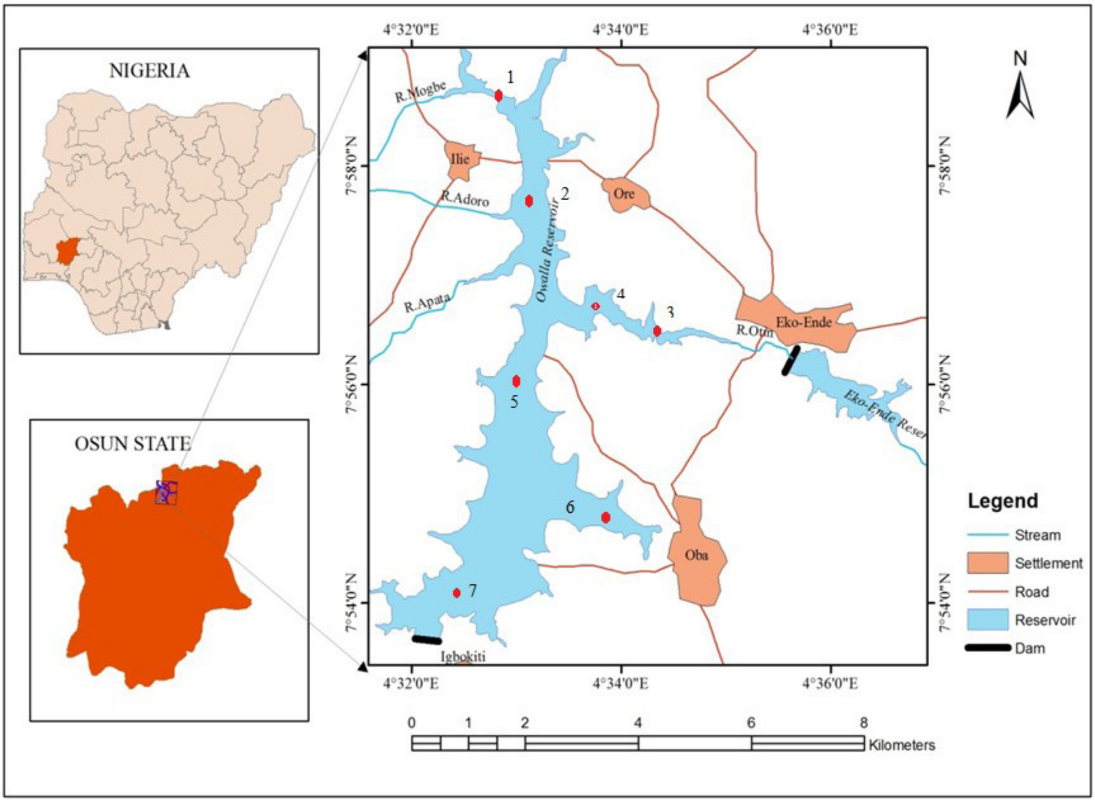


Figure 1. Map of Osun State showing Owalla Reservoir (Omoboye & Adeniyi, 2017) (Stations 2 and 5 were located at the middle basin, Stations 1, 3, 4 and 6 were sited at the inflow while Station 7 was located close to the dam)

Longitudes 004°30^1 E – 004° 35^{1}E with a surface area of 12 km^2 (1200 ha). It was impounded from Erinle River in 1989 with the major objective of providing potable water supply to a number of towns in the State (Osogbo, Ede, Ile-Ife, Gbongan, Erin-Osun, Ilobu and Ifon-Osun) while fisheries development of the reservoir is a major secondary benefit. The study area is characterized by two distinct climatic seasons namely: dry season from November to March and the rainy season from April to October. The study area constitutes a part of the Basement Complex of Southwestern Nigeria and it is characteristically underlain by hard crystalline igneous and metamorphic rocks. These rocks constitute the prominent outcrops and inselbergs that define topographic highlands (Cita.Del Consult, 1994). The area falls within the lowland tropical rain forest vegetation (Moshood & Shinichi, 2009), characterized by emergent trees with multiple canopies (Adediji & Ajibade, 2008). Also, widespread and persistent practice of rotational bush farming, coupled with the widespread cultivation of cash crops such as cocoa, kolanuts, plantain around Okinni, Ifon, Erin-Osun, Ilobu, Oba-Oke and Eko-Ende has led to the destruction of the original vegetation. It is generally used by the villagers for various domestic activities like washing and bathing. Also, cattle graze on vegetation around the reservoir.

2.2. Selection and description of sampling Stations

For this study, seven selected sampling stations (Stations 1, 2, 3, 4, 5, 6 and 7 were established along the main axis of the reservoir (Figure 1). Two stations (Stations 2 and 5) were located at the middle basin, Stations 1, 3, 4 and 6 were established at the river inflow portions of the reservoir while Station 7 was located towards the deepest portion of the reservoir close to the dam, mid-point from the shores. A permanent buoy was used to indicate the location of each of the seven sampling stations for easy of subsequent recognition. The grid co-ordinates of each station were measured and recorded using a Global Positioning System (GPS) handset.

