

Spatial and Temporal Variations of Zooplankton in Relation to Some Environmental Factors in Lake Baringo, Kenya

^{1*}Omondi, R., ²Yasindi A. W. and ²Magana A.

¹Kenya Marine and Fisheries Research Institute, P. O. Box 1881, Kisumu

Email: reubenomondi@yahoo.com

²Department of Biological Sciences, Egerton University,
P. O. Box 536, Egerton

Abstract

The zooplankton community of Lake Baringo, a shallow and turbid lake in the eastern arm of the Great Rift Valley in Kenya, was studied between April 2008 and November 2009. This study focused on the spatial and temporal distribution, composition and abundance of zooplankton in the lake. Physico-chemical variables measurements and triplicate zooplankton samples were taken monthly from five stations. The zooplankton community comprised 31 species. Only two Copepod species, *Thermocyclops consimilis* and *Thermodiaptomus galebi* were recorded in the orders Cyclopoida and Calanoida respectively. Cladocera was represented by 8 species, with *Diaphanosoma excisum* being the most common in all sampling stations. Rotifera, with five families, had a total of 21 species. Spatially, species diversity ranged from 0.649 in C2 to 0.695 in C1 while temporally these were 0.36 to 0.87 in September 2009 and June 2008 respectively. The mean zooplankton abundance per station varied from 27.46 ± 4.16 individuals Γ^{-1} in December, 2008 to 120.13 ± 17.50 individuals Γ^{-1} in November 2009. Among sampling sites, C3 had the highest abundance (79.09 ± 7.95 individuals Γ^{-1}) and the lowest abundance was recorded at C1 (56.37 ± 6.58 individuals Γ^{-1}). There was significant difference between the sampling stations ($P < 0.001$) and among the sampling months ($P < 0.001$). A number of environmental parameters were correlated with the abundance of different species of zooplankton.

Key words: Lake Baringo, Zooplankton, Distribution, Abundance, Environmental factors

Introduction

Zooplankton play a prime role in the functioning and productivity of aquatic systems and make up a major portion of the abundance and biomass of these ecosystems (Gannon & Stemberger, 1978). In addition to their numerical contribution, zooplankton occupy a significant intermediate position in aquatic food chains and are important in energy transfer and have the potential to regulate the structure of phytoplankton and zooplankton prey assemblages. The organisms form a significant component of the diets of many fish and have also been used as indicators of water quality (Ogari & Dadzie, 1988; Hoxmeier & Wahl, 2004).

The structure of zooplankton communities is influenced by climatic and physico-chemical parameters as well as biological interactions. Some species are therefore found in a wide range of environmental conditions, while others are limited by many physico-chemical factors (Gannon & Stemberger, 1978; Neves *et al.*, 2003). While Calanoida are generally abundant in oligotrophic environments, cyclopoids and cladocerans dominate in eutrophic waters (Margaleff, 1983; Wetzel, 1990). A complex set of related factors have been implicated for the seasonality in population dynamics and species succession. These include physical and chemical variables (Angino *et al.* 1973), food (Behn & Boumans, 2001; Abdel-Aziz & Gharib, 2006) and predation (Jeppesen *et al.* 2005). Comparisons have also been made between the abundance and biomass of micro- and macrozooplankton (Pace *et al.* 1998, Sprules *et al.* 1988) to algal chlorophyll *a* (Canfield & Jones, 1996).

Many lakes in the world are shallow and are thus susceptible to substantial sediment resuspension during windy conditions (Wetzel & Likens, 1990). Besides the allochthonous materials from the catchment, the high turbidity in Lake Baringo has been attributed to the resuspension of the sediment daily by winds in the lake (Oduor, 2000). The suspended solids influence the Secchi depth, euphotic zone and light attenuation coefficient. Resuspended sediments exert many direct and indirect effects on food webs. It may also decrease or increase primary productivity depending on the relative extent to which it attenuates light (Hart, 1992). Elevated turbidity also reduces the feeding success of fish that locate prey visually (Gardner, 1981).

Despite the importance of zooplankton in freshwater ecosystems, little is known about the diversity, distribution and abundance of zooplankton in Lake Baringo. The present study aims at evaluating the effect of environmental factors on spatial and temporal zooplankton community structure in the lake. Lake Baringo, like other lakes with high drainage ratios

are expected to have a Secchi depth of 4 – 5m, but the lake has much lower values (~ 50cm), indicating high turbidity, probably because of its closed endorrheic nature and catchment degradation. Nutrients inflow and retention rate are also expected to be high. This study hypothesized that zooplankton dynamics would be governed not by hydrographic and nutrient factors but rather by physico-chemical and hydrological factors such as temperature, pH, conductivity and seasonal runoff.

Materials and Methods

Study Area

Lake Baringo is located in Baringo District of Rift Valley Province in Kenya. It is one of the lakes in the eastern arm of the Great Rift Valley between latitude 0°30` N and 0°45` N and longitude 36° 00` E and 36° 10` E and lies approximately 60Km north of the equator at an altitude of 975 m above sea level (Figure 1). The lake has a surface area of approximately 130

