# Chapter 5
# Biodiversity Indicators: Plankton and Macroinvertebrates in Lake Victoria, Selected Satellite Lakes and Rivers

**Yunus D. Mgaya, S.M. Limbu, C.V. Lugomela, I.A. Kimirei, R.J. Kayanda, and G.W. Ngupula**

**Abstract** Plankton and macroinvertebrates are used as biodiversity indicators on account of their sensitivity to changes in aquatic ecosystems. This chapter assesses the changes in the diversity, abundance and distribution of plankton and macroinvertebrates in the inshore and offshore areas of Lake Victoria, selected satellite lakes and rivers within the lake basin. Samples for both plankton and macroinvertebrates were collected during dry and wet seasons between 2000 and 2006. The results indicated that cyanobacteria were most diverse in both seasons. *Microcystis* spp., *Planktolyngbya* spp. and *Anabaena* spp. were the most dominant cyanophyte species at the sampled sites. The dominant phytoplankton (cyanobacteria) are less digestible and provide poor quality food for the fish; that may have contributed to the reduction or loss of planktivorous haplochromines and tilapiines that once flourished in Lake Victoria. Zooplankton community composition in the lake is dominated by rotifers and cyclopoid copepods, in both inshore and offshore areas. The dominance of cyclopoid copepods is important in the production and sustainability of small fishes and larvae that utilize these organisms as a food base. Macroinvertebrate abundance has shifted from an oligochaete and insect dominated community in 1984 to a community dominated by molluscs. The occurrence of a relatively high

This chapter is dedicated to Ms. Revania K. Waya, a researcher at TAFIRI, Sota Station, Shirati, who passed away on 25th December 2011.

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abundance of low-oxygen tolerant macroinvertebrate taxa at inshore and offshore stations is an indication of deteriorating water quality water quality conditions due to eutrophication and pollution processes. There is a need for a reduction in nutrient loads and pollutant inputs into the lake in order to ensure the ecosystem health.

## 5.1 Introduction

Lake Victoria, the second largest lake in the world, and its basin comprise an enormous area of permanent and seasonal freshwaters, including marshes, swamps, floodplains and river systems. All these habitats are characterized by a high diversity of flora and fauna. These water bodies are important reservoirs abound with biodiversity similar to that of Lake Victoria. In the recent history of Lake Victoria, the plankton community has shown some remarkable changes in composition. The first comprehensive studies, which were carried out during the 1950s and 1960s, reported a predominance of large diatoms, particularly from the genera *Melosira* spp. (now called *Aulacoseira* spp.), *Stephanodiscus* spp. and *Nitzschia* spp. (Talling 1966). Cyanobacteria on the other hand, dominated the epilimnion during thermal stratification, while *Ceratium brachycerus* (a dinoflagellate) showed erratic variation. Studies from Verschuren et al. (2002) on changes in the pelagic diatom flora of Lake Victoria over the past 60 years revealed that the lake was stable between 1820 and 1940, with *Cyclostephanos* spp. and *Aulacoseira* spp. making a large proportion of diatoms (80% and 15%, respectively) and *Nitzschia acicularis* absent or too rare to be preserved. The abundance of *Nitzschia acicularis* started to increase between 1940 and early 1960 eventually reaching about 94% of the total diatom abundance.

Apart from the main lake, Lake Victoria basin is endowed with several satellite lakes and rivers, which support livelihood of communities surrounding them. These water bodies are shallow and receive a lot of nutrients from effluents and run-off during rainy seasons, which favour the flourishing of cyanobacteria (Sekadende et al. 2005a). In addition, these satellite lakes and rivers constitute high diversity of zooplankton, mainly crustacean and rotifers (Waya and Chande 2004). The benthic fauna in satellite lakes is the same as that in Lake Victoria, but are characterized by very low species richness and abundance (Wakwabi et al. 2006). Both zooplankton and macroinvertebrates form an important basis of fish production in these waterbodies.

The plankton and macroinvertebrates of Lake Victoria, satellite lakes and rivers can provide useful information on the health of the environment because of their sensitivity to changes in characteristics of the aquatic ecosystems. Species composition with respect to lake habitats has been used as an indicator of environmental degradation. This chapter assesses the changes in the diversity, abundance and distribution of plankton and macroinvertebrates of the Lake Victoria basin, particularly in the inshore (from 0 m to 6 m depth) and offshore (more than 7 m deep) areas of the lake and selected satellite lakes and rivers.

## 5.2 Methods and Data Analysis

### *5.2.1 Study Area*

The plankton data used in this study were collected in the Tanzania part of Lake Victoria during bottom trawl surveys conducted between 2000 and 2006. In addition, data were also collected from selected satellite lakes and rivers within the Lake Victoria basin, which included Lakes Burigi, Ikimba, Katwe, Malimbe, Kubigena, Kirumi, Mara River and Kyarano dam (Fig. 5.1). Most of these lakes are found on the western side of Lake Victoria and are associated with the Kagera River basin system.