2.3. Sampling program and field determinations

Water samples for water quality and plankton were collected at three-month intervals from October, 2012 to November, 2013 from each of the sampling stations. At stations 1 and 3, only surface water samples were collected while water samples collected from three levels through the water column (surface (A), mid-depth (B), and lose to the bottom (C) of the reservoir) at other stations (2A, 2B, 2C, 4A, 4B, 4C, 5C, 5B, 5C, 6A, 6B, 6C and 7A, 7B, 7C). The following physical parameters of the reservoir were determined on the field: depth, transparency (using a Secchi disc) and temperature (using mercury-in-glass bulb thermometer). Water samples for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) determinations were collected in 250 ml capacity glass reagent bottles, fixed on the field using Winkler's reagent and brought to the laboratory for titrimetric analysis (Golterman et al., 1978). Water samples were also analyzed for turbidity, alkalinity, acidity, electrical conductivity and pH using applicable standard methods (Golterman et al., 1978).

2.4. Plankton collection and identification

Water samples were collected from the water surface and through the water column (using water sampler). 500 ml of each sample was taking into measuring flask and preserved in 1% Lugor's solution. The water samples were later reduced to 30 ml and preserved in 5% formalin for qualitative examination and identification. Two milliliter of each preserved plankton concentrate was introduced twice into a Sedgwick-Rafter plankton counting chamber for examination at different magnification under an Olympus BH_2 microscope. The identification of the plankton was done to generic/specific level using various identification keys and guides provided by Prescott (1954), Botes (2003), Edmondson, (1959), Lind & Brook (1980), Fernando (2002) and Witty (2004). The different species of the phytoplankton and zooplankton observed in each plankton sample were enumerated for abundance expressed in number of organisms per meter cube of original water (Org/m^3).

2.5. Statistical analysis

Descriptive statistics were used to describe the community structure of plankton in Owalla Reservoir. The temporal and spatial variation in the planktonic groups were determined using analysis of variance (ANOVA) while relationship between the planktonic groups and between physico-chemical water quality parameters and planktonic groups were determined using cluster analysis and correlation (correlation index and the paired group method) using PAST (Paleontological Statistics) Statistical software.

3. Results

3.1. Physico-chemical water quality

The vertical variation in the mean values of water temperature, dissolved oxygen, conductivity, turbidity, acidity, alkalinity and pH were significantly different ($p < 0.05$) from the reservoir surface to the bottom (Table 1). Horizontally, water temperature showed significant decrease ($p < 0.05$) while the depth increased significantly ($p < 0.05$) from the upper basin to the lower basin. The highest mean alkalinity and BOD were recorded in the lower basin/dam site while dissolved oxygen (DO) had the highest mean value at the inflow section of the reservoir with no significant difference ($p > 0.05$) across the sampling points. Highest mean conductivity and pH values were recorded at the middle basin of the reservoir but with no significant difference ($p > 0.05$) across the horizontal basin. The mean values of turbidity, total acidity and dissolved oxygen (DO) were significantly higher ($p < 0.05$) in the rainy season than in the dry season while air temperature, water depth, total alkalinity and BOD were each slightly higher but not significant ($p > 0.05$) in the dry season than in the rainy season. Likewise, water temperature, Secchi disc transparency, depth of euphotic zone, conductivity and pH were each slightly higher although, not significant ($p > 0.05$) in the rainy season than in the dry season (Table 1).

3.2. Planktonic composition

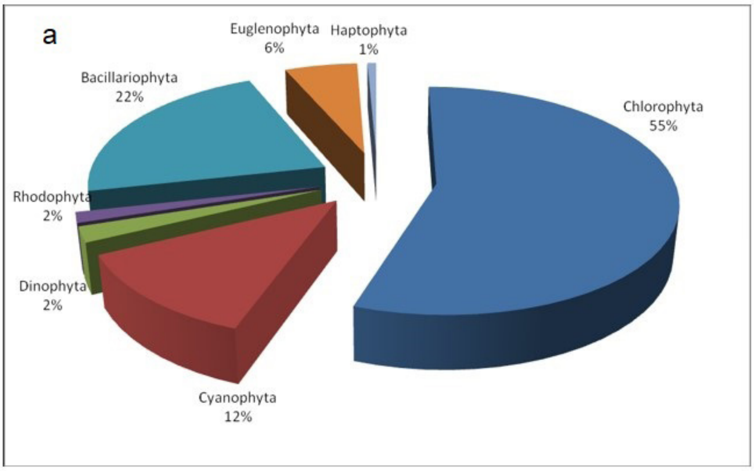
3.2.1. Phytoplankton composition and community structure

One hundred and thirty-seven (137) taxa of phytoplankton were recorded from the investigated sampling stations. The recorded taxa belong to 80 genera, 47 families 32 Orders, eight Classes and six Divisions of algae. Chlorophyta the most dominant Division accounted for 55% of total taxa composition and was closely followed by Bacillariophyta with 22% of the total composition. Cyanophyta accounts for 12%, Euglenophyta 6%, Rhodophyta and Dinophyhta had 2% each while Haptophyta was represented with 1% (Figure 2a). *Pediastrum* sp., *Pediastrum boryam*, *Anabaena* sp., *Arthrospira jenneri, Euastrum truncatum*, *Eudorina* sp., *Microcystis wesenbergii*, *M. flos-aquae, Staurastrum meyen, S. Chaetoceras* were the

Table 1. Spatial variations (vertical) in the physico-chemical water quality parameters.