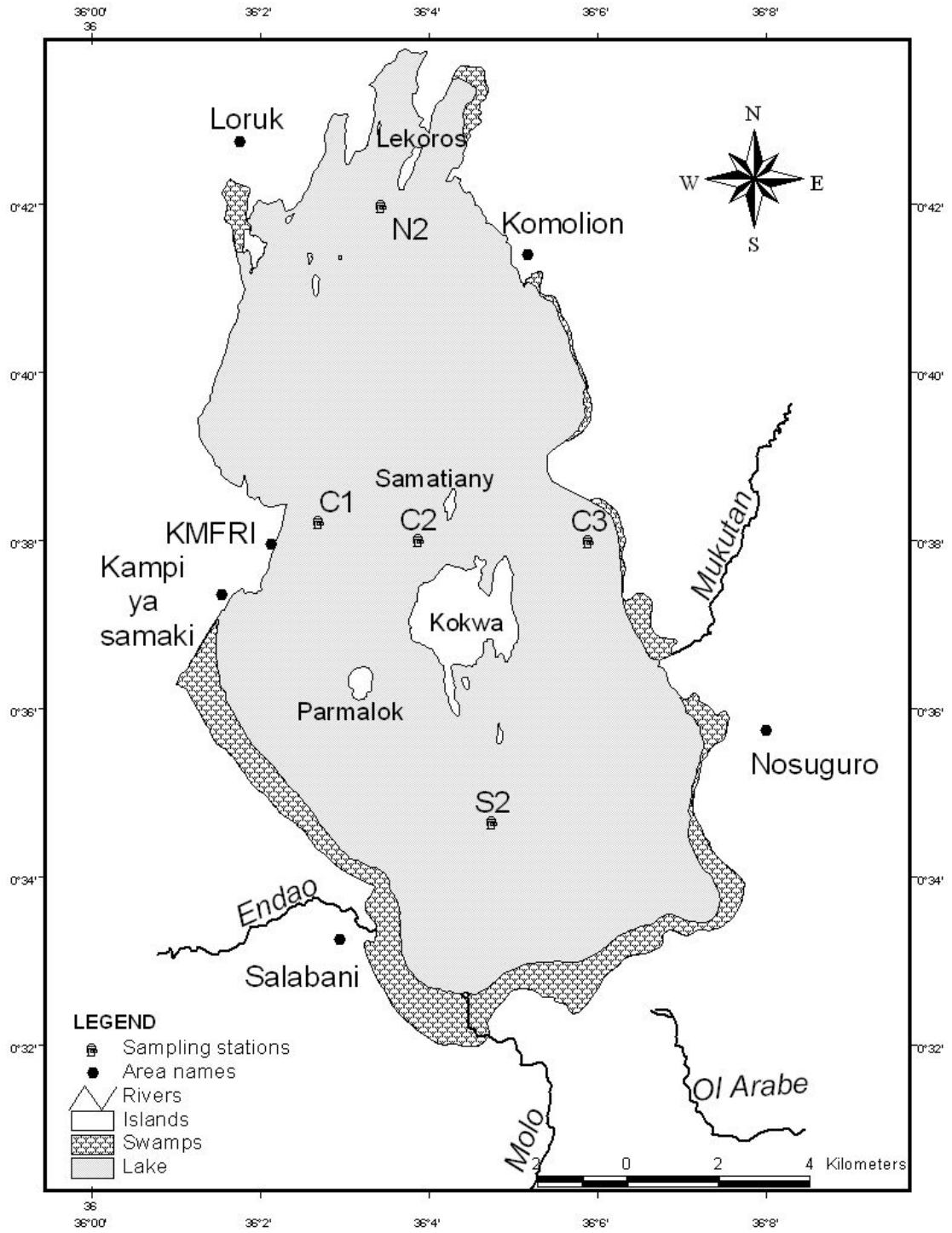


Figure 1: Map of Lake Baringo showing the sampling stations S2, C1, C2, C3 and S2

Km² and a catchment area of 6,820Km². Its depth varies with an average of about 3m and a deepest point of about 7m. The lake became a Ramsar site on the 10th January 2002. It is a critical habitat and refuge for more than 500 species of birds and fauna, some of the migratory aquatic bird species being significant regionally and globally.

The lake is part of the Great Rift Valley system with the Tugen Hills, an uplifted fault block of volcanic and metamorphic rocks, lying west of the lake at an altitude of 300-1000m Above Sea level while Laikipia escarpment lies to the east. The lake has several small islands with the largest being Ol Kokwe. A group of hot springs discharge along the shoreline at the northeastern corner of the island. The lake is fed by several rivers, Molo, Perkerra and Ol Arabel, and has no obvious outlet; the waters are assumed to seep through lake sediments into the faulted volcanic bedrock. Most of the rivers and streams enter the lake at the southern and eastern shores where they form swamps harbouring different types of macrophytes dominated by emergent *Typha domingensis* and submerged *Ceratophyllum demersum*. However, damming of some of these rivers has reduced the amount of water reaching the lake. The climate of the area is arid to semi-arid with two seasons; the dry season is from September to February while there are rains between March and August. Rainfall ranges from about 600mm on the east and south of the lake to 1500mm on the western escarpment of the Rift Valley. Soil erosion and the subsequent deposition of the eroded materials in waterways and water bodies is one of the most serious environmental problems facing Lake Baringo. The erosion has caused land damages and deposited the silt into Lake Baringo causing serious turbidity and siltation.

Samples were obtained monthly from five stations in the lake representing different habitats between April 2008 and November 2009. Stations S2 and C3 have river influence and have adjacent swampy shorelines while C1 and N2 have no river influence and have rocky adjacent shorelines. Station C2 occurs at the centre of the lake and has intermediary characteristics to the other stations. Global positioning system (GPS) navigational unit (Garmin II model) was used to track sampling positions. A surveyor II model hydrolab was used for the measurements of temperature, dissolved oxygen, pH, conductivity and redox potential at 0.5m depths. Turbidity was measured with a HACH 2100P turbidimeter while a 20cm diameter black and white Secchi disc was used to determine transparency. Maximum depth was determined using a marked rope with weight at the end.

Water samples for nutrients and chlorophyll-*a* analyses were collected using a 4 litre Van Dorn sampler and placed in plastic bottles. These were kept in a

cooler box at 4°C and transported to the laboratory. In the laboratory, samples were filtered using 0.45µm pore size filter papers to remove phytoplankton. The levels of soluble reactive phosphorus (PO₄-P), total phosphorus (TP), nitrate-nitrogen (NO₃-N), ammonium-nitrogen (NH₄-N), silica and nutrients were determined according to standard methods (APHA, 1995). These were analysed within three days after sampling.

Triplicate zooplankton samples were collected using a conical net with a mesh size of 60µm and a diameter of 30cm at the opening. The net was lowered close to the bottom of the lake without disturbing the sediment and hauled vertically to the surface and the depth noted from the marked rope. The net was rigged with a weight suspended from the receptacle to ensure the hauls are vertical. The net was washed after each haul to rinse off any zooplankton, which could remain in the net. After collection, the material retained in the net was kept in 400ml plastic bottles and fixed in 4% formalin. Zooplankters were counted in sub samples of 1-3ml, depending on their density, using a plastic pipette and a gridded counting chamber under an optical microscope (x25). The effect of surface tension on the specimens was reduced by addition of a few drops of liquid detergent while visibility was improved by dyeing with Lugol's solution.

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

$$D = N/V, \text{ where}$$

$$N = \text{number of organisms in sample}$$

$$= (\text{number in sub-sample} \times \text{Volume of sample}) / \text{sub-sample volume}$$

$$V = \text{volume of lake water filtered} = \pi r^2 d, \text{ where}$$

$$r = \text{radius of mouth of net (15cm)}$$

$$d = \text{depth of haul}$$

Abundance was expressed as individuals per litre of lake water. Besides samples from the established sampling stations, qualitative samples were also collected from a variety of different habitats using a hand net fixed to a wooden handle. The additional habitats included macrophytic areas and rocky shores. Zooplankton were identified using relevant taxonomic literature. Korovchinsky (1992) and Smirnov (1996) were used in Cladocera identification while Koste (1978), Koste & Shiel (1987) and Segers (1995) were used for the identification of Rotifera. Species diversity was calculated using Shannon-Weiner diversity index, H' (Shannon & Weiner, 1963).

The abundance data was standardized as number of individuals per litre of water (individuals l⁻¹). To compare the zooplankton abundances and

environmental parameters, Kolmogorov-Smirnov and Lilliefors tests were first applied to check the normality of distribution and the homogeneity of variances. Due to the heteroscedasticity of the zooplankton data (K-S $P < 0.01$; Lilliefors $P < 0.01$), it was transformed using $\log(x + 1)$ transformations to avoid violations of linearity assumptions and one way ANOVA was then used to determine significant differences between spatial (over all stations) and temporal (over all seasons) distribution of zooplankton abundance using STATISTICA 8.0 computer package.

