SPATIAL PATTERNS OF ZOOPLANKTON DISTRIBUTION AND ABUNDANCE IN RELATION TO PHYTOPLANKTON, FISH CATCH AND SOME WATER QUALITY PARAMETERS AT SHIRATI BAY, LAKE VICTORIA-TANZANIA

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ABSTRACT

Spatial patterns and abundance of zooplankton in aquatic habitats are important determinants for production of fish species, invertebrates and availability of phytoplankton. Weekly monitoring for zooplankton abundance was conducted in Shirati Bay, Lake Victoria, to explore their spatial patterns in relation to phytoplankton, fish catch and some water quality parameters. The vertical distribution of zooplankton was generally higher close to the bottom as compared to surface waters of the lake. Zooplankton vertical distribution positively correlated with water transparency ($r = 0.680$, $p = 0.011$). The horizontal abundance of zooplankton was not significantly different amongst the three stations ($p = 0.5143$). While Copepoda was the dominant group in terms of composition, Rotifera had the highest diversity indices of all the zooplankton groups obtained. The abundance of nauplius larvae was significantly higher than that of the copepodites ($p = 0.022$). Nile perch, Lates niloticus *dominated the total catches (47%) followed by Nile tilapia*, Oreochromis niloticus *(29%) and haplochromines (21%). The abundance of haplochromines and juvenile fishes correlated significantly with the abundance of zooplankton ($r = 0.856$, $p = 0.002$ and $r = 0.58$, $p = 0.038$, respectively). The current study revealed that zooplankton vertical distribution at Shirati Bay is mainly controlled by water transparency and predation by juvenile Nile perch, Nile tilapia and haplochromines.*

Key words: chlorophyll-*a*; calanoid; cyclopoid; nauplius larvae; juvenile fish

INTRODUCTION

Lake Victoria has received an exceptional consideration because of its changes in limnological conditions caused by nutrients inputs and regional climate change (Waya and Mwambungu 2004; Ojwang *et al.* 2014). The bays of the lake are highly impacted by eutrophication and pollution due to the chronic release of water containing higher levels of nutrients from urban/industrial effluents and agricultural activities conducted along the shoreline and in nearby catchments (Mwebaza-Ndawula 1994; Sitoki *et al.* 2010; Vincent *et al.* 2012; Ngupula 2013). Eutrophication and pollution are known to affect the structure of the lake communities by modifying its invertebrate species composition, distribution and abundance patterns which in turn affect their overall ecological functions (Mwebaza-Ndawula 1994; Ngupula *et al.* 2010).

Zooplankton are a major constituent of freshwater ecosystems, interceding the energy flow between phytoplankton communities and higher trophic levels, such as fish in pelagic habitats (Kelly *et al.* 2013). The distribution and abundance of zooplankton are heterogeneous (Castro *et al.* 2007; Mulimbwa *et al.* 2014). In most aquatic ecosystems, the spatial distribution and abundance of zooplankton are characterized by both vertical and horizontal patterns (Yurista and Kelly 2009). These patterns are important indicators of the ecological status of aquatic ecosystems and thus directly affecting human interests (Dietzel *et al.* 2013). Notably, spatial patterns and zooplankton abundance determine the production of fish species, invertebrates and availability of phytoplankton (Casper and Thorp 2007).

The zooplankton patterns and abundance in large lakes vary spatially (Lévesque *et al.* 2010). They are affected by many factors including water depth (Irvine 1995), water transparency (Semyalo *et al.* 2009), conductivity, wastewater discharged into lakes, herbicides and nutrients produced from agricultural activities which diffuse into lakes either directly through run-off or indirectly via polluted rivers (Dietzel *et al.* 2013). Predation by fishes and other invertebrates, as well as availability of algal biomass further modify zooplankton patterns, especially in shallow lakes that experience constant mixing and have uniform temperature and food gradients (Semyalo *et al.* 2009), therefore, the zooplankton distribution pattern and abundance are a function of physico-chemical and biological processes (Semyalo *et al.* 2009; Oyoo-Okoth *et al.* 2011).

Spatial patterns and abundance of zooplankton distribution are an inherent characteristic of pelagic freshwater ecosystems. Advancement in understanding spatial patterns of zooplankton distribution in relation to changes in Lake Victoria ecosystem (Ngupula *et al.* 2010) has lagged behind despite their role in supporting the flourishing fish and invertebrate productivity of the lake. Unpacking the effects of different factors that control spatial distribution and abundance of zooplankton remains an important challenge for the ecological scientists working in freshwater ecosystems including Lake Victoria (Lévesque *et al.* 2010). This study, determined the patterns of spatial distribution (vertical and horizontal) and abundance of zooplankton at Shirati bay, Lake Victoria (Tanzania) in relation to phytoplankton, fish catch, water temperature, conductivity and transparency. Understanding the distribution patterns and abundance of zooplankton is an important step in predicting their influence on phytoplankton and fish production under the changing lake environment.

MATERIALS AND METHODS

Study area

Water quality parameters, chlorophyll-*a*, zooplankton and fish samples were collected on a weekly basis (March 2005 to March 2006) from three stations (Nyangoge, 15 m deep; Nyasobu, 5 m deep; and Michire, 7 m deep) at Shirati Bay, located at latitude 1° 09' 00" S and longitude 33° 58' 00" E in the Tanzanian waters of Lake Victoria near the border with Kenya (Figure 1). On each sampling occasion, almost similar stations were visited using the aid of a Global Positioning System (GPS) model GPSMAP 62S, made in USA. Within each sampling station, samples were taken from three points and afterwards their mean was estimated as a single value for the station on each sampling occasion. The choice of the above sites was done strategically to include varying depths to capture zooplankton variation with depths. The climate of Lake Victoria basin is characterized by two distinct seasons; a dry season from July to September and a wet season with two

rainfall maxima i.e. short rains from October to December and long rains from March to May.