S/N	Parameter	Horizontal variation					Vertical variarion					Seasonal variation			
		Upper basin/ Inflow	Middle basin	Lower basin/ Dam Site			Surface (A)	Mid-depth (B)	Bottom (C)			Rainy season	Dry season		
		(n=16)	(n=28)	(n=24)	ANOVA statistics		(n=28)	(n=20)	(n=20)	ANOVA statistics		(n=34)	(n=34)	ANOVA statistics	
		Mean±SE	Mean±SE	Mean±SE	F	p	Mean±SE	Mean±SE	Mean±SE	F	p	Mean±SE	Mean±SE	F	p
1	Air Temperature (°C)	30.8±0.8	30.80.5	29.4±0.5	1.72	0.200	30.4±0.35	NA	NA	-	-	29.5±0.36	31.2±0.39	0.699	0.415
2	Water Temperature (°C)	29.2±0.44	28.6±0.34	27.7±0.40	3.45	0.037*	30±0.3	27.9±0.37	26.9±0.29	30.86	2.91E-10*	28.5±0.36	28.2±0.47	0.524	0.472
3	Turbidity (NTU)	21.9±6.5	15.2±3.2	23.4±6.3	0.80	0.453	1.37±0.45	3.41±0.57	6.82±1.14	12.37	2.05E-05*	8.70±2.20	8.50±1.60	0.081	0.779
4	Depth (m)	5.3±0.84	6.6±0.51	13.5±1.99	13.34	0.0001*	1.38+0.07	NA	NA	-	-	1.32±0.12	1.48±0.03	2.426	0.131
5	Transparency (m)	1.3±0.17	1.3±0.09	1.6±0.11	1.70	0.2031	4.13+0.21	NA	NA	-	-	4.00±0.35	4.40±0.10	2.007	0.168
6	Euphotic Zone (Zeu)(m)	3.8±0.5	3.99±0.26	4.7±0.34	1.70	0.2031	6.3±1.67	15±3.1	42.8±7.0	21.32	7.58E-08*	28.50±6.60	12.2±2.9	6.814	0.01*
7	Alkalinity(mg $CaCO_3$ l^{-1})	41.0±0.67	39.5±1.22	45.1±1.57	5.20	0.008*	42.4±1.24	41.1±1.86	41.8±1.15	0.2268	0.7977	44.0±1.4	41.9±0.67	2.227	0.140
8	Acidity (mg $CaCO_3$ l^{-1})	19.0±1.37	18.5±0.75	20.8±1.52	1.06	0.352	18.2±0.91	17.6±0.79	23.1±1.61	6.72	0.002225*	20.7±1.0	15.3±1.1	11.78	0.001*
9	DO mg l^{-1}	6.3±0.54	6.2±0.40	6.2±0.38	0.01	0.991	7.3±0.39	6.0±0.36	4.9±0.35	10.52	0.00011*	7.70±0.40	5.0±0.3	23.23	8.81×10^{-6}*
10	BOD (mg l^{-1})	2.7±0.32	2.6±0.21	3.2±0.24	1.51	0.227	3.13±0.26	2.59±0.16	2.65±0.27	1.569	0.216	3.1±0.18	2.7±0.23	1.527	0.221
11	Conductivity (µS cm^{-1})	93.1±6.43	95.1±3.42	91.1±3.48	0.27	0.768	95.4±3.81	94.3±4.5	89.1±4.2	0.6389	0.5311	77.1±2.03	109.6±1.61	162.54	1.82×10^{-19}*
12	pH	7.20±0.07	7.20±0.08	7.10±0.07	2.35	0.103	7.39±0.04	7.1±0.06	6.90±0.06	23.87	1.69E-08*	7.02±0.07	7.30±0.05	18.62	5.47×10^{-5}*

*= Significant @ ($p \leq 0.05$); NA = Not Applicable; S/N = Serial Number; SE = Standard Error.



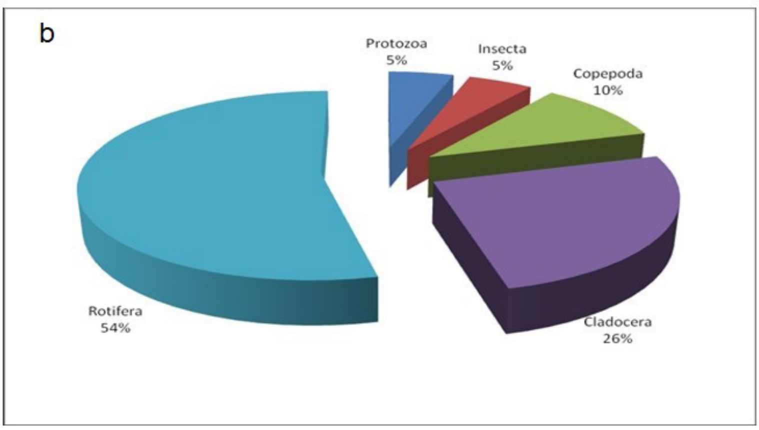


Figure 2. Taxonomic Composition of recorded phytoplankton (a) and zooplankton taxa (b) (based on recorded taxa)

dominant taxa in abundance while *Arthrospira jenneri* 47.1%, *Eudorina* sp. 35.3%, *Pediastrum boryanum* 35.3%. *Microcystis flos-aquae* 5.9%, *Microcystis wesenbergii* 5.9%, *Anabaena* sp. 23.5%. *Staurodesmus* sp. 35.3%, had the highest percentage occurrence over the study period.

3.1.2. Spatial and seasonal variation in phytoplankton abundance

Spatially, Station 1A, the inflow of the reservoir recorded the highest species number (68) followed by 4A (65), 2A (60) and 6A (54). The least species number was recorded in stations 6C and 7C with species number 24 and 27 respectively. In abundance, stations 2C, 7C, 4A, 1A and 6A recorded the highest abundance and contributed 43.4% to the total abundance (4330000 (Org/m^3) while stations 4B, 5B and 6B recorded the least abundance. In whole, the surface of the reservoir had the highest species abundance while horizontally, the dam site showed highest abundance of phytoplankton taxa (Figure 3a). Seasonally, dry season had the higher taxa number and abundance than rainy season (Figure 3b).