Results

Physico-chemical Parameters

Variations in the physico-chemical variables are shown in Table 1. There was little variation in the values of physico-chemical parameters between sampling stations (two-factor ANOVA $P = 0.164$). However, a significant difference between months was evident ($P = 0.024$). The deepest and the lowest sites in the lake were N2 (5.15 ± 0.14 m) and C3 (3.69 ± 0.14 m), respectively, with a clear increasing trend from south (S2) to north (N2). Water transparency increased from south to north with the deepest Secchi depth of 31.5 ± 0.14 cm at N2 and the shallowest of 25.68 ± 1.20 cm at S2 (Table1).

Table 1: Mean (\pm SE) values of some physico-chemical and biological parameters measured at the sampling stations (n = 20)

Parameters	Stations				
	S2	C1	C2	C3	N2
Depth (m)	4.10 \pm 0.08	4.56 \pm 0.09	4.72 \pm 0.08	3.69 \pm 0.01	5.15 \pm 0.08
Secchi (cm)	25.68 \pm 0.79	30.57 \pm 0.91	30.68 \pm 0.78	28.83 \pm 0.76	31.50 \pm 0.84
Turbidity (NTU)	90.94 \pm 2.62	82.12 \pm 2.93	87.0 \pm 3.02	93.0 \pm 3.26	82.08 \pm 2.14
Temperature ($^{\circ}$ C)	26.18 \pm 0.17	28.44 \pm 0.22	27.64 \pm 0.21	26.56 \pm 0.12	27.38 \pm 0.19
pH	8.70 \pm 0.03	8.70 \pm 0.03	8.72 \pm 0.03	8.67 \pm 0.03	8.60 \pm 0.52
Conductivity (μ Scm $^{-1}$)	652.62 \pm 10.93	647.42 \pm 10.93	652.60 \pm 1.79	655.92 \pm 10.37	648.92 \pm 10.66
Hardness	71.12 \pm 2.24	70.2 \pm 2.12	70.57 \pm 2.90	70.72 \pm 1.86	68.40 \pm 9.99
Alkalinity	198.78 \pm 6.33	202.73 \pm 6.35	201.48 \pm 6.16	196.93 \pm 6.19	194.03 \pm 6.69
DO (mg l $^{-1}$)	6.42 \pm 0.09	6.94 \pm 1.06	7.12 \pm 0.11	6.68 \pm 0.10	7.03 \pm 0.10
Chl <i>a</i> (mgm $^{-3}$)	16.84 \pm 1.69	13.27 \pm 0.75	15.35 \pm 0.84	16.26 \pm 1.21	13.96 \pm 1.08
Silicates (mg l $^{-1}$)	27.72 \pm 0.58	27.86 \pm 0.49	27.87 \pm 0.56	26.90 \pm 0.4	28.67 \pm 0.60
SRP (μ g l $^{-1}$)	14.85 \pm 1.46	17.55 \pm 2.6	17.65 \pm 2.49	16.25 \pm 1.18	15.21 \pm 1.40
NH $_4$ (μ g l $^{-1}$)	63.87 \pm 9.38	50.09 \pm 4.79	53.27 \pm 3.13	48.03 \pm 4.87	41.64 \pm 2.55
NO $_3$ (μ g l $^{-1}$)	6.33 \pm 0.52	5.99 \pm 0.57	5.94 \pm 0.42	5.37 \pm 0.4	5.36 \pm 0.42

Water temperatures were generally high with the mean temperature ranging from $26.18 \pm 0.17^\circ\text{C}$ at site S2 to $28.44 \pm 0.22^\circ\text{C}$ at site C1. Values of pH ranged between 8.67 ± 0.03 at site C3 and 8.72 ± 0.03 at C2 while dissolved oxygen concentration ranged between $6.42 \pm 0.09 \text{ mg.l}^{-1}$ at S2 and $7.12 \pm 0.11 \text{ mg.l}^{-1}$ at C2. Conductivity values were generally high but with little variation between stations.

Soluble reactive phosphates, silicates and ammonia exhibited erratic changes in concentration while nitrates concentrations showed little variation throughout the sampling period (Figure 2). The average values of nutrients fluctuated between minima of 22.44 mg.l^{-1} , $4.46 \mu\text{g.l}^{-1}$ and $15.06 \mu\text{g.l}^{-1}$ and maxima of 33.58 mg.l^{-1} , $46.14 \mu\text{g.l}^{-1}$ and $134.4 \mu\text{g.l}^{-1}$ for silicates, soluble reactive phosphates and ammonium respectively.

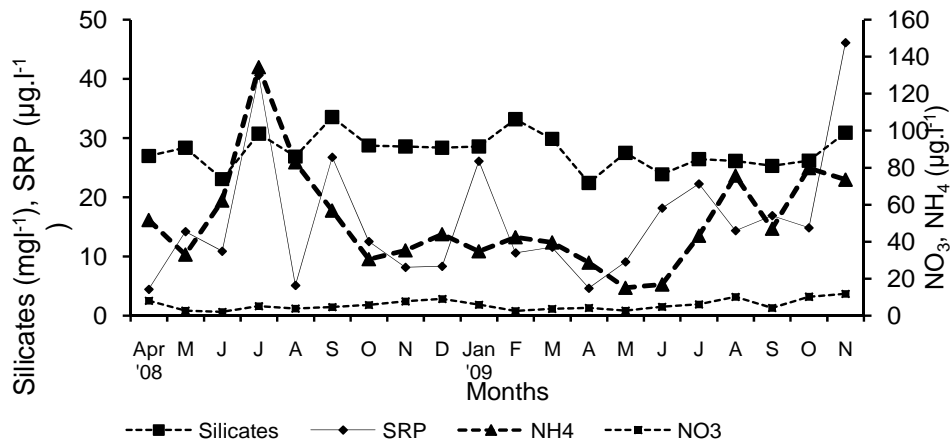


Figure 2: Chemical variables ($\pm SE$) between April 2008 & November 2009

The lowest and highest concentrations of Chlorophyll *a* of $4.86 (\pm 0.72)$ and $30.7 (\pm 5.31) \text{ mg.m}^{-3}$ were realized in June 2009 and November 2009 respectively (Figure 3). Other peaks occurred in the months of July 2008, February 2009 and July 2009. While the July 2008 peak was followed by a gradual decline up to December, in July 2009 and August there was a decrease, followed by immediate increase from September to November.