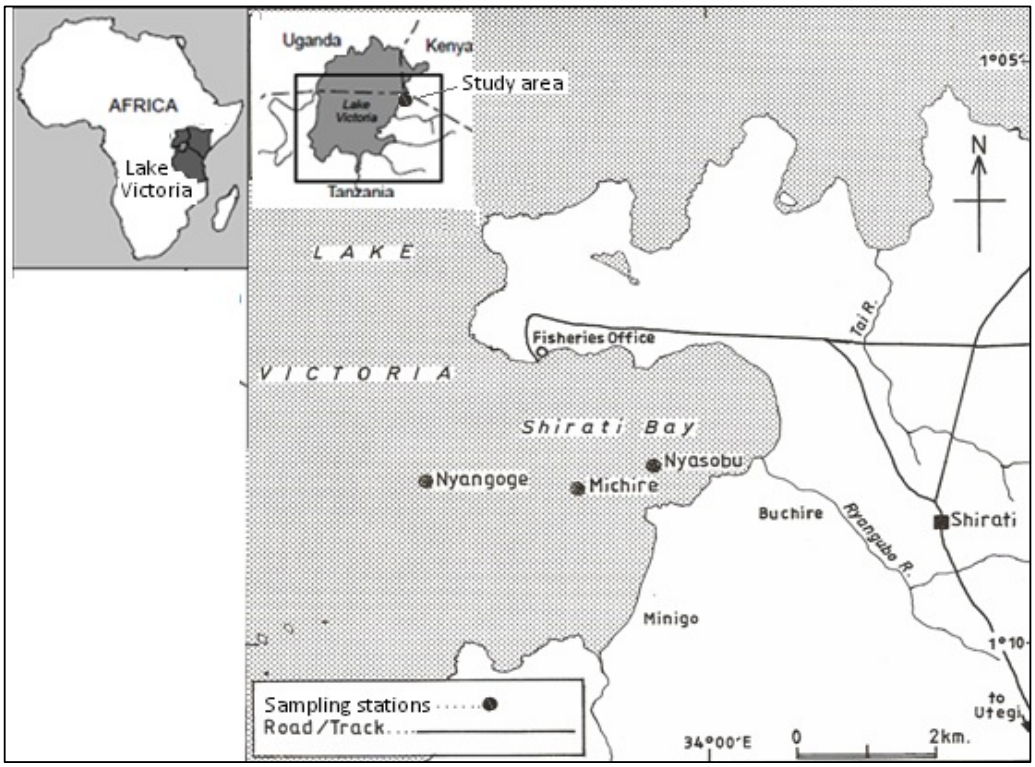


Figure 1: A map of Shirati Bay showing the three sampling stations

Sampling of water quality parameters

Water temperature, pH and conductivity were measured using a multi-meter probe deployed at the positions where the zooplankton samples were collected. Water transparency was measured using a Secchi disc with a diameter of 20 cm.

Determination of chlorophyll-a

To obtain the concentration of chlorophyll-*a* (an indirect measure of phytoplankton abundance), 150 mL of water sample was filtered through membrane filters of 0.45 µm pore size. Three to four drops of magnesium carbonate slurry were added to aid filtration and prevent acid formation during extraction. After filtration, the filter papers were transferred onto absorbent pads, folded in labeled aluminium foil, kept in darkened desiccators and subsequently stored in frozen conditions using a cool box prior to transportation to the Tanzania Fisheries Research Institute (TAFIRI) laboratory at Sota Centre for analysis. In the laboratory, chlorophyll-*a* pigment was extracted according to procedures recommended by Wetzel and Likens (2000).

Estimation of zooplankton abundance and diversity

Water samples for determination of zooplankton vertical distribution were taken at each site during the day using a one-litre van Dorn water sampler at five-metre depth

intervals between 0800 and 1000 hrs. Replicates of three samples from each site were sieved through 60 µm mesh size. Samples for determination of zooplankton horizontal distribution were taken by making three vertical hauls at each site. Hauls were made from one metre below the lake's water surface, using an open conical plankton net with a 29 cm mouth diameter, 60 μm mesh and one metre in length. The samples were preserved in four percent formaldehyde and transported in a cool box to TAFIRI laboratory at Sota Centre. In the laboratory, fixed water samples were diluted and at least 10 mL of water from each sample were examined for zooplankton under an inverted microscope at 40x magnification. Zooplankton were identified using keys and manuals by Ruttner-Kolisko (1974), Korovchinsky (1993) and Maas (1993). During counting, adult copepod males and females, ovigerous and non-ovigerous females as well as copepodite stages one to five and the nauplii stages were counted separately in order to obtain an insight into the different life stages of zooplankton. Abundance as individuals per cubic metre of water and as individuals in a given one litre of water are analysed using the following formulae (IFMP 2003-2008) according to Implementation of the Fisheries Management Plan:-

(i) $$Number\ /\ sample = \frac{Dilution\ volume \times number\ in\ a\ subsample \times split\ factor}{Count\ volume}$$

(ii) $$Number\ /\ m^2 = \frac{Number\ /\ sample}{Area\ of\ net\ mouth\ opening},$$

for a net of 30 cm opening, Area = 0.0855 m^2

(iii) $$Number\ /\ m^3 = \frac{Number\ /\ m^2}{Total\ depth\ of\ tows\ in\ metres}$$

(iv) $$Number\ /\ Litre = \frac{Number\ /\ m^3}{1000}$$

Fish composition and biomass

Fish sampling was done using beach seine with cod-end nets of two, one and 0.5 inches. On each sampling occasion, the seine nets were set to cover an area of approximately 200 m^2 and left for two hours before hauling. Hauling of nets was done three times a day. The fish caught from different hauls and nets were lumped together to make catch per net per day per sampling occasion.