3.1.3. Zooplankton composition and community structure

Thirty-nine (39) taxa of zooplankton belonging to 5 groups namely: Rotifera, Cladocera, Copepoda, Protozoa and Insecta were identified from the investigated sampling stations. Rotifera were most represented group with 54% of the taxa and was closely followed by Cladocera with 26% of the total composition. Protozoa and Insecta had the least percentage representation (5%) each (Figure 2b). *Keratella cochlearis, Keratella tropica, Brachionus falcatus, Tricocerca similigrandis, Tricocerca ruttnei, Euclanis* sp. were the dominant species of Rotifera while the Cladocerans comprised mostly of *Bosmina meridionatis, Daphnia laevis, Daphnia longiremis, Bosminopsis deitersi* during the period of study. Protozoa and insect with the least percentage composition had *Amoeba radiata*, Oocyst and *Chironomus* larvae respectively as their most dominated taxa.

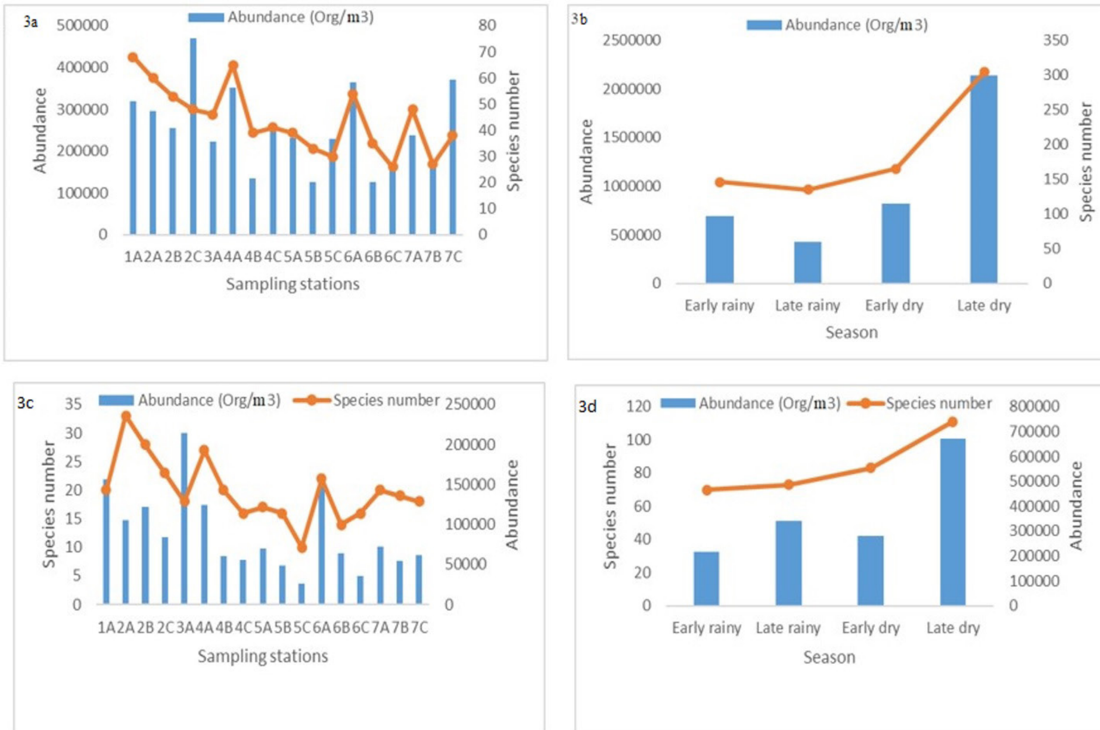


Figure 3. Spatial and seasonal pattern of phytoplankton (a & b) and zooplankton abundance (c & d) in Owalla Reservoir.

3.1.4. Spatial and seasonal variation in zooplankton abundance

The taxa number was highest in 2A, 4A, 6A, 7A and 2B while the lowest species number was recorded in 4C, 5B, 5C, 6B and 6C. Station 3A was the richest in term of abundance with 14.2% of the total abundance (1510000 Org/m^3) followed by 1A, 6A, 4A, 2B and 2A while the least abundance was recorded in 5B, 5C and 6C (Figure 3c). Seasonally, the pattern of species number tends to follow the abundance as late dry season had the highest species number and abundance while the late rainy recorded the least species number and abundance. Generally, the surface of the reservoir recorded the highest abundance and species number while dry season favors both species number and abundance (Figure 3d).

3.1.5. The relationship among sampling stations based on the phytoplankton and zooplankton species abundance (Org/m^3)

The result of the relationship among the sampling stations based on phytoplankton species abundance is illustrated by the cluster analysis diagram in Figure 4. Station 1A and 5C formed a cluster with 5A and the three stations also formed a cluster with stations 3A, 5B, 4C, 4B, 6B, and 6C. The three clusters formed another cluster with stations 4A, 6A, 7C, 7B and 2A. 2C and 2C formed cluster with all other stations except station 7A. All the stations formed one cluster with station 7A at $P<0.001$, $P<0.01$, $P<0.05$ (Figure 4a).

Stations 2B and 4B clustered with 5A and 6C. Stations 2B, 4B, 5A, 6C, 4A, 7B, 2C, 7C and 6B formed cluster with 3A, 4C, 6A, 1A, and 7A. The two clusters then formed cluster with stations 5B, 2A and 5C (Figure 4b).