Data for macroinvertebrates were obtained from studies conducted in the three countries bordering the lake in order to obtain a holistic representation of the macroinvertebrate communities. Sampling on the diversity of molluscs in Lake Victoria and a satellite Lake Burigi was carried out from January to April 2002 and March to April 2002 (Mwambungu 2004). Data from Kenyan, Tanzanian and Ugandan waters were obtained on monthly basis from March 1994 to March 1995, except in December 1994 and February 1995 (Muli 2005) and from July to August 2008 in the Tanzanian waters, and from February to March and August to September 2008 in the Ugandan and Tanzanian waters of Lake Victoria.

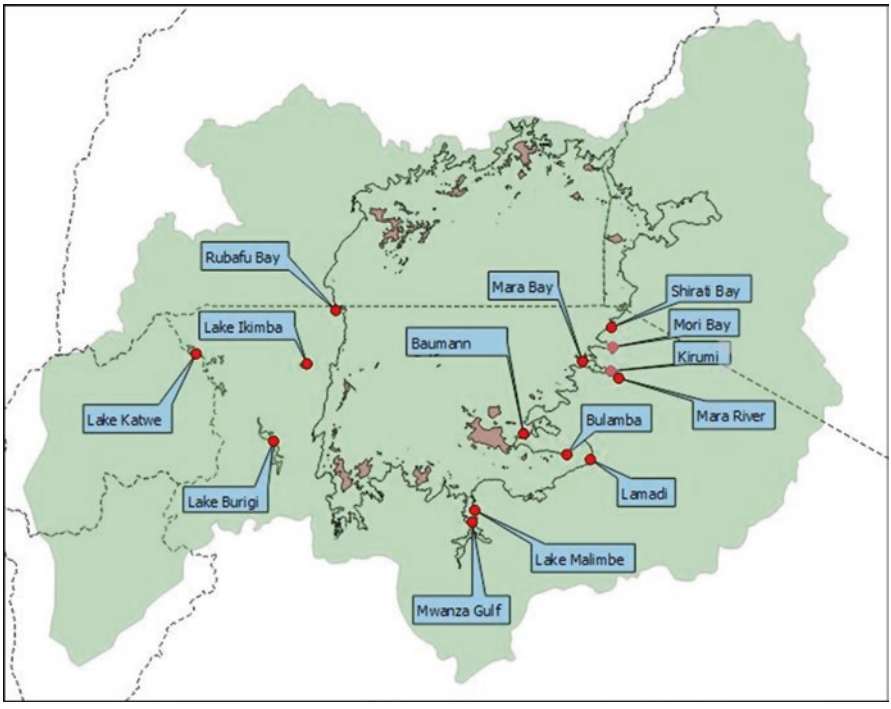



**Fig. 5.1** Map of Lake Victoria basin showing the study sites

### 5.2.2 Phytoplankton Composition and Abundance

Water samples for the analysis of phytoplankton species composition and abundance were collected in the offshore and inshore areas of Lake Victoria between 2000 and 2004 using a one-litre JT-1 Lamotte water sampler. A water sub-sample of 100 ml was preserved with Lugol's solution and formaldehyde (0.7% and 2.5% final concentrations, respectively) and transported to the laboratory at Sota Research Centre in Rorya District, Mara, for analysis. In the laboratory, samples for numerical abundance were allowed to settle for 48 hours to a final volume of 20 ml. This was homogenized by gently shaking the sample bottles by hand to obtain a uniform mixture. A final volume of two millilitres (2 ml) was analyzed for species composition using a Leica inverted microscope (model number 090–135.001) at 400× magnification. Identification of phytoplankton was done based on taxonomic keys by Van Meel (1954), Mosille (1984), and John et al. (2002). All specimens were distributed over at least two transects from the sedimentation chamber and counted. Phytoplankters were counted as numbers of filaments, colonies or cells, depending on the species. At least 10 fields were counted from each sample. The counts made from these samples were used for calculating percentage species composition. The phytoplankton numerical abundance was calculated according to Greenberg et al. (1992) using the formula:-

$$\text{Abundance} = \frac{C \times At \times v}{Af \times F \times V \times Vi}$$

where, C = number of organisms counted, At = total area of bottom of settling chamber ($mm^2$), Af = area of field ($mm^2$), F = number of fields counted, Vi = volume of the sedimented sample, V = volume of the sample observed (2 ml), v = volume of concentrated sample (20 ml).

