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Wankio Tabitha Meremo
Department of Aquatic and Fishery Sciences, Kisii University, Kisii, Kenya

Omondi Reuben
Department of Aquatic and Fishery Sciences, Kisii University, Kisii, Kenya

Yasindi Andrew Wamalwa
Department of Biological Sciences, Egerton University, Egerton, Njoro, Kenya

Daniel Mungai Ndegwa
National Aquaculture Development Centre, Kenya Fisheries Service, Sagana, Kirinyaga, Kenya

Corresponding Author:
Wankio Tabitha Meremo
Department of Aquatic and Fishery Sciences, Kisii University, Kisii, Kenya

Changes in water quality parameters and their effect on zooplankton distribution in a shallow bay of Lake Victoria, Kenya

Wankio Tabitha Meremo, Omondi Reuben, Yasindi Andrew Wamalwa and Daniel Mungai Ndegwa

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Abstract
Lake Victoria's shallow bays are increasingly becoming vulnerable to degradation whose effects are manifested ecologically. The influence of water quality parameters on zooplankton distribution in four stations at Kisumu Bay of Lake Victoria in Kenya was estimated. Selected physic-chemical parameters were measured *in-situ*, while water samples for Chlorophyll *a* determination were collected. Zooplankton was sampled using conical plankton net. The shoreline station 1 exhibited significantly higher mean zooplankton species diversity and abundance (H'=2.23; 12.65±25.21 ind. L^{-1} respectively) compared to the offshore stations. Copepoda were the most abundant zooplankton across all the sampling stations while Rotifera constituted the highest species diversity with 14 species followed by Cladocera with 7 species. There were significant relationships between zooplankton abundance and water quality parameters. This study indicated that the water quality conditions observed may have resulted in suppression of some zooplankton species and favored species-specific abundance at the same time.

Keywords: Kisumu bay, zooplankton distribution, water quality parameters

1. Introduction

Lake Victoria, with a surface area of 68 800 km², is located between 0˚20'N and 3˚0'S; 31˚39'E and 34˚53'E. It is shared by three countries, Tanzania, Uganda and Kenya. The lake is a source of livelihood to the thousands of people living within the catchment and the lake basin region. It serves as a source of food, energy, water for domestic, agricultural and industrial use, shelter and transport, recreational activities and a repository for human, agricultural and industrial wastes. It is also a biodiversity conservation center and a tourist site [1]. Lake Victoria bays are highly impacted by eutrophication [2]. Some of the Lake Victoria's shallow and sheltered bays are characterized by high human settlement. Both domestic and industrial wastes from these areas have contributed to the eutrophication of the lake [3]. Much of the untreated domestic and industrial wastes are also directly released to the littoral zones leading to high nutrient levels and thus increased phytoplankton production in the littoral zones as compared to pelagic waters. Eutrophication and pollution affect the communities of the lake thus modifying species composition of aquatic fauna, their distribution and abundance patterns. This may in turn affect the ecological functions of these communities [4].

Zooplankton occurrence, distribution and abundance are dependent on various factors including temperature, dissolved oxygen concentration and transparency. The zooplankton community of Lake Victoria is composed of mainly small bodied taxa mostly rotifers, a phenomenon which can be attributed to both predation and changes in prevailing water quality [5]. Their high species richness and abundance have been shown to occur in shallow waters of flood-plains [4]. Some zooplankton communities are very sensitive to environmental variations and therefore changes in their abundance, diversity, and composition can be used as indicators of environmental change or disturbance. Such zooplankton can be used as indicators of water quality [1, 6, 7]. Consequently, zooplankton responses to water quality variations are dependent on both ecosystems and species and vary within and between [8]. The variations of zooplankton distributions and abundance in large lakes may be affected by both biotic and abiotic factors including water depth, transparency, conductivity and contaminants including wastewater and nutrient loading from agricultural fields [2, 7, 9, 10]. Variations in distribution occur mostly in lakes that are shallow with constant mixing and uniform temperature [2]. The major zooplankton groups found in most tropical freshwater lakes include Rotifera and Crustacea. Different zooplankton species may be dominant in specific areas compared to others. For instance, cladocerans and rotifers prefer areas covered by macrophytes to open waters while copepods prefer open waters [10]. Changes in water quality impact differently on the various zooplankton communities. Tolerance to stress conditions such as eutrophication and pollution, vary from one community to another. Rotifers are the most common and diverse zooplankton community in Lake Victoria [11]. They occur abundantly in littoral zones to a depth of 20 m and are relatively rare in deep waters. On the other hand, copepods and cladocerans are more abundant and occur throughout the lake waters [12]. The ability of some zooplankton communities, such as rotifers, to tolerate diverse environmental conditions shows their potential use as biological indicators of the trophic state of freshwater ecosystems.