Stomach content analysis of juvenile fish species

The procedures and the experiments in this study were done in respect of the internationally recognized guidelines for ethical use of animals (Håstein 2004; Grigorakis 2010). The fish used for analysis of stomach contents when caught alive were sacrificed by hypothermia through immersing them in an ice-slurry to avoid causing stress and pain before death (Sneddon 2006). By using ice water, it was possible to calm down the fish for several hours until osmoregulatory problems and exhaustion occurred. It has been demonstrated that pre-chilling prior to slaughter is a minor stressor (Sneddon 2012).

Eight samples per week of juvenile fish species (*L. niloticus*, *O. niloticus*, *T.*

rendalli) with relatively similar size and haplochromines species from each haul were analyzed for stomach contents. A total 1536 stomachs were removed soon after capture and preserved in specimen bottles containing 4% formalin and instantly transferred to the laboratory for analysis. In the laboratory the stomachs were analyzed for food content based on the modified Amundsen *et al*. (1996) point method. Each individual fish was dissected, stomach opened and its content emptied into a petri dish and uniformly mixed with some freshwater. The mixture was then transferred to a slide for microscopic examination. Identification and biomass of plankton food items were done as explained for phytoplankton and zooplankton above. The food items observed were identified and assigned percentages on the basis of their relative abundances.

Data analyses

Results are presented as mean ± standard error of the mean (SE). To safeguard against violation of the assumptions of parametric statistics, data were tested for homogeneity of variances using Levene's test. One-way analysis of variance (ANOVA) was used to test for differences in abundance and water quality parameters among stations. Specific significant differences were detected using Tukey's multiple comparisons test. Significant differences between female and male calanoid and cyclopoid copepods as well as nauplius larvae and copepodites were tested using independent samples *t*-test. A Spearman rank correlation (r) was used to test for realationships between zooplankton and chlorophyll-*a,* and water temperature, transparency, conductivity and pH. It was further used to relate the abundance of Nile perch and haplochromines with that of zooplankton. The Shannon-Weaver diversity index was used for the analysis of zooplankton diversity (Shannon and Weaver 1949). Significant differences were judged at a probability level of $p \leq 0.05$. All statistical analyses were performed using SPSS version 15 for windows.

RESULTS

Water quality parameters

Generally, with the exception of water transparency, water temperature, pH and conductivity were comparatively higher at the nearshore station (Nyasobu) than at the offshore station (Nyangoge) (Table 1). The mean water temperature in the bay ranged between 25.65 ± 0.32 °C and 26.36 ± 0.20 °C at Nyangoge and Nyasobu respectively. No significant difference in water temperature was found among the sampling stations during the study period ($F = 2.499$, $p = 0.096$). The average conductivity of the water ranged from 113.32 ± 5.82 µS/cm to 125.33 ± 7.29 µS/cm at Nyangoge and Nyasobu stations respectively. Water conductivity did not differ significantly among sampling stations during the study period ($F = 1.033$, $p = 0.434$).

The three stations along the bay showed significant difference in transparency values ($F = 3.779$, $p = 0.032$). Tukey multiple comparisons test showed significantly higher transparency at the offshore station (Nyangoge), than the nearshore station (Nyasobu) ($p = 0.036$; Table 1). Insignificant difference in transparency was obtained between Nyangoge and Michire ($p = 0.879$) and Michire and Nyasobu ($p = 0.104$; Table 1). The average water pH was 9.08 ± 0.13 and 9.76 ± 0.05 recorded at Nyangoge and Nyasobu stations respectively. The pH differed significantly among stations ($F = 13.656$, $p < 0.001$; Table 1). Post hoc test showed significantly higher values in pH at Nyasobu than Nyangoge ($p < 0.001$) and Michire ($p = 0.022$). However, no significant difference in pH was detected between Nyangoge and Michire ($p = 0.052$).

Vertical distribution of zooplankton

Table 1: Variation of water quality parameters (mean ± standard error) measured during the study

	Sampling stations		
Water quality parameter	Nyangoge	Michire	Nyasobu
Temperature (°C)	25.65 ± 0.32[a]	26.23 ± 0.17[a]	26.36 ± 0.20[a]
Conductivity (µS/cm)	113.32 ± 5.82[a]	119.25 ± 6.29[a]	125.33 ± 7.29[a]
Transparency (m)	1.71 ± 0.12[a]	1.64 ± 0.11[a,b]	1.34 ± 0.06[b]
pH	9.08 ± 0.13[a]	9.39 ± 0.08[a,b]	9.76 ± 0.05[b]

a,b: Means in each row sharing the same superscript are not significantly different ($p > 0.05$).