### 5.2.3 Zooplankton Composition, Abundance and Biomass

The samples for zooplankton composition and abundance were collected between 2000 and 2005 surveys while those for zooplankton biomass were collected between March 2005 and March 2006. Triplicate zooplankton samples were collected by vertically hauling 65-$\mu$m mesh size plankton net (30 cm diameter and one m length) from one metre above the sediment surface. Samples were filtered through a 90-$\mu$m mesh plankton sieve (Sethi Standard Test Sieves, Ambala Cantt, India). They were preserved using 4% formaldehyde and transported in cool box to the laboratory at the Sota Research Centre in Rorya District, Mara. In the laboratory, samples were diluted and homogenized by gently shaking the sample bottles by hand. At least 10 ml of each homogenized sample was examined. The identification was done with taxonomic keys and manuals by Ruttner-Kolisko (1974), Korinek (1984), Maas

(1993) and Korovchinsky (1993) as deemed appropriate. Zooplankton species that were identified were counted under a light microscope (model number XSZ-10BN) at x 40 magnification. The data (no./sub-sample) were used to calculate the numbers of zooplankton per sample depending on the split factor and numbers per $m^2$ according to IFMP (2003–2008) using the formulae:–

$$\text{Abundance}\left(\text{no. sample}^{-1}\right) = \frac{\text{Dilution volume} \times \text{number in a subsample} \times \text{split factor}}{\text{Count volume}}$$

$$\text{Abundance}\left(\text{no. m}^{-2}\right) = \frac{\text{Number per sample}}{\text{Area of net mouth opening}}$$

for a net of 30-cm opening, area = 0.0855 $m^2$.

For biomass determination, copepod body length was measured from the top of the head to the tip of the furcal rami. Cladocera and rotifers were measured from the top of the head to the tip of the abdomen, excluding spines and other projections. The biomass (mg wet wt $m^{-2}$) was determined on the basis of the length-weight relationship (Herzig 1984) using the formula:

$$\text{Biomass}\left(mg\ wet\ wt\ \text{m}^{-2}\right) = \left[\frac{\left(4/3^{*}\ \pi\ \text{a}\ \text{b}^2\right)}{10^6}\right] * \text{Numerical abundance of taxa}$$

where $\pi = 3.14$, a = 0.5 length and b = 0.5 width.

This method is appropriate for zooplankton species in Lake Victoria because it had previously been applied by Waya and Chande (2004) in the same lake and was found acceptable.

### *5.2.4 Macroinvertebrates*

Sampling for macroinvertebrates was quantitatively done using an Ekman grab with a sampling area of 225 $cm^2$ (Muli 2005) and 384.16 $cm^2$ (Mwambungu 2004; Ngupula and Kayanda 2010). The duplicate grab samples collected at a site were combined to form one composite sample. Organisms were separated from sediment using a series of sieves of progressively finer mesh size (20, 2, 1 and 0.5 mm) (Muli 2005) and a net of 500 μm (Ngupula and Kayanda 2010). In the field, specimens were fixed using 10% and 4% formalin (Muli 2005; Ngupula and Kayanda 2010) respectively, and taken to the laboratory for analysis. Mollusca were first anaesthetized using menthol crystals (Muli 2005). In the laboratory, and samples were rinsed with water to remove the formalin and sorted to the lowest taxonomic groups

possible, using identification keys by Mandahl-Barth (1958, 1973, 1988) and Brown (1994). The different individuals were then counted and average numbers of organisms per $m^2$ per station computed. All specimens were preserved in alcohol (70%) for later identification (Muli 2005; Ngupula and Kayanda 2010).

### *5.2.5 Data Analysis*

Data obtained were entered into MS Excel for calculations of abundance and diversity. Zooplankton biomass was analyzed using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test for specific differences. The Shannon-Weaver Diversity Index (H′) (Shannon and Weaver 1949) was used to calculate species diversity. The Mann-Whitney (U′) test was used to compare Shannon-Weaver Diversity Indices between seasons. The Quasi-likelihood method was used to test significant differences from different sites; in all cases the level of significance was set at $p < 0.05$.

## 5.3 Results

### *5.3.1 Phytoplankton*

#### Offshore Areas

A total of 133 phytoplankton species belonging to 52 different genera were identified in the offshore areas of Lake Victoria during the January to February 2000, December 2000, and July to August 2002 samplings (Table 5.1). A total of 96 and 37 species were recorded in the January to February 2000 and the July to August 2002 sampling sessions, respectively. The cyanobacteria were most diverse in both seasons. The Shannon-Weaver Diversity Index (H′) was high in January to February 2000 ($H' = 0.149$) compared to July to August 2002 ($H' = 0.209$) (Table 5.1). However, the difference was not statistically significant ($U' = 21.0$; $p = 0.095$). The three dominant taxa were Cyanophyta, Chlorophyta and Bacillariophyta while Dinophyta and Euglenophyta were rarely observed.

In the December 2000 sampling, a total of 82 different species belonging to 39 genera were identified, while 16 species were not identified. Common phytoplankton phyla encountered included Cyanophyta, Chlorophyta, Bacillariophyta and Dinophyta. The overall results of species richness show that the phylum Chlorophyta had the highest number of species with a total of 31 species while dinophytes were the least in richness (4 species).