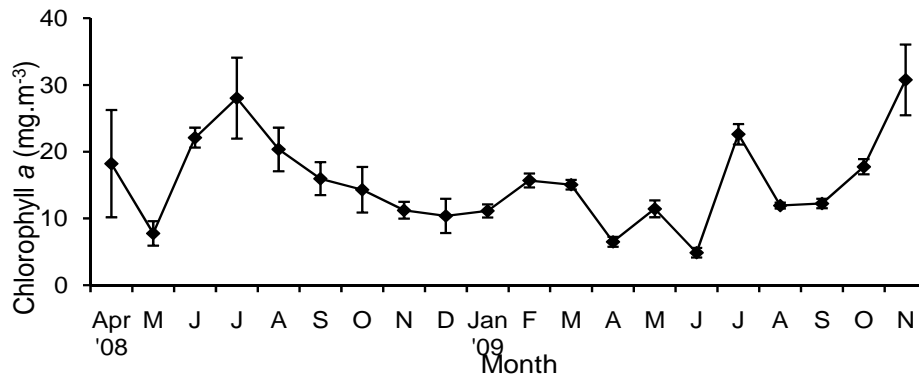


Figure 3: Mean values (\pm SE) of Chlorophyll a during the sampling period

Zooplankton Species Composition and Distribution

A total of 31 species of zooplankton were recorded in Lake Baringo between April 2008 and November 2009 (Table 2). Only two species of Copepoda were recorded, *Thermodiaptomus galebi* (Diaptomidae) and *Thermocyclops consimilis* (Cyclopidae) in the orders Calanoida and Cyclopoida, respectively. Cladocerans were represented by five families dominated by Chydoridae with three species. Others included Daphnidae, Sididae, Macrothricidae and Moinidae. Rotifera, which was the most speciose, was dominated by Lecanidae with 12 species followed by Brachionidae with 6 species. Other families represented were Euchlanidae, Filinidae and Mytilinidae. The list of rotifers may, however, not be complete considering the mesh size of the net used. Because of the turbidity use of smaller mesh size had the risk of clogging. During the study period, zooplankton was dominated by euplanktonic organisms. However, littoral and periphytic rotifers (*Lecane* spp and *Mytilina ventralis*) and cladoceran species (*Macrothrix spinosa*, *Alona* spp and *Chydorus* sp) occurred in the lake pelagial in low numbers. The latter were common in the qualitative samples from the swampy areas in the southern and eastern parts of the lake.

Table 2: List of zooplankton species recorded in Lake Baringo between April 2008 and November 2009

Copepoda	Cladocera	Rotifera
Cyclopoida	Daphnidae	Brachionidae
Cyclopidae	<i>Ceriodaphnia cornuta</i>	<i>Brachionus angularis</i>
<i>Thermocyclops consimilis</i>	<i>Daphnia barbata</i>	<i>B. calyciflorus</i>
Calanoida	Sididae	<i>B. falcatus</i>
Diaptomidae	<i>Diaphanosoma excisum</i>	<i>B. patulus</i>

<i>Thermodiaptomus galebi</i>	Moinidae <i>Moina micrura</i>	<i>Keratella tropica</i> <i>Platytias quadricornis</i>
	Macrothricidae <i>Macrothrix spinosa</i>	Euchlanidae <i>Euchlanis meneta</i>
	Chydoridae <i>Alona sp</i> <i>Alona sp</i> <i>Chydorus sp</i>	Filinidae <i>Filinia opoliensis</i>
		Lecanidae <i>Lecane aspasia</i> <i>L. curvicornis</i> <i>L. lateralis</i> <i>L. leontina</i> <i>L. ludwigii</i> <i>L. luna (Monostyla?)</i> <i>L. mira</i> <i>L. unguitata</i> <i>Lecane spp (4)</i>
		Mytilinidae <i>Mytilina ventralis</i>

Copepoda dominated zooplankton in abundance in all the study sites and throughout the study period. Among the sampling stations the group formed 60-72% of the total zooplankton (Figure 3a) while in the sampling period this proportion was 44-87% (Figure 3b). Copepods were in turn dominated by the juvenile stages, nauplii, with a minimum and maximum proportion of 37.3 and 90.4% in August 2008 and September 2009, respectively. The proportion of Calanoida decreased from 7.4% in April 2008 to 0.04% in October 2008 after which none was recorded in the samples.

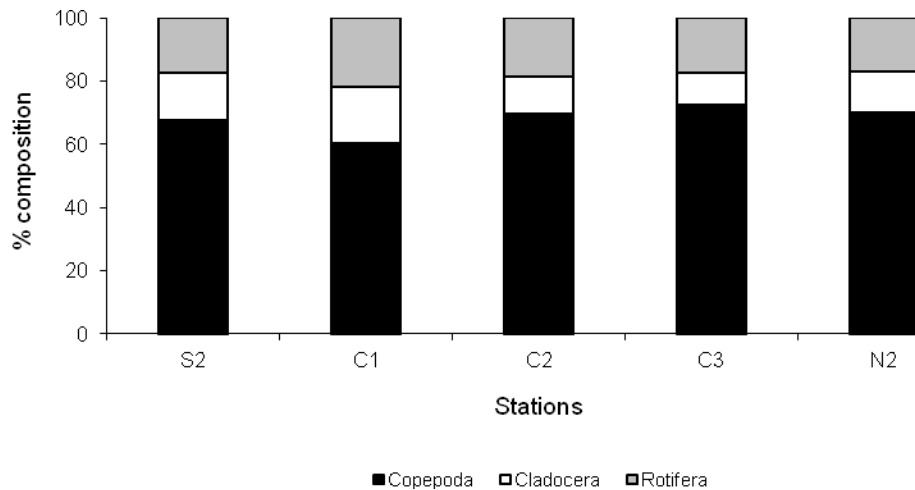


Figure 3a: Percentage composition of the major zooplankton groups at stations sampled

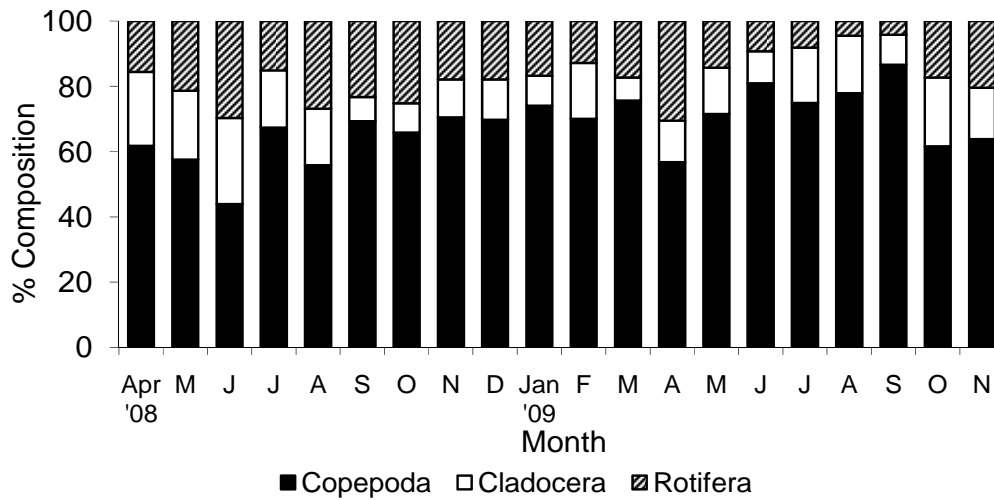


Figure 3b: Percentage composition of the major groups of zooplankton in Lake Baringo during the study period

Cladocerans were dominated by *D. excisum* which appeared in all samples throughout the study period. The species dominated in 80% of the sampling period with a dominance ratio of between 26 and 96% in the months of November 2008 and August 2009, respectively (Figure 4). Other common species included *M. micrura*, *C. cornuta*, *D. barbata* and *M. spinosa*.