This study focused on the influences of water quality parameters on zooplankton distribution in four sampling stations in the shallow waters of Lake Victoria, all being located in Kisumu Bay of Lake Victoria Kenya.

2. Materials and Methods

2.1 Study area

The study was conducted at Kisumu Bay (Figure 1) which lies south of the equator between 0˚4'0''S-0˚ 6'30''S and 34˚ 43'30''E- 34˚ 45'0''E and at an altitude of 1,135 meters above sea level. The bay has a depth ranging between 2 m and 10 m. Found on the equator, the bay experiences equatorial climate with temperatures ranging between 20 ºC and 35 ºC. The rainfall ranges between 1000 mm and 1500 mm with two main rainy seasons, the long, heavy rains occurring between March and May and the short rains from October and December [13]. The dry season is between January and March. Kisumu Bay supports lives of thousands of people within the catchment area and serves as a major source of water supply for both domestic and industrial purposes. The bay also supports other activities such as fishing, ecotourism, academic and scientific research and cultural benefits to the surrounding population. The bay also serves as the terminal of the Kenya Ports Authority (KPA) that support transport of goods and cargo to Uganda and Tanzania by water.

The study was carried out between the months of May and October 2019 at Kisumu Bay in Lake Victoria. The study had four sampling stations chosen on a horizontal transect within the littoral zones. The first two stations were at the shoreline and the last two stations towards the offshore waters (Figure 1). The sampling stations were mapped by the Magellan Global Positioning System (GPS) 78 GARMIN and their depths recorded. All samples were taken in triplicates.