3.1.6. Relationship between physico-chemical water quality and plankton group

The relationship of the planktonic groups with regards to the abundance of the species using Principal Component Analysis is presented in Figure 5. Seventeen principal components were extracted from the data set on the seventeen sampling stations. Ten principal components contributed 100% of the total variance (Table 2). The first two axes contributed 82.8% of the total variance. Axis 1 showed strong positive correlation ($R = 0.989$) with Bacillariophyta and moderate correlation ($R = 0.613$) with Copepoda. Axis 6 showed strong, positive and negative correlation ($R = 0.944$ and $R=0.876$) with haptophyte and rotifer. Axis 15 recorded strong, direct

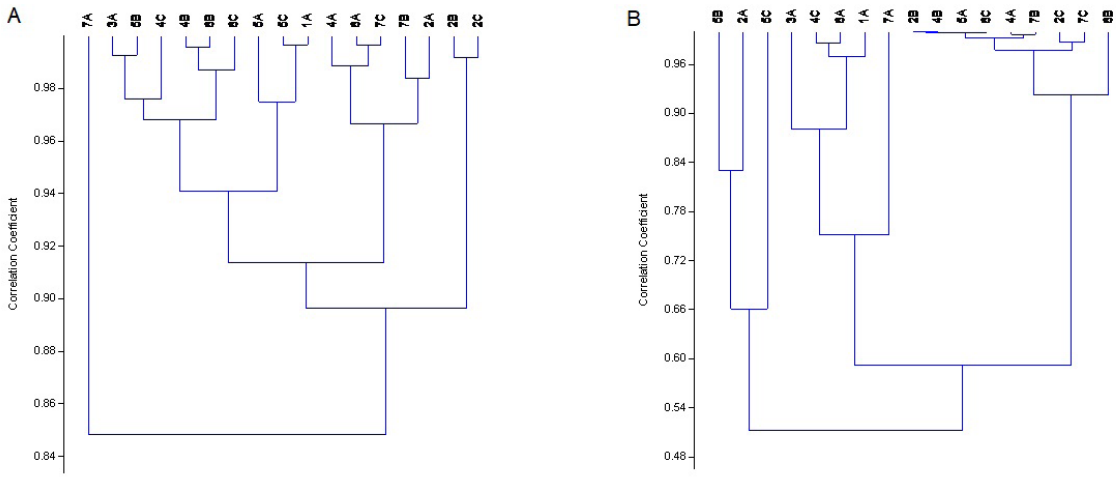


Figure 4. Cluster diagram showing the relationship among the sampling stations based on abundance of phytoplankton (a) and zooplankton (b) species.

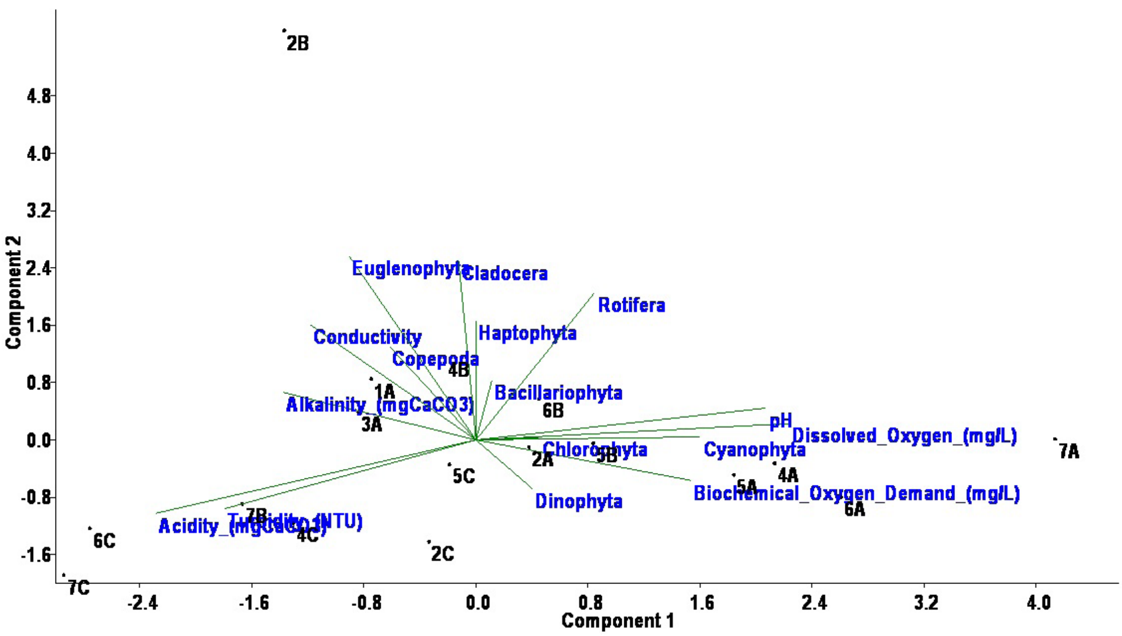


Figure 5. Principal component diagram showing relationship between plankton groups and physico-chemical parameters.