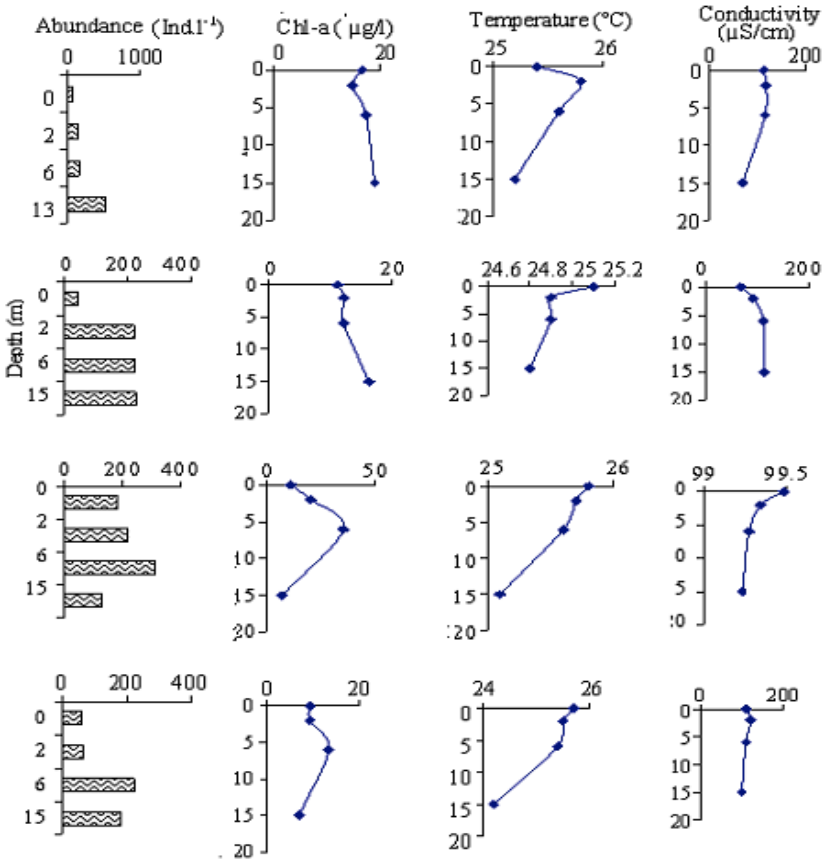


Figure 2: Vertical distribution of zooplankton, chlorophyll-*a* and some physical water quality parameters at Shirati Bay during the study period

The vertical distribution of zooplankton varied with depths. Generally higher abundance was found close to the bottom of the lake as compared to surface waters (Figure 2). On the contrary, water temperature and conductivity generally decreased with depth. Chlorophyll-*a*, varied with depths but without any notable distinct trends (Figure 2). Zooplankton vertical distribution significantly positively

correlated with water transparency (r = 0.680, p = 0.011). However, zooplankton vertical abundance was insignificantly inversely correlated with chlorophyll-*a* (r = -0.640, p = 0.360), water temperature (r = - 0.258, p = 0.750) and conductivity (r = -0.800, p = 0.333) during the study period. pH was insignificantly positively correlated with zooplankton abundance (r = 0.161, p = 0.600),

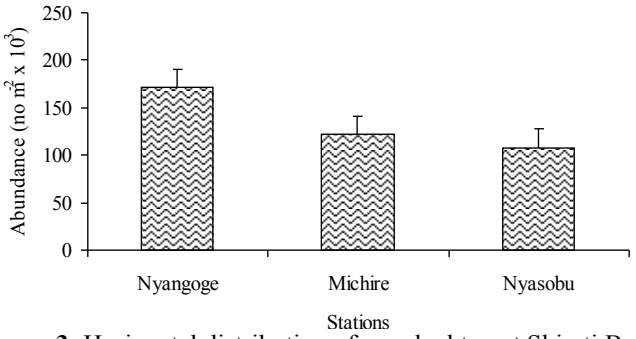


Figure 3: Horizontal distribution of zooplankton at Shirati Bay during the study period

Zooplankton horizontal distribution species composition, and diversity

On average Nyangoge station had the highest zooplankton mean abundance of 171,512 ± 14,624 ind. m^{-2} followed by Michire (122,383 ± 11,156 ind. m^{-2}) and Nyasobu (107,985 ± 15,156 ind. m^{-2}; Figure 3). However, there was no significant difference in horizontal zooplankton abundance among the three stations (F = 0.668, p = 0.5143).

A total of 41 zooplankton species were identified from the three sampling stations. The Copepoda was the most dominant group (94%) at all the three stations with *Thermocyclops neglectus* and *Thermocyclops emini* being the most common species. The abundance of Rotifera was 4.6% and Cladocera, which was the least abundant group, had an abundance of 1.4%. The abundance of female copepods dominated that of males throughout the study period. Female calanoid copepods (9061.04 ± 1624.43 ind. m^{-2}) were significantly more abundant than that of male calanoid copepods (4526.33 ± 1055.82 ind. m^{-2}; t = 2.341, p = 0.023). Equally, female cyclopoid copepods abundances were significantly higher (4046.97 ± 844.38 ind. m^{-2}) than those of males (1297.85 ± 229.88 ind. m^{-2}; t = 3.141, p = 0.002). Furthermore, cyclopoid copepods contributed more to copepod biomass followed by calanoids and then the harpacticoids. In general, the abundance of nauplius larvae was significantly higher (20955.42 ± 1805.223 ind. m^{2}) than that of the copepodites (14854.24 ± 1953.511 ind. m^{-2}; t = 2.294, p = 0.022).

Nyasobu station had the highest diversity (H') for Cladocera and Rotifera at 0.603 and 2.489, respectively (Table 2). Further,

Table 2: Shannon-Weaver (H') diversity indices for the different groups of zooplankton at Shirati Bay.