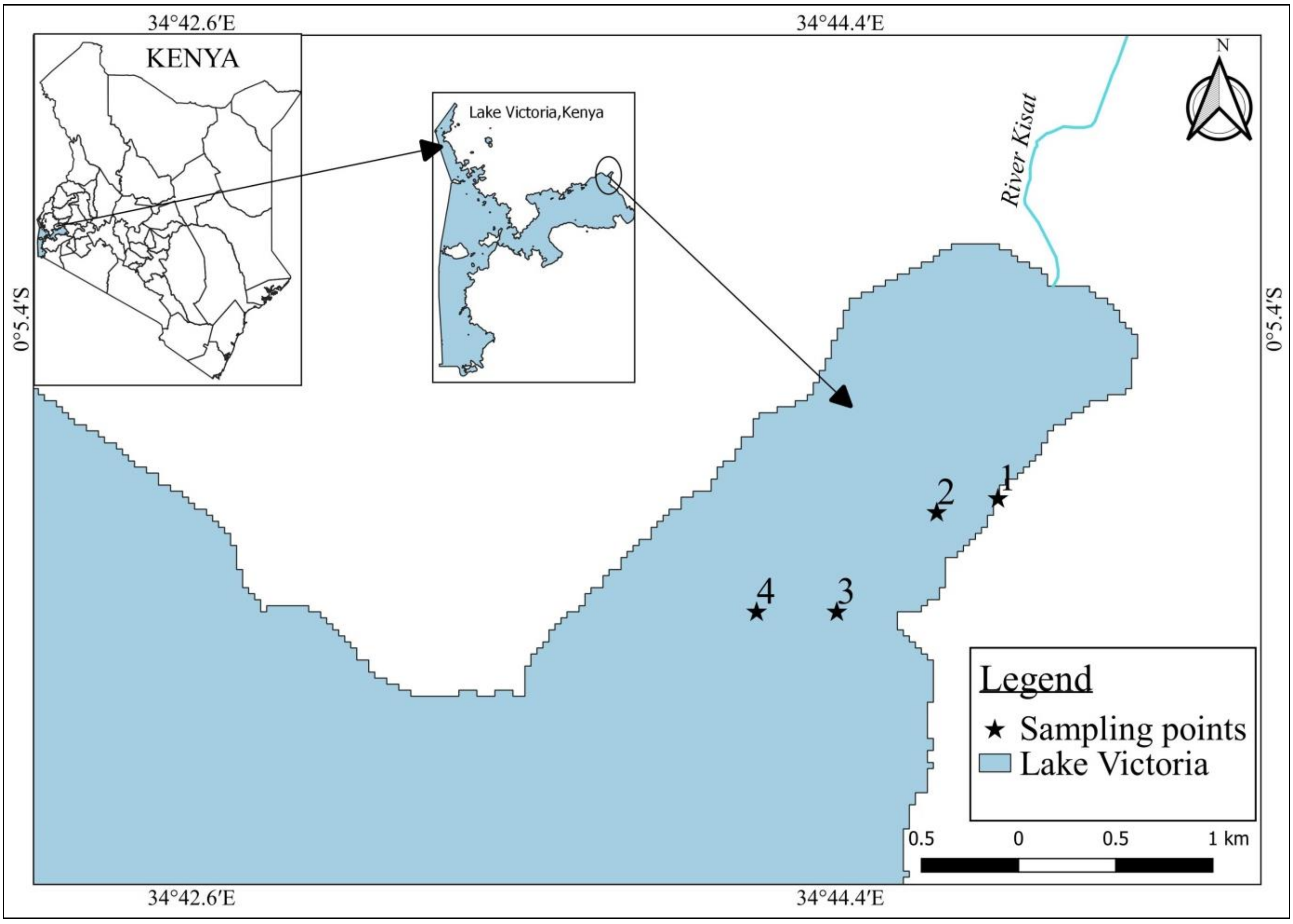

Fig 1: A map of Kisumu Bay showing sampling stations 1 to 4

2.2 Sampling procedures

Water quality parameters (dissolved oxygen concentration (mg L^{-1}), water temperature (˚C), electrical conductivity (µS cm^{-1}), TDS (mg L^{-1}), salinity (ppt) and pH) were measured *in situ* using a multi-parameter probe YSI model 15. The water depth was determined using a marked rope weighted at the end, Secchi depth was determined using a black and white Secchi disc (25 cm diameter) vertically lowered in the water column using a calibrated string. Water samples for Chlorophyll *a* analysis were collected just below the water surface in 500 ml sampling bottles from each sampling station and kept in a cool box for analysis in the laboratory. In the laboratory, collected water sample was filtered using Whatman GFC filter paper of 0.45 micrometers pore. Chlorophyll *a* was extracted from the filtrate using 95% ethanol refrigerated overnight and then measured spectrophotometrically.

Zooplankton was collected monthly at each station using conical plankton net (Nansen type; 60 µm mesh size and 30 cm mouth diameter). The net was lowered vertically through the water column close to the bottom and vertically hauled to the surface and the depth recorded from the marked rope. Each of the samples was then preserved in 5% formalin solution. In the laboratory, zooplankton samples was made to a known volume and thoroughly shaken for uniform distribution of the organisms. Subsamples of 1-4 ml (depending on observed concentration) were taken and placed in a 6 × 6 × 1 cm counting chamber and examined under a Leica dissection microscope at X40 magnification for counting and taxonomic identification. Zooplankton was identified to possible taxonomic levels using published keys [14, 15]. Adult copepods were identified as either calanoids or cyclopoids while their young were grouped into nauplii. Both Cladocera and Rotifera were identified up to species level. The mean densities of zooplankton were taken from the triplicate counts made, considering the sample volume (S), sub-sample volume (s) and the volume of water filtered along the water column [16] and the densities expressed as individuals per litre (ind. l^{-1}) of lake water.

The number of individuals per litre of lake water (D) was determined using the formula: D = N/V

Where

N = Number of organisms in the sample.

= (Number in sub-sample × Volume of sample (S))/sub-sample volume (s).