In the January to February 2000 sampling, the abundance of phytoplankton varied from a minimum of 77 to a maximum of 2,450 cells/ml, while in the July to August 2002 sampling, higher numbers were recorded, which ranged from 276 to

**Table 5.1** The number of algal species from each algal phylum encountered and unidentified individuals (others) in the five surveyed zones of Lake Victoria – Tanzania

| Phyla | Mwanza gulf | Speke gulf | Mara zone | Kagera zone | Emin Pasha gulf |
|---|---|---|---|---|---|
| **Rainy season (January to February 2000)** | | | | | |
| Cyanophyta | 15 | 24 | 40 | 15 | 18 |
| Bacillariophyta | 7 | 10 | 16 | 12 | 5 |
| Chlorophyta | 15 | 12 | 26 | 11 | 11 |
| Dinophyta | 0 | 0 | 4 | 0 | 0 |
| Euglenophyta | 4 | 0 | 0 | 1 | 0 |
| Others (unidentified) | 9 | 13 | 22 | 15 | 10 |
| TOTAL | 50 | 59 | 108 | 54 | 44 |
| $H'$ | 0.1802 | 0.149 | 0.1 | 0.134 | 0.18 |
| **Dry season (July to August 2002)** | | | | | |
| Cyanophyta | 6 | 11 | 10 | 5 | – |
| Bacillariophyta | 4 | 8 | 6 | 4 | – |
| Chlorophyta | 4 | 4 | 10 | 5 | – |
| TOTAL | 14 | 23 | 26 | 14 | – |
| $H'$ | 0.252 | 0.154 | 0.209 | 0.223 | – |

$H'$ = Shannon-Weaver Diversity Index

5,190 cells/ml. Cyanobacteria dominated the three commonly encountered phyla in almost all stations during both sampling periods (Table 5.1). The total abundance of phytoplankton species was significantly higher ($U' = 315$; $p = 0.009$) during July to August 2002 than the January to February 2000 sampling. Cyanobacteria *Microcystis* spp., *Planktolyngbya* spp. and *Anabaena* spp. were the most dominant cyanophyte species throughout the lake. The diatoms were dominated by *Nitzschia acicularis*.

In the December 2000 sampling, the abundance of phytoplankton at different depths from the offshore stations are presented in Fig. 5.2a–d. There was no discernible pattern in the vertical distribution of phytoplankton. However, cyanobacteria and diatoms were prominent at all depths. The vertical distribution (to 20 m depth) of phytoplankton was assessed at deep stations (Bulamba, Mori, Mwanza and Shirati Bays) only during the January to February 2000 sampling. In general, there were no significant differences in phytoplankton abundance at different depths at these stations.

## Inshore Areas

A total of 141 species of phytoplankton belonging to six phyla were identified in inshore areas of Lake Victoria during the period from 2000 to 2004. Results for phytoplankton abundance for each station are presented in Fig. 5.3a–d. In the surface waters, Cyanophyta was generally the most abundant phylum. A total of 37 species belonging to 30 different genera were identified from the sampled stations. Among the five phytoplankton phyla found, Cyanophyta had the highest percentage

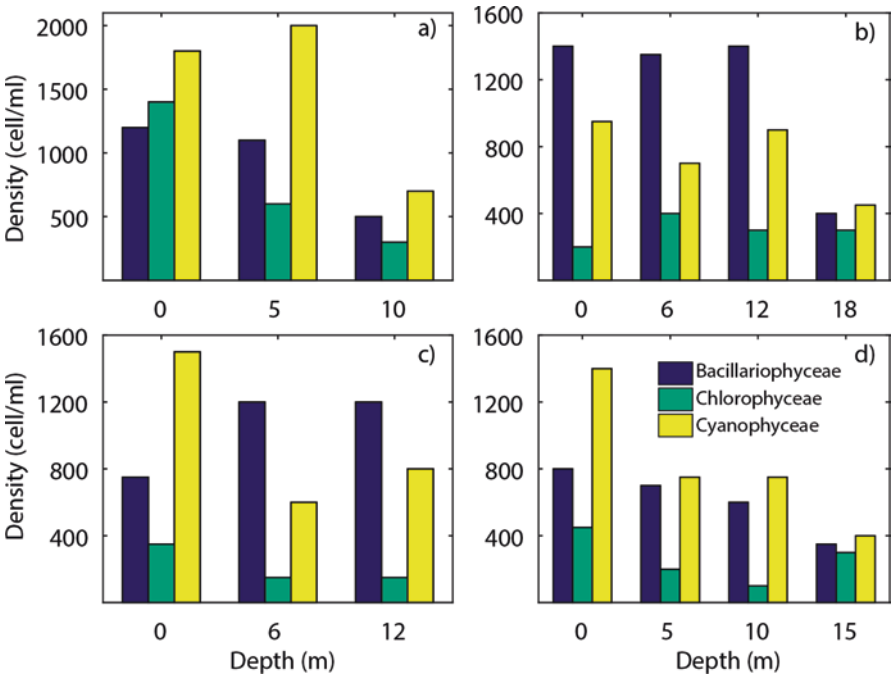



**Fig. 5.2** (**a–d**) Numerical abundance and vertical distribution of common groups of phytoplankton in different offshore stations of the Lake Victoria basin (Tanzania, December 2002). *a = Bulamba; b = Mori Bay; c = Shirati Bay; d = Mwanza Gulf* (Data from TAFIRI Unpublished Reports)