	Stations		
	Nyangoge	Michire	Nyasobu
Zooplankton groups	H'	H'	H'
Cladocera	0.479	-0.011	0.603
Copepoda	1.844	1.813	1.701
Rotifera	1.985	2.455	2.489

Nyangoge station had the highest diversity indices for Copepoda followed by Michire and Nyasobu (Table 2). Generally, Rotifera had the highest diversity indices among the dominant groups at the three sampled stations.

Fish catch composition

Fish catches at Shirati Bay comprised mainly *Lates niloticus* (Nile perch), *Oreochromis niloticus* (Nile tilapia), *Oreochromis leucostictus, Tilapia rendalli* and haplochromines. *L. niloticus* dominated the total catches (47%) followed by *O. niloticus* (29%) and haplochromines (21%). The *O. leucostictus (*2%) and *T. rendalli* (1%) were the least dominant fish species. There was no significant correlation between zooplankton abundance and total fish abundance (r = 0.172, p = 0.5760). However, abundance of haplochromines and juvenile fishes correlated significantly with that of zooplankton (Haplochromines: r = 0.856, p = 0.002 and juvenile fishes: r = 0.580, p = 0.038). Stomach contents analysis of juvenile planktivorous fishes revealed that, all fishes sampled included zooplankton in their diet (Table 3).

DISCUSSION

The results showed higher water transparency at the offshore station than the nearshore station, corroborating the results obtained by Kishe (2009) and Gikuma-Njuru *et al*. (2013) at different sites in Lake Victoria. The lower water transparency at the inshore station is related to flushing of sediments from anthropogenic activities in the catchment area. Due to their proximity to the land, the nearshore stations received higher amount of sediment laden runoff compared to the offshore station. The results further showed that, zooplankton vertical distribution was significantly positively correlated with water transparency. This is similar to results obtained by Akindele

Table 3: Gut contents of juvenile planktivorous fish of Shirati Bay, March 2005 to March 2006

Food item	*Lates niloticus*	*Oreochromis niloticus*	Haplochromine	*Tilapia zillii*
Asplanchna spp.	+	-	+	-
Caridina nilotica	+	-	-	-
Cyclopoid copepodite	+	+	+	+
Cyclopoid	+	+	+	+
Calanoid	+	+	+	+
Ceriodaphnia cornuta	-	-	+	-
Chaobrid larvae	-	-	+	-
Chironomid larvae	-	-	+	+
Filinia opoliensis	-	-	+	-
Insects	-	-	+	+
Lecane spp.	-	-	+	+
Macrothrix spp.	-	-	+	-
Moina micrura	-	-	+	-
Nauplii	-	-	+	+
Ostracods	-	-	+	-
Phytoplankton	-	+	+	+

Key, + = Present, - = Absent

(2013). The positive relationship between zooplankton and water transparency is due to the significant role played by water transparency during zooplankton diel vertical movement and feeding (Williamson et al. 2011) as well as visual predator avoidance (Hu et al. 2014). Thus, based on these results the vertical zooplankton distribution at sampled sites is controlled by water transparency.

The results have shown variation of zooplankton distribution and abundance with depths whereby higher values were found close to the bottom. Similar results have been obtained by White (1998) in Lake Miramar, Isumbisho *et al.* (2006) in Lake Kivu and Lévesque *et al.* (2010) in Lake Memphremagog. The existence of high abundance of zooplankton close to the bottom of the lake is due to predator avoidance behaviour (Lampert 1993; Waya 2004) which triggers their diurnal vertical migrations (Lampert *et al.* 2003; Waya 2004). Most zooplanktivorous fish and invertebrates (visual predators) concentrate at the water surface during the day and vice-versa at night (Mgana *et al.* 2014). To counteract predation, zooplankton have developed avoidance strategies (Masson *et al.* 2001) which include diel vertical migration by concentrating in the deep dark layers during the day light hours and in surface waters at night when visual predators are inactive and predation threats have been reduced (Lampert 1993; Semyalo *et al.* 2009; Mgana *et al.* 2014). This is a normal behaviour in many zooplankton species including rotifers, cladocerans and copepods which lead to the observed spatial distribution patterns. The relatively higher composition of Nile tilapia and haplochromines obtained in the current study might be controlling the vertical distribution of zooplankton. Therefore, predator avoidance influenced the observed vertical distribution pattern in zooplankton during the current study. Other migration cues, e.g. food concentration and moonlight were not investigated in the present study.

The results of the current study depicted dominance of the zooplankton community by copepods. Similar results in Lake Victoria were obtained by Waya and Mwambungu (2004), Semyalo *et al.* (2009) and Ngupula *et al.* (2010). Elsewhere, Isumbisho *et al.* (2006) obtained similar results in Lake Kivu, Mageed and Heikal (2006) in Lake Nasser, Sellami *et al.* (2011) in a Kasseb Reservoir, Tunisia and Mgana *et al.* (2014) in Lake Tanganyika. In view of their dominance, Savitha and Yamakanamardi (2012) concluded that copepods constitute a dominant zooplankton group for both freshwater and marine habitats and play a vital role as primary consumers in the aquatic ecosystems. The high dominance of copepods at Shirati Bay is due to their relatively small size and being successful feeders. Fish species exert size-selective predation on zooplankton species by preferentially preying on large-sized ones (Hansson *et al.* 2007b; Oguz *et al.* 2013). Based on selective feeding, Helenius *et al.* (2015) found that, cladocerans rather than copepods were efficiently removed by predation, consequently altering zooplankton community. Due to their relatively smaller size compared to cladocerans, it is possible that fish predators consumed more cladocerans leaving the smaller-sized copepods to flourish in the bay resulting in the observed higher dominance.