V = Volume of lake water filtered = $\pi r^2 d$.

Where

r = Radius of mouth of net (15cm).

d = Depth of haul.

Statistical analyses were done using MINITAB Release 19 for windows. One-way analysis of variance (ANOVA) and Tukey *post hoc* tests were used to compare variations in mean values and determine the significance differences. Pearson correlation coefficient was used to determine relationships between zooplankton abundance and water quality parameters. Species diversity was determined using Shannon-Weaver Diversity Index [17].

3. Results

3.1 Water quality parameters

The water temperature and dissolved oxygen concentration increased progressively from the shoreline stations towards the offshore stations (Table-1) (from station 1 (26.24±0.75 ˚C; 2.65±1.19 mg L^{-1}) to station 4 (26.60±0.67 ˚C; 4.35±1.16 mg L^{-1}) respectively). Markedly, water transparency (measured as Secchi depth), had a varying trend across the sampling stations whereby the shoreline stations 1 and 2 recorded the lowest (0.31±0.08 m) and highest (0.36±0.07 m) Secchi readings respectively. Electrical conductivity and total dissolved solids showed comparable trends across all the sampling stations with a slight decrease towards the offshore stations. Salinity remained stable and unchanged throughout the sampling stations while pH increased from the shoreline towards the offshore stations (Table 1). Relatively, Chlorophyll *a* concentration showed a decreasing trend from the shoreline stations towards the offshore stations. One way ANOVA applied on water quality parameters indicated no significant differences in the means across all the sampling stations ($F_{(3, 20)}$; $p>0.05$).

Table 1: Spatial water quality parameters (mean±SE) measured at Kisumu Bay

Parameter	Stations						
	1	2	3	4	Df	F	***P***
Temperature (°C)	26.24±0.75	26.49±0.83	26.5±0.74	26.60±0.67	3	0.29	0.83
Secchi depth (m)	0.31±0.08	0.36±0.07	0.34±0.10	0.33±0.13	3	0.24	0.871
DO (mg L^{-1})	2.65±1.19	3.54±1.33	4.26±1.21	4.35±1.16	3	2.51	0.088
Conductivity (µS cm^{-1})	176.3±25.7	175.2±25.2	170.9±22.2	172.9±21.8	3	0.06	0.979
Salinity (ppt)	0.08±0.01	0.08±0.01	0.08±0.01	0.08±0.01	3	0.13	0.94
TDS (mg L^{-1})	111.5±15.4	110.1±15.1	107.3±13.4	107.5±14.0	3	0.12	0.95
pH (range)	7.5±0.4	7.7±0.6	7.9±0.6	7.5±0.4	3	0.92	0.451
Chl *a* (mg L^{-1})	82.0±87.5	40.0±17.1	66.4±69.3	64.4±63.4	3	0.44	0.729

Temporally, the month of May 2019 recorded the highest values for temperature, conductivity, salinity and TDS (27.60±0.12 °C; 218.94±6.62 µS cm^{-1}; 0.096±0.005 ppt and135.71±4.29 mg L^{-1} respectively) while September 2019 had the lowest values for Secchi depth, conductivity, salinity and TDS (0.21±0.08 m; 155.05±1.66 µS cm^{-1}; 0.070±0.067 ppt and 96.46±0.82 mg L^{-1} respectively). May 2019 had lowest values recorded for dissolved oxygen concentration, pH and Chlorophyll *a* concentration (2.07±1.01 mg L^{-1}; 7.037±0.260 and 19.21±7.95 mg L^{-1} respectively) while September 2019 recorded the highest values for dissolved oxygen concentration and pH (5.12±0.61 mg L^{-1} and 8.330±0.141) respectively (Table 2). One way ANOVA applied on the selected water quality parameters indicated significant differences across the sampling months for temperature ($F_{(5, 18)}$ = 46.97, p = 0.000), Secchi depth ($F_{(5, 18)}$ = 13.22, p = 0.000), dissolved oxygen concentration ($F_{(5, 18)}$ = 6.86, p = 0.001), conductivity ($F_{(5, 18)}$ = 184.64, p = 0.000), TDS ($F_{(5, 18)}$ = 114.82, p = 0.000), salinity ($F_{(5, 18)}$ = 39.73, p = 0.000), and pH ($F_{(5, 18)}$ = 5.98, p = 0.002).