correlation with water temperature (R = 0.926), alkalinity (R = 0.846), DO (R = 0.701) and pH (R = 0.934) and negative correlation (R = 0.706) with conductivity. pH also had a strong negative and positive correlation with axis 15 (R = -0.934) and 17 (R = 0.907). Most groups clustered with one another except Bacillariophyta, Chlorophyta, Copepoda, Cyanophyta and Rotifera (Figure 5). Chlorophyta, Copepoda and Cladocera showed significant correlation r = 0.532, $p < 0.05$, and very significant correlation r = 0.634, $p < 0.01$, r = 0.576, $p < 0.01$ with water temperature. Also, Cyanophyta showed significant correlation, 0.533, 0.521, $p < 0.05$ with DO and Zeu. Also, Cyanophyta, Haptophyta and Rotifer showed a very significant and significant correlation with transparency r = 0.521, $p < 0.05$, r = 0.639, $p < 0.01$ and r = 0.473, $p < 0.05$. Copepoda and Cyanophyta showed a significant correlation r = 0.483 and r = 0.521, $p < 0.05$ with water conductivity while Cladocera showed a very highly significant correlation r = 0.698, $p < 0.001$ with BOD and significant correlation, r = 0.498 $p < 0.05$ with pH (Table 3).

Table 2. Extracted principal Components values of the abundance Planktonic groups and physico-chemical parameters.

0	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6	Axis 7	Axis 8	Axis 9	Axis 10	Axis 11	Axis 12	Axis 13	Axis 14	Axis 15	Axis 16	Axis 17
Eigenvalue	1.240	1.730	1.110	0.980	0.446	0.197	121	0.056	0.006	0.003	0.005	0.067	2.47^{-6}	1.25^{-7}	3.94^{-8}	1.07^{-8}	3.11^{-9}
% Variance	72.671	10.164	6.523	5.767	2.621	1.161	0.710	0.333	0.036	0.014	3.00^{-4}	3.92^{-5}	1.45^{-5}	7.34^{-7}	2.32^{-7}	6.32^{-8}	1.83^{-8}
% Cummulative	72.671	82.8355	89.358	95.125	97.746	98.907	99.617	99.950	99.986	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Chlorophyta	3.755	-0.441	-1.441	-	-1.826	0.375	-1.005	-0.397	-	-	-	-	-	-	-	-	-
Cyanophyta	1.072	2.355	3.059	2.173	-0.402	-	-	-	-	-	-	-	-	-	-	-	-
Rhodophyta	-0.501	-	-	-	-		-0.389	-	0.252	0.343	-	-	1.114	0.716	-1.909	0.172	0.370
Dinophyta	-0.311	-	-	-	0.663	-2.183	-0.433	-3.911	-0.314	-0.282	-	-	-	-	-	-	-
Bacillariophyta	0.989	-1.362	-1.165	2.741	2.452	-	1.658	0.728	-	-	-	-	-	-	-	-	-
Euglenophyta	-	-	-	-0.684	-2.077	-2.478	2.997	0.956	-0.444	-	-	-	-	-	-	-	-
Haptophyta	-0.392	0.381	-	-	-	0.944	-	-	-4.413	-0.419	-	-	-	-	-	-	-
Rotifera	1.297	-1.726	2.342	-2.337	1.880	-0.876	-0.518	0.884	-0.288	-	-	-	-	-	-	-	-
Crustacea	-	-0.591	1.054	-0.752	-0.302	3.006	2.473	-1.856	0.561	-	-	-	-	-	-	-	-
Copepoda	0.613	3.270	-1.493	-1.782	1.913	-	0.686	-	0.623	-	-	-	-	-	-	-	-
Protista	-0.479	-	-	-	-	-	-0.398	0.539	0.726	-4.432	0.315	-	-	-	-	-	-
Air Temp.	-0.498	-	-	-	-	-	-0.379	-	0.273	0.280	-1.037	-1.711	-2.398	0.289	-0.321	1.087	-1.151
Water Temp.	-0.499	-	-	-	-	-	-0.380	-	0.271	0.286	-1.024	-1.633	-2.068	-0.501	0.926	-0.610	1.653
Depth	-0.500	-	-	-	-	-	-0.387	-	0.259	0.333	-0.661	-0.361	0.362	-	0.339	-	-1.564
Transparency	-0.501	-	-	-	-	-	-0.388	-	0.254	0.340	-0.573	-	0.928	0.588	-1.656	-	0.469
Turbidity	-0.497	-	-	-	-	-	-0.404	-	0.287	0.495	-0.261	3.774	-2.050	-1.023	-0.627	-0.451	-
Alkalinity	-0.490	-	-	-	-	-	-0.397	-	0.272	0.466	1.193	-	0.892	-2.496	0.846	3.256	0.251
Acidity	-0.496	-	-	-	-	-	-0.401	-	0.260	0.432	0.292	1.112	-	3.320	2.521	1.095	-
DO	-0.500	-	-	-	-	-	-0.389	-	0.249	0.349	-0.426	-	1.087	-0.737	0.701	-1.435	-3.277
BOD	-0.500	-	-	-	-	-	-0.390	-	0.250	0.350	-0.448	-	1.251	-1.239	1.973	-2.136	1.746
Conductivity	-0.473	-	-	-	-	-	-0.402	-	0.295	0.663	4.035	-0.820	-0.799	0.416	-0.706	-1.291	-
pH	-0.499	-	-	-	-	-	-0.390	-	0.256	0.361	-0.265	-	1.007	0.379	-0.934	0.316	0.907
Zeu	-0.500	-	-	-	-	-	-0.387	-	0.256	0.334	-0.633	-0.266	0.557	0.334	-1.149	-	0.665

Table 3. Correlation table of the relationship between physico-chemical water quality parameters and zooplankton groups.