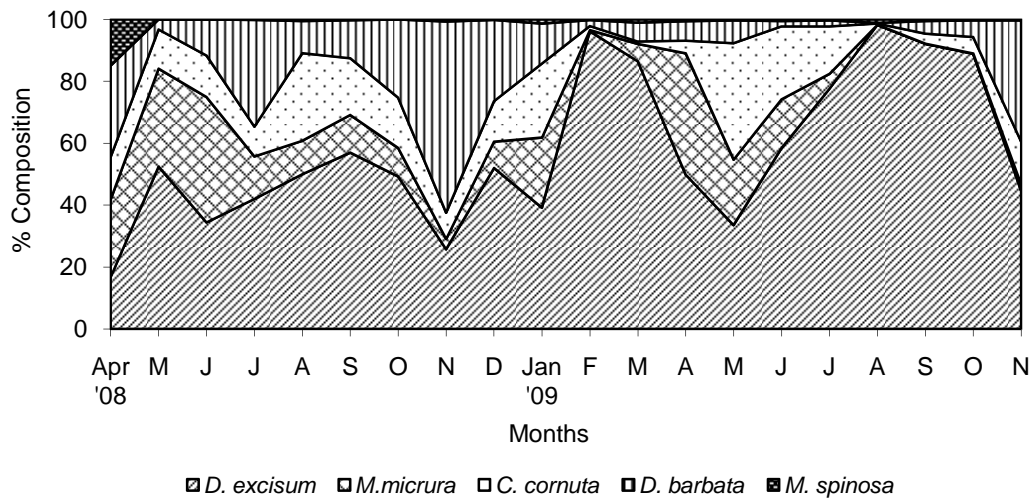
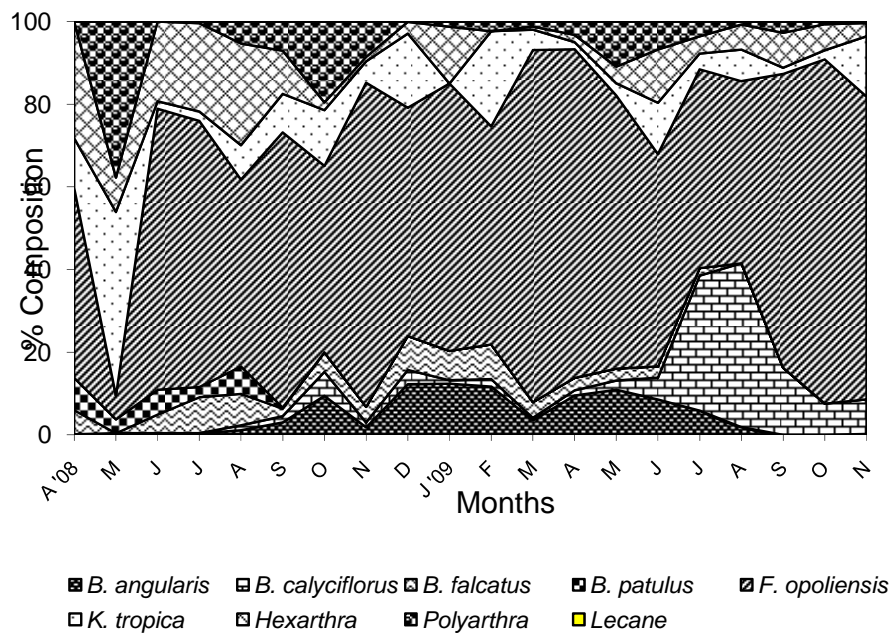


Figure 4: Percentage composition of different Cladocera species in Lake Baringo between April 2008 and November 2009

Rotifera were dominated by *F. opoliensis* and *K. tropica*. The former dominated in all the months sampled, with a dominance ratio of between 6 and 85%, except in May 2008 when the latter dominated. Other species recorded included *B. angularis*, *B. calyciflorus*, *B. falcatus*, *B. patulus*, *Hexarthra* sp and *Polyarthra* sp (Figure 5). Proportion of *F. opoliensis* was highest (85%) in March 2009 followed by 83% in the month of October 2009. The species, however, had the lowest relative composition of 6% in May 2008 when *K. tropica* had the highest proportion of 44%. *B. patulus* was observed between April and September 2008 after which the organism was absent in the samples.



Zooplankton Abundance and Diversity

Zooplankton abundance ranged from 17 individuals Γ^{-1} at station C2 in December 2008 to 163 individuals Γ^{-1} at N2 in November 2009 over the period of study. Among sampling sites C3 had the highest mean abundance (79.1 ± 8.0 individuals Γ^{-1}) and the lowest abundance was recorded at C1 (56.4 ± 6.6 individuals Γ^{-1}) (Figure 6a). The mean zooplankton abundance per station varied from 27.46 ± 4.16 individuals Γ^{-1} to 120.13 ± 17.50 individuals Γ^{-1} in December 2008 and November 2009 respectively (Figure 6b).

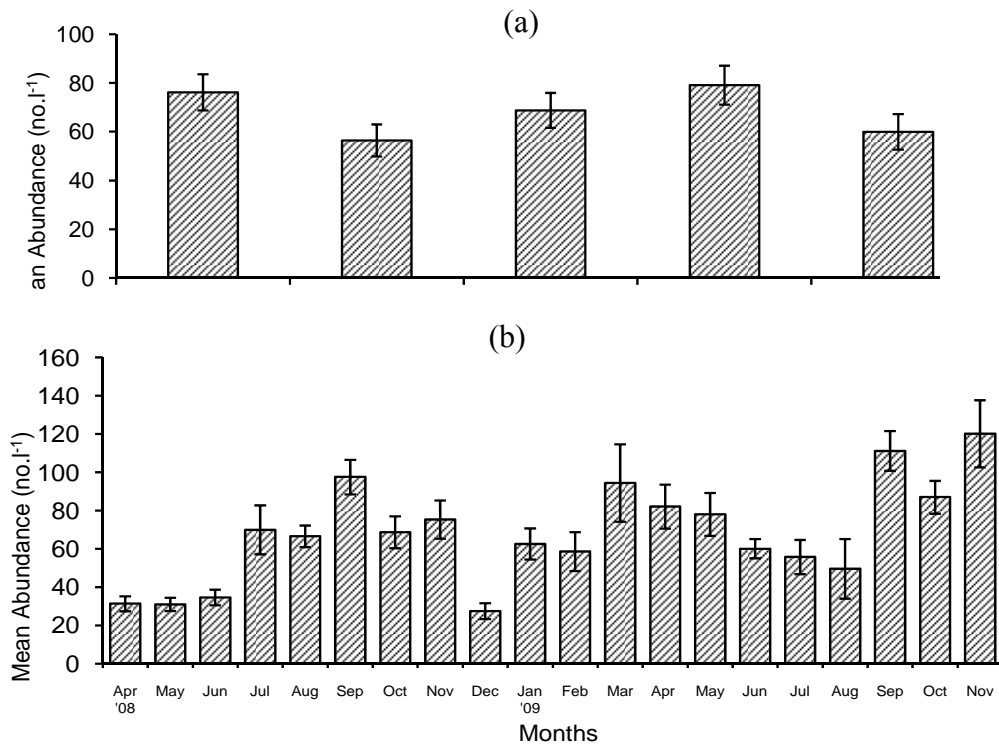


Figure 6: Mean abundance (\pm SE) of zooplankton in the stations sampled (a) in the different months (b)

Two-way analysis of variance on log (x+1) transformed abundance data revealed that there was significant difference among the sampling months ($P < 0.001$), and between the sampling stations ($P < 0.001$). Further analyses using Duncan's multiple range test grouped similar stations and months with respect to densities. Stations C2 and N2 ($P = 0.472$) and S2 and C3 ($P = 0.472$) formed the two group of stations while several groups of months were also formed.