Table 2: Temporal water quality parameters (mean±SE) measured at Kisumu Bay

Parameter	Sampling Months						Df	F	*P*
	May	June	July	August	September	October			
Temperature (°C)	27.6±0.12	26.34±0.07	25.80±0.08	25.99±0.21	27.16±0.32	25.96±0.326	5	46.97	0
Secchi depth (m)	0.35±0.03	0.46±0.05	0.40±0.01	0.33±0.05	0.21±0.08	0.26±0.05	5	13.22	0
DO (mg L^{-1})	2.07±1.01	2.69±0.74	4.71±1.03	3.81±1.12	5.12±0.61	3.81±0.70	5	6.86	0.001
Conductivity (µS cm^{-1})	218.94±6.62	179.43±3.04	164.55±2.09	164.24±2.38	155.05±1.66	160.84±2.45	5	184.6	0
Salinity (ppt)	0.10±0.00	0.08±0.00	0.08±0.00	0.08±0.01	0.07±0.00	0.07±0.00	5	39.73	0
TDS (mg L^{-1})	135.71±4.29	113.78±1.86	105.417±1.434	104.69±1.78	96.46±0.82	98.48±3.95	5	114.8	0
pH (range)	7.04±0.26	7.47±0.39	7.78±0.51	7.53±0.44	8.33±0.14	7.89±0.29	5	5.98	0.002
Chl *a* (mg L^{-1})	19.21±7.95	24.62±7.50	105.1±98.7	131.9±74.6	45.21±6.22	53.12±8.43	5	3.19	0.031

3.2 Zooplankton composition, abundance and species diversity

The zooplankton community in Kisumu Bay of Lake Victoria was composed of three main groups; Copepoda, Cladocera and Rotifera. Copepoda was the most dominant across all sampling stations (Figure 2) while Rotifera was the most diverse among the zooplankton (Table 3). The shoreline station 1 had the highest zooplankton abundance (12.65±25.21 ind. L^{-1}) while offshore station 3 recorded lowest zooplankton abundances (8.60±22.93 ind. L^{-1}). Temporally, zooplankton abundance ranged between 9.41±22.11 ind. L^{-1} and 13.25±31.30 ind. L^{-1} in August and May 2019 respectively.

Spatially, shoreline stations 1 recorded the highest abundances for Cladocera and Rotifera (6.46±2.52 ind. L^{-1} and 5.66±2.69 ind. L^{-1} respectively) and station 2 (75.37±10.23 ind. L^{-1}) for Copepoda. Offshore station 3 recorded the least abundances for Copepoda (53.97±9.66 ind. L^{-1}), Cladocera (3.156±0.835 ind. L^{-1}) and Rotifera (1.597±0.250 ind. L^{-1}). ANOVA applied on zooplankton abundances showed significant differences among the sampling stations (Copepoda, Cladocera and Rotifera ($F_{(3, 20)}$ = 3.65, p = 0.030), ($F_{(3, 20)}$=5.89, p=0.005) and ($F_{(3, 20)}$ = 8.40, p = 0.001) respectively).