composition (59%) in almost all the stations (Fig. 5.3a–d). The occurrence of *Aulacoseira* spp. in Mara Bay, Mori Bay and Lamadi stations (data not shown) was the most interesting realisation in this survey. However, *Romeria* spp., *Nitzschia acicularis* and *Microcystis flos-aquae* were the most abundant species throughout the sampled stations.

## Satellite Lakes and Rivers

During the August to September 2002 sampling, a total of 128 species belonging to 54 different genera were identified from phytoplankton samples collected from different satellite lakes of the Lake Victoria basin, which included Lake Burigi, Lake Ikimba, Lake Katwe, Lake Malimbe, Lake Kubigena, Lake Kirumi, Mara River and Kyarano dam. Results for phytoplankton abundance and vertical distribution are presented in Fig. 5.4a–h. The most abundant phytoplankton group in all lakes (except Kyarano dam) was Cyanophyceae. The phytoplankton abundance increased during the rainy season, but the increase was statistically comparable between the seasons ($U' = 17.0$; $p = 0.420$). The most abundant phytoplankton group during the

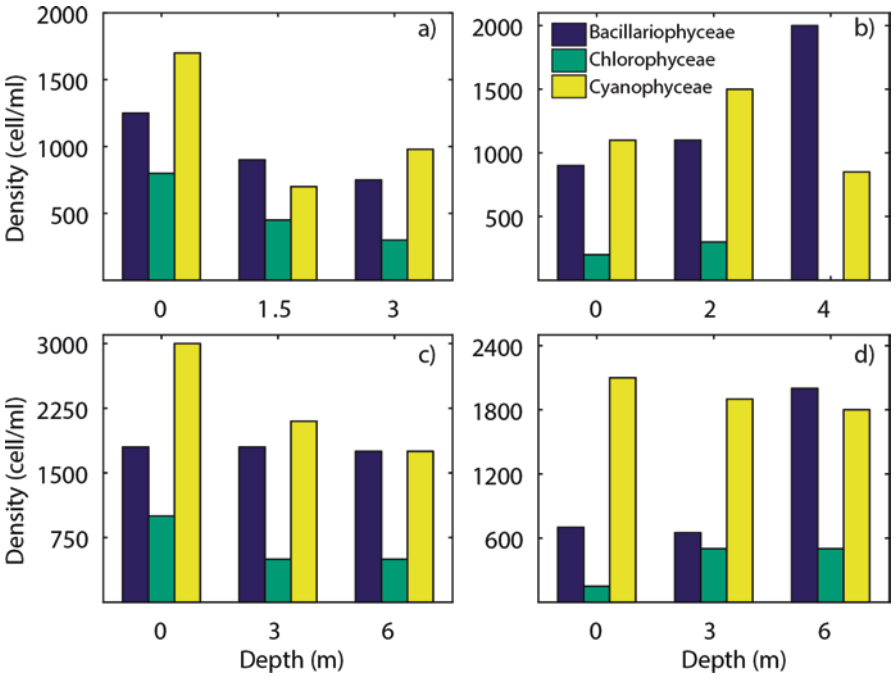



**Fig. 5.3** (**a–d**) Vertical distribution of common groups of phytoplankton in different inshore stations of Lake Victoria Basin (August to September 2002). *a = Bawmann Gulf; b = Mara Bay; c = Rubafu Bay; d = Lamadi.* (Data from TAFIRI Unpublished Reports)

dry season was Chlorophyta, which was dominated by *Pediastrum* spp. and *Scenedesmus* spp. The diatom *Aulacoseira* spp., which is now hardly found in the main lake, was abundant in all small water bodies during the dry season. In the rainy season, the Cyanophyta (mainly *Microcystis* spp. and *Planktolyngbya* spp.) was the most abundant group. However, a euglenophyte, *Trachelomonas* sp., was also fairly well represented. Chlorophyta was the most diverse group in both seasons and it was represented by a great number of species (70) followed by Bacillariophyta (19). There was no significant difference between the diversity indices in the two seasons ($U' = 15.0$; $p = 0.690$).