Lake depth was negatively correlated with all zooplankton species except *D. barbata* ($r = 0.20$) and *M. micrura* ($r = 0.14$) (Table 3). Turbidity was positively correlated to all the zooplankton except *D. barbata* and *B. patulus*. Conductivity was positively correlated with all the organisms except *M. micrura*, *D. barbata*, *B. calyciflorus* and *B. patulus* while Chlorophyll *a* was only negatively correlated to *D. barbata* and *B. patulus*.

Table 3: Pearson's correlation coefficients (r) between some abiotic and biotic factors

	Cop	De	Mm	Cc	Db	Ba	Bc	Bf	Bp	Fo	Kt	Dep	Turb	Cond	DO	Chl a
Cop	1															
De	0.37	1														
Mm	0.21	0.92	1													
Cc	0.85	0.66	0.44	1												
Db	-0.75	-0.03	0.00	-0.31	1											
Ba	0.88	0.71	0.54	0.99	-0.41	1										
Bc	0.09	0.84	0.72	0.30	-0.05	0.36	1									
Bf	0.58	0.23	0.06	0.29	-0.85	0.36	0.45	1								
Bp	-0.54	-0.49	-0.69	-0.44	0.44	-0.57	-0.12	-0.11	1							
Fo	0.62	0.41	0.34	0.82	0.01	0.79	-0.13	-0.25	-0.52	1						
Kt	0.57	0.93	0.74	0.79	-0.24	0.82	0.82	0.47	-0.36	0.41	1					
Dep	-0.65	-0.22	0.14	-0.78	0.20	-0.67	-0.07	-0.30	-0.19	-0.5	-0.50	1				
Turb	0.95	0.37	0.13	0.92	-0.58	0.90	0.10	0.50	-0.33	0.67	0.62	-0.85	1			
Cond	0.94	0.09	-0.10	0.76	-0.69	0.75	-0.18	0.48	-0.32	0.60	0.35	-0.75	0.95	1		
DO	-0.63	-0.82	-0.55	-0.81	0.30	-0.82	-0.76	-0.57	0.20	-0.37	-0.97	0.66	-0.71	-0.46	1	
Chl a	0.98	0.54	0.39	0.91	-0.66	0.95	0.22	0.53	-0.61	0.68	0.70	-0.64	0.94	0.88	-0.72	1

(Cop: Copepods, De: *D. excisum*, Mm: *M. micrura*, Cc: *C. cornuta*, Db: *D. barbata*, Ba: *B. angularis*, Bc: *b. calyciflorus*, Bf: *B. falcatus*, Bp: *B. patulus*, Fo: *F. opoliensis*, Kt: *K. tropica*, Dep: depth, Turb: turbidity, Cond: conductivity, DO; dissolved oxygen).

Mean zooplankton diversity was found, in some instances, to be inversely related to zooplankton abundance. Mean (\pm SE) zooplankton diversity was highest at C1 followed by N2 (Figure 7a) while temporally this was highest in June 2008 and lowest in September 2009 (Figure 7b). Diversity decreased steadily from April 2008 to March 2009 after which there was an increase in April 2009 followed with another constant decline to September then a rise to November.

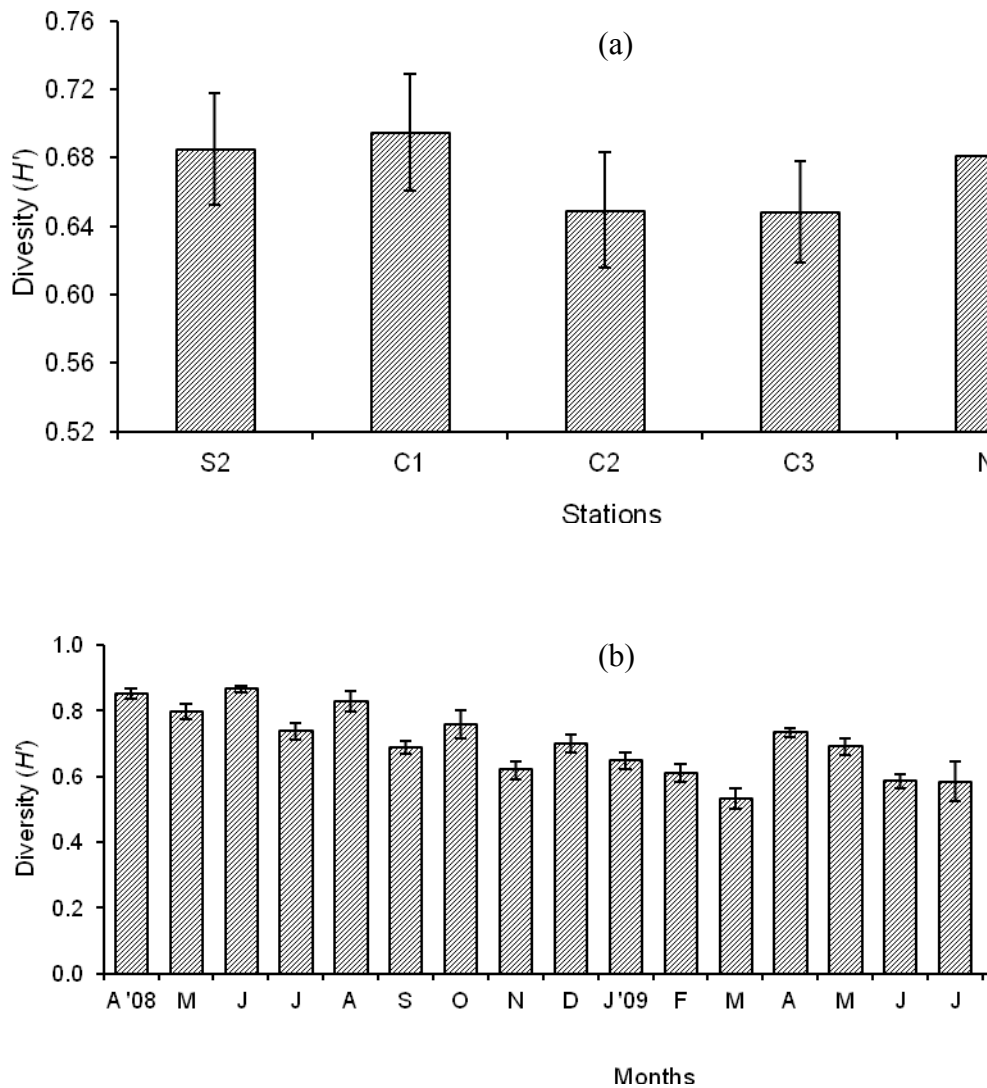


Figure 7: Mean zooplankton diversity by station (a) and by month (b)

Discussion

The high water temperatures recorded in the study were mainly due to the high intensity of solar radiation the lake being situated in an arid area. The difference in temperatures at different stations was due to the different times of sampling with stations sampled early in the morning recording lower temperatures. Besides the belief that there is an underwater outlet in the

northern part of the lake, the steady decrease of depth at the rate of 12 cm per month between May and November 2009 could also be attributed to the high temperatures which led to loss of lake water through evaporation. With increased evaporation of water from the lake, the decrease in water transparency was expected due to increased concentration of insoluble particles. The same reason could be given to the steady increase in conductivity. The frequent peaks of nutrients were probably caused by their flushing into the lake after rains in the catchment.