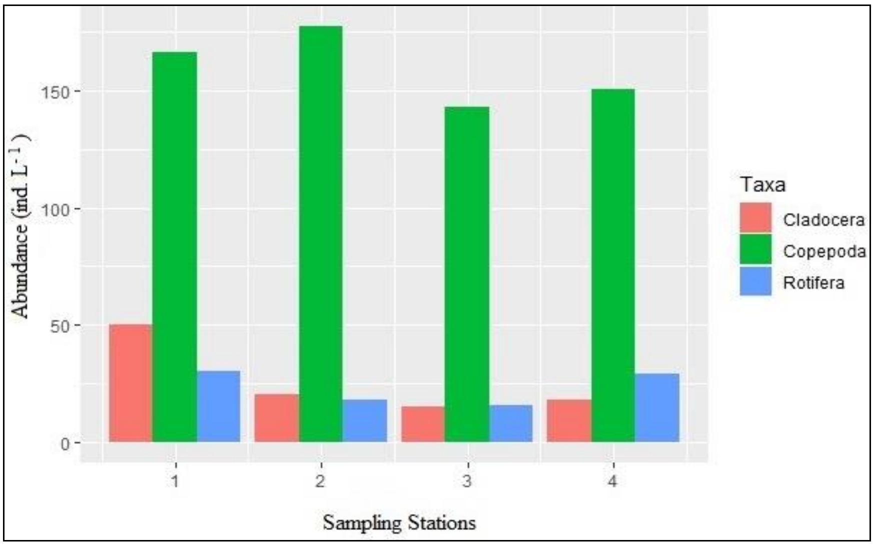

Fig 2: Spatial zooplankton abundance (mean±SE) at Kisumu Bay

Temporally, the month of May 2019 had the highest abundances for Copepoda and Rotifera (72.30±16.85 ind. L^{-1}; 5.00±3.81 ind. L^{-1} respectively) while August 2019 had the lowest abundances for both Copepoda and Rotifera (53.55±11.07 ind. L^{-1}; 1.834±0.778 ind. L^{-1} respectively). Cladocera abundance on the other had ranged between 2.945±0.541 ind. L^{-1} and 5.656±1.829 ind. L^{-1} in June and August 2019 respectively. ANOVA applied to zooplankton abundances showed no significant differences among sampling months ($F_{(3, 20)}$; p>0.05).

Table 3: Checklist of zooplankton taxa recorded in Kisumu Bay between May and October 2019

Copepoda	Rotifera
Cyclopoidae	Brachionidae
Calanoidae	*Brachionus angularis* Gosse, 1851
Cladocera	*B. calyciflorus* Pallas, 1776
Daphnidae	*B. falcatus* Zacharias, 1898
Daphnia barbata Weltner, 1898	*B. patulus* Muller, 1786
Daphnia lumhortzi	*Keratella tropica* Apstein, 1907
Ceriodaphnia cornuta Sars, 1885	Euchlanidae
Moinidae	*Euchlanis* sp.
Moina micrura Kurz, 1874	Lecanidae
Chydoridae	*Lecane* spp (2)
Chydorus sp	Filinidae

Sididae	*Filinia opoliensis* Zacharias, 1898
Diaphanosoma excisum Sars, 1885	Trichorcercidae
Bosminidae	*Trichorcerca* sp.
Bosmina longirostris	Synchaetidae
	Polyarthra sp.
	Hexarthridae
	Hexathra sp.
	Asplanchnidae
	Asplanchna sp.

Species diversity

A decreasing trend of the species diversity index (H') was observed from the shoreline station 1 (2.23) and station 2 (1.65) towards the offshore stations. Temporally, the zooplankton species diversity varied with time or months of the year. The highest diversity was recorded in May 2019 with an index value of 1.79 while the lowest was in July 2019 with index value of 1.64.

3.3 Relationship between physico-chemical parameters and zooplankton abundance

Pearson correlation coefficients showed that there were significant negative correlations between abundance of Copepoda with Chlorophyll *a* (r = -0.5). Rotifera was significantly and negatively correlated with depth (r = -0.7), dissolved oxygen (r = -0.51) but significantly positively correlated with TDS (r = 0.5), salinity (r = 0.5) and conductivity (r = 0.5). Cladocera was significantly and negatively correlated with depth (r = -0.73) (Table 4).

Table 4: Correlation matrix between physico-chemical parameters, Chlorophyll *a* and zooplankton abundance in Kisumu Bay between May and October 2019

	Secchi	Depth	Temp	DO	Cond	TDS	Salinity	pH	Chl-*a*
Copepoda	-0.08	-0.1	0.35	-0.16	0.3	0.27	0.26	-0.01	-0.5*
Cladocera	-0.45	-0.73*	-0.14	-0.25	-0.04	-0.05	-0.06	-0.08	0.16
Rotifera	-0.04	-0.7*	0.22	-0.51*	0.5*	0.5*	0.5*	-0.2	-0.07

*Significant at $p<0.05$.