A higher numerical abundance of phytoplankton was observed in May 2004 sampling, when the abundance reached 2,885.77 cells/ml while in the October to November 2003 sampling the abundance was 2,219.6 cells/ml. Among the six-phytoplankton phyla found in May 2004, Cyanophyta was the most abundant group in all the lakes, followed by Chlorophyta and Bacillariophyta. The abundance of Euglenophyta and Dinophyta was low and Chrysophyta had no representative species during this sampling season in the samples for abundance data. In the October to November 2003 sampling, the most abundant phytoplankton group in all lakes was Chlorophyta.

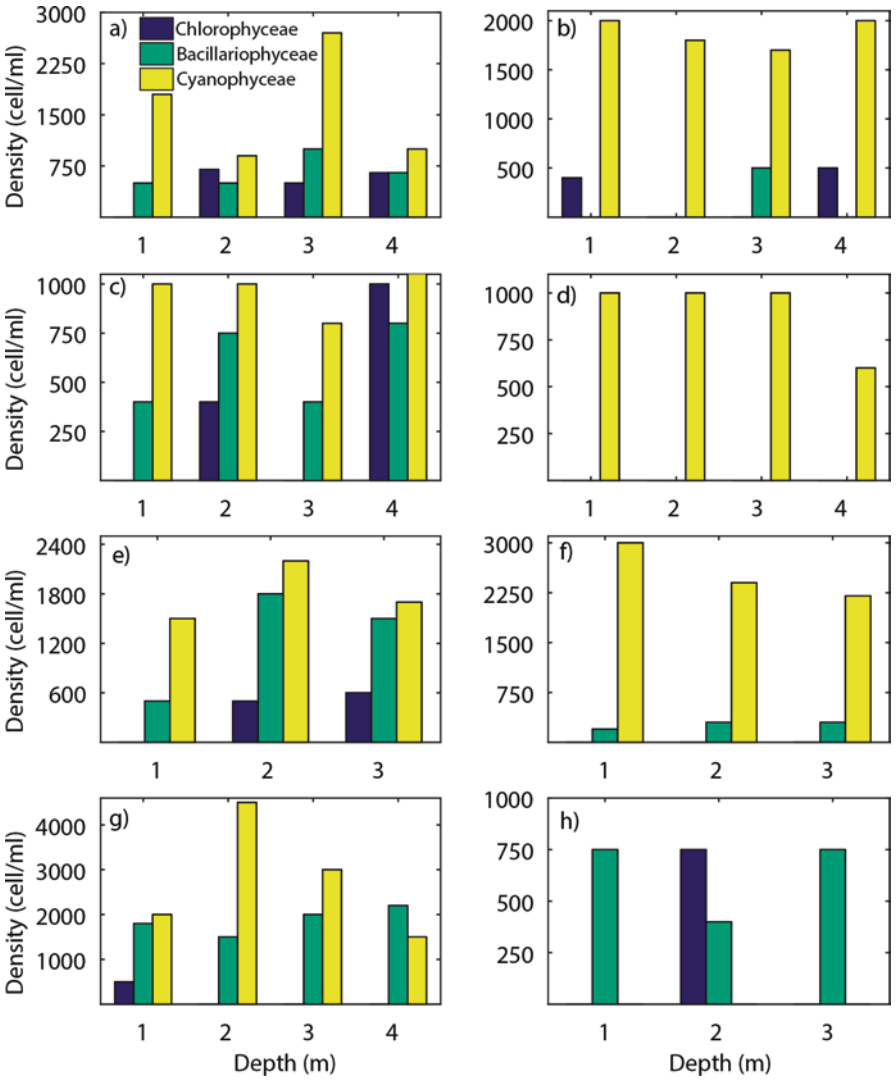



**Fig. 5.4** (**a**–**h**) Vertical distribution of common groups of phytoplankton in different satellite lakes of Lake Victoria Basin (August to September 2002). *a = Lake Burigi; b = Lake Katwe; c = Lake Ikimba; d = Lake Malimbe; e = Lake Kubigena; f = Lake Kirumi; g = Mara River; h = Kyarano Dam.* (Data from TAFIRI Unpublished Reports)

### 5.3.2 *Zooplankton*

#### Offshore Areas

The zooplankton taxonomic composition during the January to February 2000, March to April 2000, December 2000, and August and September 2002 samplings in the offshore stations consisted of rotifers and crustaceans, comprising mainly of cladocerans and cyclopoid and calanoid copepods Other planktonic organisms found amongst the zooplankton were the meroplanktonic representatives including larval stages of insects, especially Chaoboridae and the atyid prawns, *Caridina niloticus*. Overall, a total of 20 genera and 32 species of zooplankton were identified from the samples collected. Rotifera comprised the largest number of species (19) followed by Copepoda (8) [cyclopoids (7) and calanoid (1)]. Cladocera contributed only 5 species. The mean zooplankton numerical abundance in Lake Victoria during March to April 2000, August 2002 and September 2002 samplings is shown in Fig. 5.5. The highest number of zooplankton was recorded in December 2000 whereby the number of individual zooplankton reached 745,867 individuals per $m^2$ and few zooplankton species were recorded for the January and February 2000 sampling with a numerical abundance of 40,072 individuals per $m^2$. In general, the zooplankton community of Lake Victoria is dominated by rotifers and copepods. Among the copepods, cyclopoid copepods (adults, copepodites and nauplius larvae) were the most common group throughout the study period.