PC < 0.25 omitted0	Water-Temp	Transparency	Turbidity	Alkalinity	Acidity	DO	BOD	Cond.	pH	Zeu
Transp.	0.117									
Turbidity	-0.520	0.046	0							
Alkalinity	0.096	0.032	-0.119	0						
Acidity	-0.636	-0.061	0.331	-0.204	0					
DO	-0.127	-0.062	0.014	0.430	-0.107	0				
BOD	0.275	-0.185	-0.344	-0.016	-0.227	0.578	0			
Conductiv	0.562	-0.226	-0.398	-0.311	-0.475	0.164	0.685			
pH	0.755	0.300	-0.389	0.122	-0.669	0.130	0.251	0.401		
Zeu_(M)	0.117	1	0.046	0.032	-0.061	-0.062	-0.185	-0.226	0.300	
Chlorophyta	0.532*	0.236	-0.349	0.070	-0.278	-0.448	-0.051	0.128	0.137	0.236
Cyanophyta	0.436	0.521*	-0.237	-0.063	-0.318	-0.533*	-0.184	-0.034	0.378	0.521*
Pyrophyta	0.353	-0.206	-0.276	-0.175	-0.214	0.116	0.278	0.474	0.260	-0.206
Rhodophyta	0.069	-0.062	0.224	-0.004	-0.012	0.215	-0.030	-0.051	0.194	-0.062
Bacillariophyta	0.303	-0.289	-0.292	0.330	-0.189	0.204	0.420	0.379	-0.151	-0.289
Euglenophyta	0.146	0.053	0.064	0.290	-0.243	0.037	-0.260	-0.166	0.368	0.053
Haptophyta	-0.026	0.639**	0.262	-0.190	0.021	-0.267	-0.269	-0.027	0.001	0.639***
Rotifera	0.358	0.473*	-0.292	-0.009	-0.271	-0.254	-0.005	0.051	0.442	0.473*
Cladocera	0.576**	-0.027	-0.519	0.227	-0.293	0.408	0.698***	0.5211*	0.4996*	-0.027
Copepoda	0.634**	0.015	-0.321	0.322	-0.427	-0.442	-0.155	0.124	0.482*	0.015
Protista	0.208	0.022	-0.046	0.094	-0.277	0.223	-0.035	-0.008	0.331	0.022

*= significant; ** = highly significant; *** = very highly significant.

4. Discussion

4.1. Physico-chemical properties

In Owalla Reservoir, hydrogen ion concentration (pH) was near neutral (mean±SE pH= 7.2±0.04) for most of the period of the study, suggesting that it was midway in the pH range of most inland waterbodies (pH 6.5 to 8.5), as reported by Robertson-Bryan, Inc. (2004). Thus, the pH values obtained in this study were within the suitable pH range for fish culture (6.7 and 9.5) (Bhatnagar & Devi, 2013) and the acceptable levels for drinking water (6.5–9.5) (WHO, 2003). The pH range reported in this study also compares well with the values recorded by other workers in Nigeria such as Idowu & Ugwumba (2005), Ayoade et al. (2006) and Adams (2014) that recorded pH range of 6.9 to 9.6, 6.2 to 8.5 and 6.9 to 8.2 respectively. The conductivity values of the reservoir (ranged of 58.2 to 126.1 µS cm^{-1} with the mean value 93.2 µS cm^{-1}) also compare well with the values reported by Ikenweiwe & Otubusin (2005) with a range and mean conductivity of 64.5 to 100.1 µS cm^{-1} and 82.5±0.6 µS cm^{-1} respectively. These values are low compared to that of Akin-Oriola (2003) on Awoba reservoir (mean 239.65±74.31 µS cm^{-1}) which was regarded as being intermediate. The values of conductivity and pH decreased vertically from surface to bottom of Owalla Reservoir exhibiting the usual stratification pattern of tropical lakes as temperature also followed the same vertical pattern. Torgersen & Branco (2008) reported that the decomposition of organic matter and respiration by bacteria in the benthic zone typically decreases pH by producing CO_2 .

The alkalinity of a reservoir is a reflection of its carbonate and bicarbonate profile (Wetzel, 2001). With regards to the pH range of the reservoir, it is obvious that its total alkalinity was due mainly to bicarbonate ions. The range of the total alkalinity obtained in the present study (24 to 62 mg $CaCO_3$ l^{-1}) compare favorably with the range given by Gupta & Gupta, (2006) that waters having hardness values of 15 mg l^{-1} or above are satisfactory for the growth of fish while values less than 5 mg CaCO3 l^{-1} equivalent cause slow growth, distress and eventual death of fish. Likewise, Alkalinities at or above 20 mg $CaCO_3$ l^{-1} trap free CO_2 and increase the concentrations available for photosynthesis because phytoplankton use mainly free CO_2 in photosynthesis indicating a well buffered waterbody. Therefore, the alkalinity range recorded during the study period can adequately support phytoplankton productivity (pond fertility). Dissolved Oxygen (DO) enters the aquatic environment through the atmosphere and photosynthesis but lost through respiration and decomposition (Gupta & Gupta, 2006). The DO levels of Owalla Reservoir occurred over a wide range of 1.6 to 10.6 mg l^{-1} with a mean of 6.2±0.2 mg l^{-1} suggesting wide variability but overall, well oxygenated. The lower photosynthetic activity at the bottom of the reservoir but higher decomposition of organic matter there probably accounts for the decrease in DO and pH from surface to bottom of the reservoir.