Moreover, copepods are known to have the toughest exoskeleton, the longest and the strongest appendages among all zooplankton species (Savitha and Yamakanamardi 2012). This body form helps them to swim faster during the search for food and predator avoidance than any other zooplankton species. The ability to swim faster makes them the most successful grazers and predators among zooplankton species (Waya and Mwambungu 2004). Thus, due to their

relatively smaller size, physical structure and effective feeding capacity copepods were able to flourish at Shirati bay leading to their dominance.

The study has revealed significantly higher abundance of nauplius larvae than copepodites. This result concurred with those by de Azevedo and Bonecker (2003), Semyalo *et al.* (2009) and Mgana *et al.* (2014). The higher abundance of nauplii is due to their small size which helps them to avoid predators. It has been shown that nauplii are not very susceptible to fish predation, due to their small size which provide a potential defense against predators (Castro *et al.* 2007). As noted earlier, predation by fish on zooplankton is size-dependent whereby larger-sized prey is consumed first. It is more likely that copepodites were preferred by predators leaving the smaller-sized nauplius larvae to thrive. Thus, the size of nauplius larvae helped them to avoid predators resulting in higher abundance than copepodites at Shirati Bay during the study.

The zooplankton community composition indicated that rotifers ranked second in terms of diversity at all study stations of Shirati Bay. High diversity of rotifers is a characteristic of tropical lakes (Ghadouani *et al.* 1998; Oueda *et al.* 2007; Badsi *et al.* 2010; Okogwu 2010) including Lake Victoria (Waya and Chande 2004; Mwebaza-Nadwula *et al.* 2005; Vincent *et al.* 2012) and other lakes (Özçalkap and Temel 2011). The high diversity of rotifers is related to their ability to survive in a harsh environment (Mwebaza-Ndawula 1994), their versatile feeding habit (Savitha and Yamakanamardi 2012) and reproductive success in the eutrophic waters of Lake Victoria. Rotifers are more tolerant to adverse environmental conditions than cladocerans and copepods (Hansson *et al.* 2007a; Okogwu 2010). They are more responsive to water quality changes and exhibit a wide tolerance range for turbidity compared to cladocerans and copepods (Vincent *et al.* 2012). Their tolerance to environmental variables has enabled rotifers to flourish in most eutrophic waters than copepods and cladocerans (Waya and Chande 2004; Waya and Mwambungu 2004). Furthermore, the feeding habit of rotifers enables them to thrive in eutrophic lakes. Their unspecialized feeding (Joseph and Yamakanamardi 2011) enables them to ingest small particles such as bacteria and organic detritus that are often abundant in eutrophic environments (Badsi *et al.* 2010). Due to the position of the study site, sedimentation of the organic matter from storm water at Shirati bay and its degradation might have resulted in the production of high density of bacteria and detrital matter which were effectively consumed by the rotifers to build up their high diversity.

In addition, rotifers have frequent parthenogenetic reproduction that is favoured in unstable and eutrophic environments (Joseph and Yamakanamardi 2011). Consequently, the high diversity of rotifers at Shirati Bay could be explained by their ability to live in harsh environments, unspecialized feeding and reproductive success in the eutrophic conditions of the lake.

CONCLUSIONS

The present study revealed that the vertical zooplankton distribution at Shirati Bay is mainly controlled by water transparency. The dominance of copepods and rotifers at Shirati Bay signifies more eutrophication in the lake thus creating a difficult environment for other zooplankton species to survive; consequently, altering the zooplankton species composition. The predation by Nile perch, Nile tilapia and haplochromines at Shirati Bay influenced the vertical zooplankton distribution pattern observed in the current study. These results call for

monitoring programmes at the watershed areas to reduce the levels of sediments flushed into the lake. The changes in water quality parameters are likely to affect the distribution patterns and abundance of zooplankton which form an important food item for fish in the lake.

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REFERENCES

Akindele E 2013 Relationships between the physico-chemical water parameters and zooplankton fauna of Tiga Lake, Kano, Nigeria. *Bayero J. Pure and Appl. Sci.* **6**: 95-100.

Amundsen PA, Gabler HM, Staldvik FJ 1996 A new approach to graphical analysis of feeding strategy from stomach contents data-modification of the Costello (1990) method. *J. Fish Biol.* **48**: 607-614.

Badsi H, Ali HO, Loudiki M, El Hafa M, Chakli R and Aamiri A 2010 Ecological factors affecting the distribution of zooplankton community in the Massa Lagoon (Southern Morocco). *Afr. J. Environ. Sci. Technol.* **4**: 751-762.

Casper AF and Thorp JH 2007 Diel and lateral patterns of zooplankton distribution in the St. Lawrence River. *River Res. Appl.* **23**: 73-85.

Castro BB, Marques SM and Gonçalves F 2007 Habitat selection and diel distribution of the crustacean zooplankton from a shallow Mediterranean lake during the turbid and clear water phases. *Freshwat. Biol.* **52**: 421-433.

de Azevedo F and Bonecker CC 2003 Community size structure of zooplanktonic assemblages in three lakes on the upper River Paran´a floodplain, PR-MS, Brazil. *Hydrobiologia* **505**: 147-158.