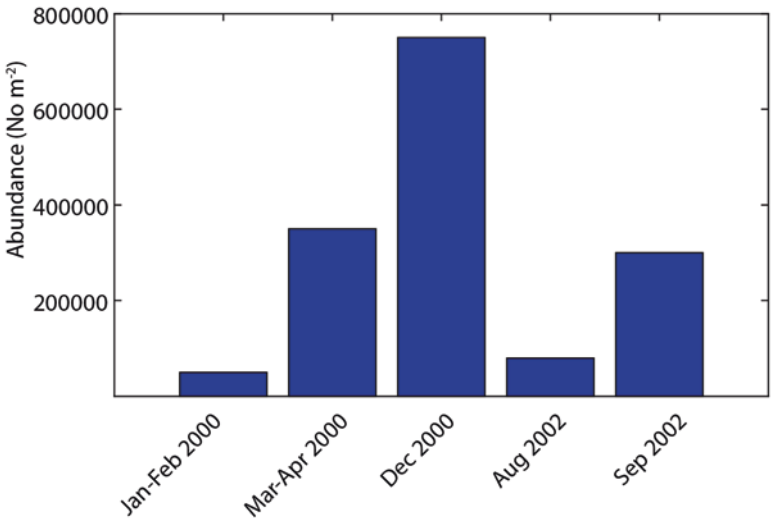



**Fig. 5.5** Zooplankton abundance in the offshore areas (≥28 m deep) of Lake Victoria, January to February 2000, March to April 2000, December 2000, August 2002 and September 2002. (Data from TAFIRI Unpublished Reports)

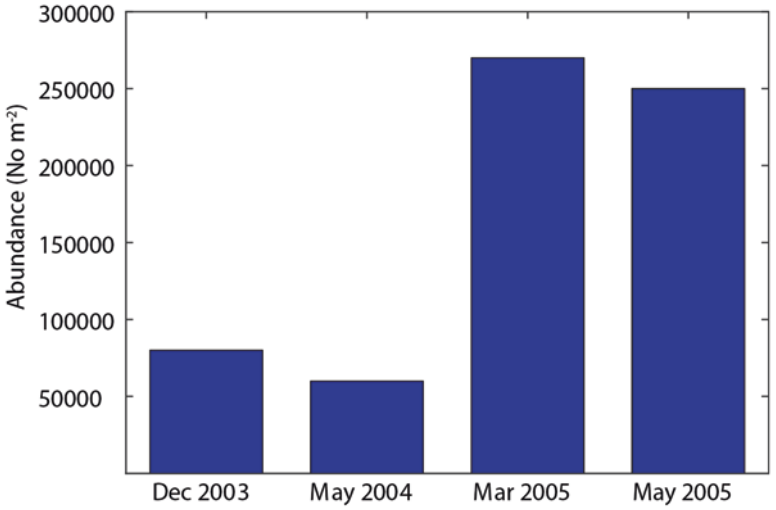



**Fig. 5.6** Zooplankton abundance in the inshore areas of Lake Victoria, 2003–2005. (Data from TAFIRI Unpublished Reports)

### Inshore Areas

The study on inshore areas was conducted during December 2003 to May 2005. The zooplankton taxonomic composition during the study period consisted of a total of 38 species and 25 genera. Among them, Rotifera contributed the largest number of species (20) followed by Cladocera (9) and Copepoda (9; cyclopoids - 7, calanoid - 1 and harpacticoid - 1).

The total zooplankton numerical abundance is presented in Fig. 5.6. The highest biomass of zooplankton was observed in March 2005 with a mean total abundance of 265,597.12 individuals per $m^2$ and the lowest abundance was recorded in May 2004. The cyclopoid copepod and its developmental stages (nauplii larvae and copepodites) was the most dominant group throughout the study period.

### Zooplankton Biomass

The lowest (31 ± 9 mg wet wt $m^{-2}$) and the highest biomass (488 ± 148 mg wet wt $m^{-2}$) were recorded in April 2005 and November 2005, respectively (Fig. 5.7). Zooplankton biomass differed significantly among the different months during the study period ($F = 4.141$, $p < 0.001$). The biomass of zooplankton was significantly higher in November 2005 than in all other months ($p < 0.05$) but had statistically comparable biomass in the months of October 2005 and February 2006 ($p > 0.05$). Similarly, the month of February 2006 had significantly higher zooplankton biomass than all other months ($p < 0.05$) except September 2005, October 2005 and January 2006 ($p > 0.05$). Likewise, the month of October 2005 had significantly