Most pristine rivers will have BOD below 1 mg l^{-1}. Moderately polluted rivers may have a BOD value in the range of 2 to 8 mg l^{-1}. Rivers may be considered severely polluted when BOD values exceed 8 mg l^{-1} (Connor, 2016). Therefore, the mean BOD_5 value (2.8±0.1 mg l^{-1}) of the reservoir indicates that the water may be considered as fairly clean. Turbidity, alkalinity, acidity, dissolved oxygen, biochemical oxygen demand all showed higher mean values during rainy season than in the dry season. Rainfall and temperature patterns vary seasonally and control the water levels in the lakes and can influence water quality (Sahoo et al., 2016). That pH showed higher mean values during dry season than in the rainy season may be due to the fact that photosynthesis (which is higher in the dry season) uses up dissolved carbon dioxide, which acts like carbonic acid in water. CO_2 removal reduces the acidity of the water and so pH increases.

4.2. Phytoplankton community

Most of all the phytoplankton species recorded in this study seems to occur commonly in African freshwaters and have been documented to occur in a number of Nigerian freshwater ecosystems (Edward & Ugwumba, 2010; Offem et al., 2011). Members of the dominant families recorded in this study i.e Chlorophyceae are known to dominate the phytoplankton taxa composition of Nigerian freshwater ecosystems (Sorayya et al., 2011). The dominance of Chlorophyta agrees with the works of Akoma (2008) on Imo River estuary, Boonyapiwat et al. (2008) on the Bay of Bengal where desmids of the Chlorophyta were the most abundant group. The high diversity of desmids in Owalla Reservoir may be an indication that the water body is largely unpolluted as similarly reported by Ekhator (2010). The highest planktonic abundance which mostly occurred at the dam area might be due to reduced water current and higher transparency in that basin of the reservoir (Gosselain et al., 1994). Comparatively fewer organisms are adapted to high current hence, the lower mean abundance of phytoplankton at the upper basin which was characterized by a lotic regime. The fact that almost all the plankton groups had their highest mean abundance during dry season may be due to the fact that light intensity (major source of energy for photosynthesis), temperature and transparency were all higher at the season than in the rainy season (Offem et al., 2011). Okogwu & Ugwumba (2013) and Ewa et al. (2013) recorded high abundance in the dry season and also attributed it to increased temperature, solar radiation and water residence time at this period. These factors according to Soares et al. (2007) and Perbiche-Neves et al. (2011), support algae development in rivers. Similarly, the fact that most of the phytoplankton species showed a decrease from surface towards the bottom of the reservoir might be as a result of decrease in water temperature and light attenuation down the column of the reservoir. It is known that temperature indirectly affects the amount of dissolved oxygen available and the rate of photosynthesis and light being the major energy activating it. Also transparency and light intensity which are important in the phytoplankton production were highest at the water surface (Nwankwo & Akinsoji, 1989). Phytoplankton species were always found throughout the water column suggesting that there was proper mixing of the reservoir over the two seasons of the annual cycle.

The presence of some potentially toxic cyanobacteria, namely *Anabaena* spp., *Microcystis* spp., *Aphanizomenon-flosaquae*, and also, some dinoflagellates (*Peridinium* sp) and Euglenoids were also recorded in the phytoplankton population. Some human activities (like open space defecation, washing and bathing with detergents and soaps and grazing of cows within the reservoir water shed) were also noticed. These findings suggest the presence of a potential risk for public health, and indicate the need to implement mitigation measures (stopping activities like grazing of cattle, washing, bathing and defaecating around the reservoir) in the reservoirs.

4.3. Zooplankton community

The dominance of rotifers in the zooplankton fauna of freshwater has been documented by many workers in Nigeria and beyond as reported by Imoobe & Adeyinka (2009), Ayodele & Adeniyi (2006), Nogueira, (2001), Mozumder et al. (2014) and Sharma et al. (2013). The dominance of this group over the other zooplankton groups may be due to the fact that most of the species are warm water adapted, occurring mostly in tropical water bodies, with high temperature. Also, it may be attributed to their low environmental requirement hence their wide geographical distribution. The vertical variation in the mean abundance of zooplankton revealed that the highest mean abundance of zooplankton groups occurred at the surface except for the Rotifers which had their highest mean abundance at the bottom. This has been explained to be due to the fact that the surface provides adequate food sources (photosynthesis) to support the zooplankton community (Burger et al., 2002). Also the migration of rotifers to the bottom may be connected with the need to seek concealment (Waya, 2004; Ngupula, 2013), as invertebrate predators (e.g clams, krill, sponges, crayfishes) move upwards at this time of day (Dorak et al., 2013). Zooplankton groups had their highest mean abundance at the upper basin. This was probably due to the higher availability of detrital particles in the area as well as higher oxygen concentration, higher total suspended solids and lower water transparency which may enable them to avoid predators. This compares well with the work of Yusoff et al. (2002) on Kenyir Reservoir, Malaysia.

The seasonal distribution of zooplankton recorded from the reservoir showed that zooplanktons were most abundant during the dry season. This is in contrast to what was recorded by Yusoff et al. (2002) for Kenyir Reservoir, Malaysia where there was increase in zooplankton abundance during the rainy season. High abundance during the dry season followed increase in phytoplankton abundance at this period. In conclusion, Owalla Reservoir comprised highly diversified phytoplankton flora and zooplankton fauna with great potential to support rich aquatic community and fishery production. However, the lake should be subjected to regular proper monitoring because of the presence of some potentially toxic cyanobacteria identified among the phytoplankton flora as well as the likely effect of some human activities (like open space defecation, washing and bathing with detergents and soaps and grazing of cows around the water shed) observed during the study. Such activities may add nutrients to the water body leading to algal bloom which in turn will cause deterioration in water quality.

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