Dietzel A, Mieleitner J, Kardaetz S and Reichert P 2013 Effects of changes in the driving forces on water quality and plankton dynamics in three Swiss lakes – long-term simulations with BELAMO. *Freshwat. Biol.* **58**: 10-35.

Gikuma-Njuru P, Hecky RE, Guildford SJ and MacIntyre S 2013 Spatial variability of nutrient concentrations, fluxes, and ecosystem metabolism in Nyanza Gulf and Rusinga Channel, Lake Victoria (East Africa). *Limnol. Oceanogr.* **58**: 774-789.

Ghadouani A, Alloul BP, Zhang Y, Prepas and Ellie E 1998 Relationships between zooplankton community structure and phytoplankton in two lime-treated eutrophic hardwater lakes. *Freshwat. Biol.* **39**: 775-790.

Grigorakis K 2010 Ethical issues in aquaculture production. *J Agricult Environ Ethics* **23**: 345-370.

Hansson L, Gustafsson S, Rengefors K and Bomark L 2007a Cyanobacterial chemical warfare affects zooplankton community composition. *Freshwat. Biol.* **52:** 1290-1301.

Hansson L-A, Nicolle A, Brodersen J, Romare P, Anders Nilsson P, Brönmark C and Skov C 2007b Consequences of fish predation, migration, and juvenile ontogeny on zooplankton spring dynamics. *Limnol. Oceanogr.* **52**: 696-706.

Håstein T, 2004. Animal welfare issues relating to aquaculture. In: Vallat B (Ed), *Global conference on animal welfare: an OIE initiative*. European Communities, Paris, France. pp. 212-221.

Helenius LK, Aymà Padrós A, Leskinen E, Lehtonen H and Nurminen L 2015 Strategies of zooplanktivory shape the dynamics and diversity of littoral plankton communities: a mesocosm approach. *Ecol. Evolut.* **5**: 2021-2035.

Hu C, Wang S, Guo L and Xie P 2014 Effects of the proximal factors on the diel vertical migration of zooplankton in a plateau meso-eutrophic lake Erhai, China. *J. Limnol.* **73**: 375-386.

IFMP. 2003-2008. Manuals for limnological studies. In: Implementation of Fisheries Management Plan (IFMP) for Lake Victoria, EDF Project No. 8ACP. ROR. 029. LVFO Secretariat, Jinja, Uganda. P78.

Irvine K 1995 Standing biomasses, production, spatial and temporal distributions of the crustacean zooplankton. In: A Menz (Ed.), The Fishery Potential and Productivity *of the Pelagic Zone of Lake Malawi/Niassa*. Chatham, United Kingdom Natural Resources Institute. pp. 85-140.

Isumbisho M, Sarmento H, Kaningini B, Micha J-C and Descy J-P 2006 Zooplankton of Lake Kivu, East Africa, half a century after the Tanganyika sardine introduction. *J. Plankton Res.* **28**: 971-989.

Joseph B and Yamakanamardi SM 2011 Monthly changes in the abundance and biomass of zooplankton and water quality parameters in Kukkarahalli Lake of Mysore, India. *J. Environ. Biol.* **32**: 551-557.

Kelly NE, Yan ND, Walseng B and Hessen DO 2013 Differential short- and long-term effects of an invertebrate predator on zooplankton communities in invaded and native lakes. *Divers. Distrib.* **19**: 396-410.

Kishe M A 2009 Physical and chemical characteristics of water in selected locations in Lake Victoria, Tanzania. *Tanz. J. Sci.* **30***:* 65-72.

Korovchinsky N 1993 *Introduction to the Cladocera*. Universiteit Gent, Belgium, International Training Course Manuscript. pp 36.

Lampert W 1993 Ultimate causes of diel vertical migration of zooplankton, new evidence for the predator avoidance hypothesis. *Arch. Hydrobiol.–Beih. Ergebn. Limnol.* **39**: 79-88.

Lampert W, McCauley E and Manly BFJ 2003 Trade-offs in the vertical distribution of zooplankton: Ideal free distribution with costs? *Proc. R. Soc. Lond. B* **270**: 765-773.

Lévesque S, Beisner BE and Peres-Neto PR 2010 Meso-scale distributions of lake zooplankton reveal spatially and temporally varying trophic cascades. *J. Plankton Res.* **32**: 1369–1384.

Maas S 1993 *Introduction to the Copepoda*. Universiteit Gent, Belgium, International Training Course Manuscript. Pp 204

Mageed AAA and Heikal MT 2006 Factors affecting seasonal patterns in epilimnion zooplankton community in one of the largest man-made lakes in Africa (Lake Nasser, Egypt). *Limnologica* **36**: 91-97.

Masson S, Angeli N, Guillard J and Pinel-Alloul B 2001 Diel vertical and horizontal distribution of crustacean zooplankton and young of the year fish in sub-alpine lake: an approach based on high frequency sampling. *J. Plankton Res.* **23**: 1041-1061.

Mgana H, Herzig A and Mgaya Y 2014 Diel vertical distribution and life history characteristics of *Tropodiaptomus simplex* and its importance in the diet of *Stolothrissa tanganicae*, Kigoma, Tanzania. *Aquat. Ecosyst. Health Manage.* **17**: 14-24.

Mulimbwa N, Raeymaekers JAM and Sarvala J 2014 Seasonal changes in

the pelagic catch of two clupeid zooplanktivores in relation to the abundance of copepod zooplankton in the northern end of Lake Tanganyika. *Aquat. Ecosyst. Health Manage.* **17**: 25-33.