The high turbidity recorded in the lake had also been recorded by other investigators (Wahlberg *et al.*, 2003) and was attributed to the resuspension of the sediment by wind action (Oduor, 2000). The active resuspension of bottom sediments into the water column is a common feature of shallow lakes which may have negative or positive impact on distribution and abundance of zooplankton (Ghidini *et al.*, 2009). The suspended solids in turn influence the Secchi depth, euphotic zone and light attenuation coefficient. Brown-water lakes have some physical and chemical features different from those of clear water lakes, which can affect the growth and distribution of plankton organisms. The latter absorbs solar radiation and results in a steep thermal stratification and high thermal stability, in particular in small and sheltered lakes, and an increased extinction of light (Eloranta, 1999). Turbidity indirectly affects the level of dissolved oxygen by limiting photosynthesis by reducing light penetration in water.

Zooplankton community of Lake Baringo was characterized by both planktonic and macrophytic-loving species with fairly low species richness, especially for Copepoda. The highest species diversity was recorded at C1, a station adjacent to a shelter bay, with least influence of the rivers and wind. Tiwari & Vijayalakshimi (1993) attributed high diversity to calmer and more stable waters. The low species richness of copepoda has also been reported in the Ethiopian Rift Valley Lakes Abiata and Langano (Wodajo & Belay 1984) and Kivu (Sarmiento *et al.* 2009). The low abundance and diversity found in this study might be explained by the unfavourable conditions such as the low penetration of light due to high turbidity of water and presence of planktivorous fish species. Higher abundances and species richness in shallow lakes than in the larger African Great lakes pelagic environments had earlier been reported by Lehman (1996). Green (1967) showed that rotifers are more species rich and abundant in the lake littoral regions than in the open waters which is corroborated by results of our studies where most of the rotifer species, especially *Lecane* spp, were realized in the qualitative samples from the littoral swampy areas. Besides their small size which them difficult to locate by predators, their life history

characteristics of parthenogenesis and eutely results in short maturation times and rapid rates of population growth under suitable conditions (Bennett & Borass, 1989).

The occurrence of macrophytic species may be attributed to the presence of swamps in the southern and eastern parts of the lake. Occurrences of such species have previously been associated with algal blooms in Lake Turkana (Ferguson 1982). Gehrs (1974) had earlier also observed that horizontal distribution of the animals may be influenced by aquatic macrophytes. The latter have been reported to affect the distribution and abundance of zooplankton by providing refugia and food (Carpenter & Lodge, 1986; Cronin *et al.*, 2006).

The dominance of cyclopoids in the lake in this study corroborates the findings of earlier investigations in African lakes (Mavuti & Litterick, 1991, Ndawula, 1994). Drenner *et al.* (1978) attributed the dominance of cyclopoid copepods in turbid habitats to their efficiency at escaping from fish predators. In the present study, while nauplii and cyclopoids were recorded throughout the sampling period, no calanoids were recorded after September 2008 a phenomenon which we attributed to the increasing conductivity. Conductivity was negatively correlated to Calanoida ($r = -0.251$) and *B. patulus* ($r = -0.320$).

In the present study, *D. barbata* was found to be strongly correlated to turbidity ($r = 0.634$). Hart (1992) described the species as a typical turbid water species. The occurrence of the large bodied *D. barbata* in Lake Baringo where several species of fish occur is probably because of the high turbidity. This has also been reported in the turbid Lake Chilwa in Malawi where the cladoceran dominated the zooplankton community despite the high densities of cichlid fishes (Kalk, 1979). Geddes (1984) also reported that fish predators in turbid habitats may be non-selective thus allowing the persistence of large zooplankton species.

The two stations, S2 and C3, which had the highest zooplankton densities, were at the vicinity of river/ stream mouths confirming earlier reports of increases of abundance in such habitats in other water bodies (Green, 1971; Gophen, 1972). The inflowing water brings into the lake particulate organic matter and nutrients. Peak zooplankton densities in our study coincided with those of nutrients and Chl *a*, findings supported by the positive correlation between Chl *a* and density of most zooplankton species. These increase may be due to greater availability of food in form of phytoplankton in the lake due to increase of nutrients brought in from inflowing river waters. Green

(1971) also attributed peak zooplankton abundance during rains to the nutrient influx thus increase in phytoplankton production.

Recommendation

Considering the possible effects of frequent resuspension of sediments and high turbidity on some zooplankton taxa, care should be taken to protect Lake Baringo from catchment nutrient loads as this could easily lead to rapid eutrophication and consequent ecological problems.

Acknowledgements

We would like to thank the mercantile and technical personnel at Kenya Marine and Fisheries Research Institute for field and laboratory assistance. We are also indebted to National Council Science and Technology for providing financial support.

References

- Abdel-Aziz, N.E. and Gharib, S.M. (2006). The interaction between phytoplankton and zooplankton in a lake- Sea connection, Alexandria, Egypt. *International Journal of Oceans and Oceanography* 1: 151- 165.
- Angino E.A, Armitage, K.B. and Saxera, B. (1973). Population dynamics of pond zooplankton II *Daphnia ambigua* Scourfield. *Hydrobiologia* 42: 491-507.
- APHA (1995). Standard methods for the examination of water and waste water. American Public Health Association, Washington, 1524p.
- Behn, P.M and Boumans, R.M. (2001). “Modelling herbivorous consumer consumption in the Great Bay Estuary, New Hampshire”. *Ecological Modelling* 143: 71-94.
- Bennett, W.N and Borass, M.E. (1989). A demographic profile of the fastest growing metazoan: a strain of *Brachionus calyciflorus* (Rotifera). *Oikos* 55: 365-369.
- Canfield T.J. and Jones, J.R. (1996). Zooplankton abundance, biomass, and size-distribution in selected midwestern waterbodies and relation with trophic state. *Journal of Freshwater Ecology* 11:171-181.
- Carpenter, S.R and Lodge, D.M (1986). Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany* 26: 341-370.