4. Discussion

4.1 Water quality parameters

Within the tropics, amount of rainfall received remains to be a major factor influencing the changes in the characteristics of water bodies including Lake Victoria [7]. The minimal variations in the water quality parameters observed across the sampling stations in Kisumu Bay could be attributed to the shallow depth of the study area and the daily mixing of the lake water by wind action. Similarly, it is difficult to establish spatial heterogeneity in tropical lakes because of their small sizes and shallow depths [18]. Temporal variations in the water quality parameters could be attributed to changes in seasons, water depth, solar radiation, sampling time and the process of photosynthesis. Relatively high temperature is a characteristic of tropical lakes and shallow bays [7]. Resuspension of bottom sediments into the water column reduces water transparency [19]. The resuspension of sediments from the bottom into the water column is a common phenomenon of shallow water bodies [20]. Onset of rains is an indication of great changes in the physical and chemical properties of tropical lakes [21]. High level of TDS is associated with cultivated areas [22]. The pH level could be determined by the rates of photosynthesis and respiration in a water body [23]. High amount of Chlorophyll *a* concentration is an indication of high phytoplankton biomass [24].

4.2 Zooplankton

The zooplankton community at Kisumu Bay is a characteristic of typical freshwater species [25]. The species composition did not differ significantly from those observed by [12]. Copepods dominated the zooplankton community in abundance across all the sampling stations and throughout the period of the study. This observation agrees with previous studies where this group dominates the zooplankton community in tropical freshwater ecosystems [12]. The scarcity of bigger cladocerans could be explained by the predatory nature of zooplanktivorous fish with size selective feeding action [26]. Besides, increasing concentrations of suspended solids can block the filtering apparatus of bigger cladocerans and impede their ability to feed leading to their low abundances [2]. The high nutrient input into the lake may have resulted in eutrophication. Physico-chemical factors and eutrophication appear to influence the zooplankton community structure in Lake Victoria [26].

The relatively higher zooplankton abundance at the shoreline than offshore waters could be attributed to high phytoplankton biomass at the shoreline which forms primary food for zooplankton. These findings corroborate previous observations that zooplankton community tend to be more abundant in eutrophic waters [12]. The low zooplankton abundance in the offshore stations could have been attributed to low dissolved oxygen concentration in the water [4]. The generally low species diversity observed in this study has also been reported in other tropical freshwater lakes [7]. Most studies on ecology show that species diversity mostly varies with both ecosystem productivity and habitat heterogeneity [27]. Habitat connectivity may also influence species diversity through passive dispersal [28]. Temporal variations in zooplankton species diversity observed in Kisumu Bay could be attributed to the variations in the biotic and abiotic factors in the lake.

4.3 Relationship between water quality parameters and zooplankton abundance

Copepoda abundance was negatively correlated to Chlorophyll *a* concentration. The high amounts of Chlorophyll *a* concentrations observed was probably an indication of eutrophication in the bay which negatively impacts on the distribution of copepods [7]. This observation could be used to infer a possibility of an ecosystem imbalance where most of the zooplankton relied on other food sources including bacteria and microzooplankton rather than phytoplankton [6]. Cladocera abundance negatively correlated to water depth. Water depth increases with increase in precipitation. Increased water volume leads to dilution of suspended matter and organisms. Low or decreased water depth as a result sedimentation of organic materials, leads to increase in nutrients which in turn increase primary productivity [7]. Rotifers correlated negatively with water depth and DO and positively correlated with TDS, conductivity and salinity. High levels of TDS lead to increased water conductivity and salinity which in turn lower the amount of dissolved oxygen. Rotifers are known for their ability to tolerate high levels of TDS, conductivity and salinity with low dissolved oxygen as compared to other groups [29].

5. Conclusions
It may be concluded that zooplankton community structure observed at Kisumu Bay was largely as a result of both physico-chemical and biotic conditions. Differences in food availability and predation pressure probably also played a role in structuring the zooplankton communities. The low species diversity of zooplankton may suggest existence of stressful conditions in the bay which could be attributed to inflowing effluent from catchment and consequently leading to high nutrient loads in the lake. Nutrient rich conditions suppress zooplankton species diversity [9].

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