Mwebaza-Nadwula L, Sekiranda SBK and Kiggundu V 2005 Variability in zooplankton community along a section of the Upper Victoria Nile, Uganda *Afr. J. Ecol.* **43**: 251-257.

Mwebaza-Ndawula L 1994 Changes in relative abundance of zooplankton in northern Lake Victoria, East Africa. *Hydrobiologia* **272**: 259-264.

Ngupula GW 2013 How does increased eutrophication and pollution in the Lake Victoria waters impacts zooplankton? *J. Environ. Ecol.* **4**: 151-164.

Ngupula GW, Waya RK and Ezekiel CN 2010 Spatial and temporal patterns in abundance and distribution of zooplankton in the Tanzanian waters of Lake Victoria. *Aquat. Ecosyst. Health Manage.* **13**: 451-457.

Oguz T, Macias D, Renault L, Ruiz J and Tintore J 2013 Controls of plankton production by pelagic fish predation and resource availability in the Alboran and Balearic Seas. *Prog. Oceanogr.* **112–113**: 1-14.

Ojwang WO, Ojuok JE, Nyamweya C, Agembe S, Owili M, Yongo E and Wakwabi EO 2014 The intriguing dynamics of *Rastrineobola argentea* fishery in the Kenyan waters of Lake Victoria. *Aquat. Ecosyst. Health Manage.* **17**: 80-89.

Okogwu OI 2010 Seasonal variations of species composition and abundance of zooplankton in Ehoma Lake, a floodplain lake in Nigeria. *Rev. Biol. Trop.* **58**: 171-182.

Oueda A, Guenda W, Kabre AT, Zongo F and Kabre GB 2007 Diversity, abundance and seasonal dynamics of zooplankton community in a South Saharan Reservoir (Burkina Faso). *J. Biol. Sci.* **7**: 1-9.

Oyoo-Okoth E, Muchiri M, Ngugi CC, Njenga EW, Ngure V, Orina PS, Chemoiwa EC and Wanjohi BK 2011 Zooplankton partitioning in a tropical alkaline–saline endorheic Lake Nakuru, Kenya: Spatial and temporal trends in relation to the environment. *Lakes Reserv.: Res. Manage.* **16**: 35-47.

Özçalkap S and Temel M 2011 Seasonal changes in zooplankton community structure in Lake Küçükçekmece, İstanbul, Turkey. *Turk. J. Zool.* **35**: 689-700.

Ruttner-Kolisko A 1974 *Plankton rotifers, Biology and Taxonomy*. Stuttgart, Germany, Schweitzerbart'sche Verlang.

Savitha N and Yamakanamardi SM 2012 Studies on abundance of zooplanktons in lakes of Mysore, India. *J. Environ. Biol.* **33**: 1079-1085.

Sellami I, Elloumi J, Hamza A, Mhamdi MA and Ayadi H 2011 Local and regional factors influencing zooplankton communities in the connected Kasseb Reservoir, Tunisia. *Water SA* **37**: 201-212.

Semyalo R, Nattabi JK and Larsson P 2009 Diel vertical migration of zooplankton in a eutrophic bay of Lake Victoria. *Hydrobiologia* **635**: 383-394.

Shannon CE and Weaver W 1949 *The Mathematical Theory of Communication*. Illinois, USA, Urbana University Illinois Press.

Sitoki L, Gichuki J, Ezekiel CN, Wanda F, Mkumbo OC and Marshall BE 2010 The environment of Lake Victoria (East Africa): current status and historical changes. *Int. Rev. Hydrobiol.* **95**: 209-223.

Sneddon L (2006) Ethics and welfare: pain perception in fish. *Bull. Eur. Assoc. Fish. Pathol*. **26**: 6-10.

Sneddon LU (2012) Clinical anesthesia and analgesia in fish. *J. Exot. Pet. Med*. **21**: 32-43.

Vincent K, Mwebaza-Ndawula L, Makanga B and Nachuha S 2012 Variations in zooplankton community structure and water quality conditions in three habitat types in northern Lake Victoria. *Lakes Reserv.: Res. Manage*. **17**: 83-95.

Waya RK 2004 Diel vertical migration of zooplankton in the Tanzanian waters of Lake Victoria. *Tanz. J. Sci.* **30**: 123-134.

Waya RK and Chande AI 2004 Species composition and biomass estimates of zooplankton in some water bodies within Lake Victoria basin. *Tanz. J. Sci.* **30**: 44-52.

Waya RK and Mwambungu JA 2004 Zooplankton communities of selected stations of Lake Victoria. *Tanz. J. Sci.* **30**: 12-20.

Wetzel RG and Likens GE 2000 *Limnological analyses*. 3rd edn ed. New York, USA, Springer-Verlag.

White MD 1998 Horizontal distribution of pelagic zooplankton in relation to predation gradients. *Ecography* **21**: 44-62.

Williamson CE, Fischer JM, Bollens SM, Overholt EP and Breckenridge JK 2011 Toward a more comprehensive theory of zooplankton diel vertical migration: integrating ultraviolet radiation and water transparency into the biotic paradigm. *Limnol. Oceanogr*. **56**: 1603-1623.

Yurista PM and Kelly JR 2009 Spatial patterns of water quality and plankton from high-resolution continuous in situ sensing along a 537-km nearshore transect of western Lake Superior, 2004. In: Munawar M and Munawar IF (Eds.), *State of Lake Superior. Ecovision World Monograph Series, Aquatic Ecosystem Health and Management Society*. M Munawar, Munawar IFeditors Ed., Burlington, Ont., Canada. 439 - 471.