- Cronin, G, Lewis Jr W. M. and Schiehsler, A. (2006). Influence of freshwater macrophytes on the littoral ecosystem structure and function of a young Colorado reservoir. *Aquatic Botany* 85: 37-45.
- Drenner, R.W, Strickler, R. and O'Brien, W. J. (1978). Capture probability: the role of zooplankton escape probability in selective feeding of zooplanktivorous fish. *Journal of the Fisheries Research Board of Canada* 35: 1370-1373.
- Eloranta, P. (1999). Humus and water physics. *In* J. Keskitalo and P. Eloranta (eds), *Limnology of humic waters*. Backhuys Publishers, Leiden, The Netherlands, pp. 59-74.
- Ferguson, A.J.D. (1982). Studies on the zooplankton of Lake Turkana. *In* Hopson A. J (ed) p 163-245. A report on the findings of the Lake Turkana project 1972-75. pp 1614.
- Gannon, E.J. and Stemberger, S. (1978). Zooplankton as indicators of water quality. *American Microstructure Society* 97(1): 16-25.
- Gardner, M.B. (1981). Effects of turbidity on feeding rates and selectivity of bluegills. *Transactions of the American Fisheries Society* 110: 446-450.
- Geddes, M.C. (1984). Seasonal studies on the zooplankton community of Lake Alexandrina, River Murray, South Australia and the role of turbidity in determining zooplankton community structure. *Australian Journal of Marine and Freshwater Research* 35: 417-26.
- Gehrs, C.W. (1974). Horizontal distribution and abundance of *Diaptomus clavipes* Schacht in relation to *Potamogeton foliosus* in a pond and under experimental conditions. *Limnology and Oceanography* 19: 100-104.
- Ghidini, A.R, Serafim-Jr, M., Neves, G.P. and de Brito, L. (2009). Distribution of planktonic cladocerans (Crustacea: Branchiopoda) of a shallow eutrophic reservoir (Parana state, Brazil). *Pan- American Journal of Aquatic Sciences* 4: 294-305.
- Gophen M. (1972) Zooplankton distribution in Lake Kinneret (Israel), 1969-1970. *Israel Journal of Zoology* 21: 17-27.
- Green, J. (1967). Associations of Rotifera in the zooplankton of the lake sources of the white Nile. *Journal of Zoological Society, London* 151: 343-378.
- Green, J. (1971). Associations of Cladocera in the Zooplankton of the Lake Sources of the White Nile. *Journal of Zoological Society* 165: 373-414.

- Hart, R.C. (1992). Experimental studies of food and suspended sediment effects on growth and reproduction of six planktonic cladocerans. *Journal of Plankton Research* 14: 1425-1448.
- Hoxmeier, R.J.H and Wahl, D.H. (2004). Growth and survival of larval Walleyes in response to prey availability. *Transactions of the American Fisheries Society* 133:45–54.
- Jeppesen, E., Sondergaard, M., Mazzeo, N., Meeroff, Branco, M., Huszar, C. V. and Scasso, F. (2005). Lake restoration and biomanipulation in temperate lakes: relevance for subtropical and tropical lakes. In Reddy M. V. (Ed), *Restoration and management of tropical eutrophic lakes*. Science Publishers.
- Kalk, M (1979). Zooplankton in quasi-stable phase of an endorheic lake (Lake Chilwa, Malawi). *Hydrobiologia* 66: 7-15.
- Korovchinsky N. M (1992). Sididae and Holopidae (Crustacea: Daphniformes). *Guides to the identification of the Microinvertebrates of the continental waters of the world*. 3, SPB. The Hague, 82pp.
- Koste W (1978). *Rotatoria: Die Radertiere Mitteleuropas*. 2 Auflage neubearbeitet von. Gebruder Borntraeger, Berlin. Stuttgart. 234p.
- Koste W & R. J Shiel (1987). Rotifera from Australia Inland waters. II. Epiphinidae and Brachionidae (Rotifera: Monogononta) *Aust. J. Mar. Freshw. Res.* 37: 765-92.
- Lehman, J.T. (1996). Pelagic food webs of the East African Great Lakes, pp 281-301. in T. C Johnson and E. O. Odada (eds), *The Limnology, Climatology and Paleoclimatology of the East African Lakes*, Gordon and Breach. Toronto.
- Margaleff, R. (1983). *Limnologia*. Omega, Barcelona. 1010p.
- Mavuti, K.M. and Litterick, M.R. (1991). Composition, distribution and ecological role of zooplankton community in Lake Victoria, Kenya waters. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 24:1117-1122.
- Ndawula, L.M (1994). Changes in relative abundance of Zooplankton in northern Lake Victoria, East Africa. *Hydrobiologia* 272: 259-264.
- Neves, I.F., Rocha, O., Roche, K.F. and Pinto, A.A. (2003). Zooplankton community structure of two marginal lakes of the River Cuiaba (Mato Grosso, Brazil) with analysis of Rotifera and Cladocera diversity. *Brazilian Journal of Biology* 63: 329- 343.

- Oduor, S.O. (2000). Physico-chemical Dynamics, Pelagial Primary Production and Algal Composition in Lake Baringo, Kenya. MSc. Thesis, IHE, Deft, Austria. 83pp.
- Ogari, J. and Dadzie, S. (1988). The food of the Nile perch *Lates niloticus* after the disappearance of the haplochromine cichlids in the Nyanza Gulf of Lake Victoria. *Journal of Fisheries Biology* 32: 571-7.
- Pace, M.L., Cole, J.J. and Carpenter, S.R. (1998). Trophic cascades and compensation: differential responses of microzooplankton in whole-lake experiments. *Ecology* 79: 138-152.
- Sarmiento, H., Isumbisho, M., Stenuite, S., Darchambeau, F., Leporcq, B. and Descy, J.P (2009). Phytoplankton ecology of Lake Kivu (eastern Africa): biomass, production and elemental ratios. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 30: 709-713.
- Segers, H. (1995). Rotifera: The Lecanidae (Monogononta). Guides to the Identification of the Microinvertebrates of the Continental Waters of the World. SPB Academic Publishing bv. The Netherlands, 226 pp.
- Shannon, C.E and Weiner, W. (1963). The mathematical theory of communication. University of Illinois Press, Urbana, 117pp.
- Smirnov N. N. (1996). Cladocera: Chydorinae and Sycinniae (Chydoridae) of the world. Guides to the Identification of the Microinvertebrates of the Continental waters of the World. SPB Academic Publishing bv, The Netherlands, 197pp.
- Sprules, W.G., Munawar, M. and Jin, E.H. (1988). Plankton community structure and size spectra in the Georgian Bay and North Channel ecosystems. *Hydrobiologia* 163:135-140.
- Tiwari, R.L and Vijayalakshmi, R.N. (1993). Zooplankton composition in Dharamtar creek adjoining Bombay harbour. *Indian Journal of Marine Sciences* 22:63-69.
- Wahlberg, H.T., Harper, D. and Wahlberg, N.T. (2003). A first limnological description of Lake Kichiritith, Kenya: a possible reference site for the freshwater lakes of the Gregory Rift Valley. *South African Journal of Science* 99: 494-496.
- Wetzel, R.G. (1990). Land-water interfaces metabolic and limnological regulators. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie* 24: 6-24.

- Wetzel, R.G. and Likens, G.E. (1990). *Limnological Analyses*. Springer-Verlag, New York. 391p.
- Wodajo, A. and Belay, A. (1984). Species composition and seasonal abundance of zooplankton in two Ethiopian Rift Valley lakes- Lakes Abiata and Langano. *Hydrobiologia* 113: 129-136.