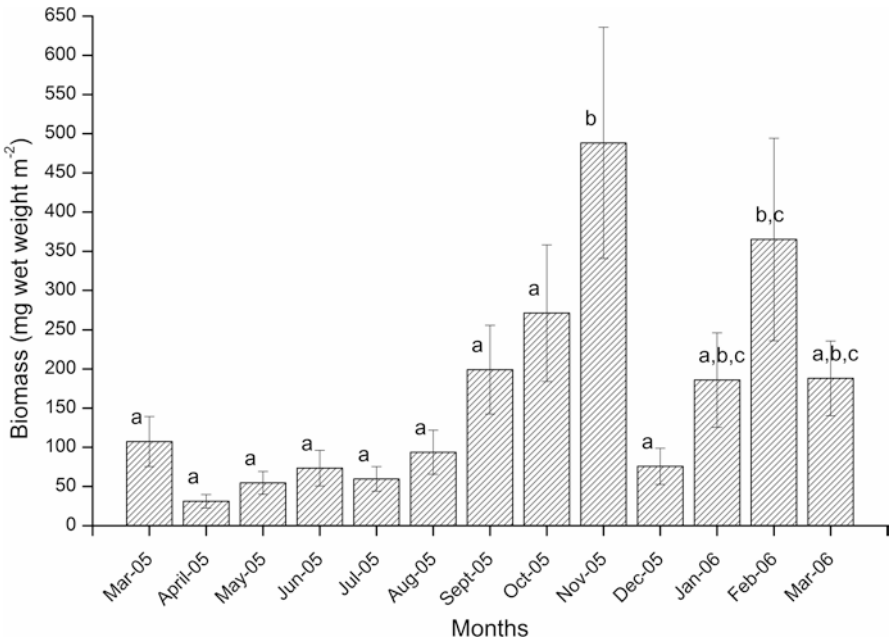



**Fig. 5.7** The biomass of zooplankton in Shirati Bay from March 2005 to March 2006. Different letters above the bars indicate sifnificant difference ($p \leq 0.05$). (Redrawn from Waya et al. (2017).

higher biomass than all other months ($p < 0.05$) except September 2005, January 2006 and March 2006 ($p > 0.05$). The month of April 2005 had significantly lower biomass than all other months ($p < 0.05$); while March 2005 had significantly higher biomass than May 2005 ($p = 0.046$) and July 2005 ($p = 0.048$). The months of March 2005, June 2005, August 2005 and December 2005 had statistically comparable biomass ($p > 0.05$). Similarly, May 2005, June 2005, July 2005, August 2005 and December 2005 also had statistically comparable zooplankton biomass ($p > 0.05$).

Generally, the heavy rain season was associated with comparatively higher zooplankton biomass ($278 \pm 62$ mg/m$^2$) than the light rain season ($118 \pm 23$ mg/m$^2$) and the dry season ($95 \pm 17$ mg/m$^2$). Zooplankton biomass depicted significant difference among the three seasons ($F = 7.378$, $p = 0.001$). Significantly higher zooplankton biomass was recorded in heavy rain than light rain ($p = 0.009$) and dry season ($p = 0.001$). However, the light rain and dry seasons recorded statistically comparable zooplankton biomass ($p = 0.899$).

### Satellite Lakes and Mara River

Data on taxonomic composition from the satellite lakes in the Lake Victoria basin are presented in Fig. 5.8. The water bodies sampled were Mara River, Kyarano Dam, Kirumi pond, Kubigena oxbow lake, Lake Burigi, Lake Ikimba, Lake Katwe and

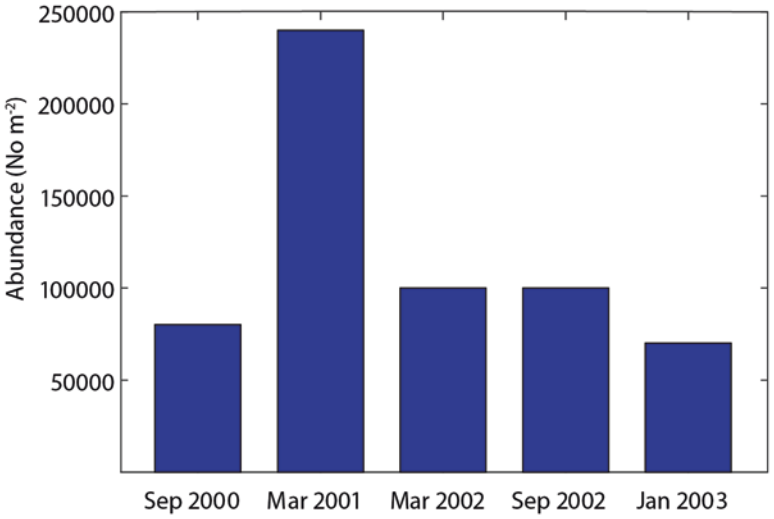



**Fig. 5.8** Abundance of zooplankton (total number) in the satellite lakes of the Lake Victoria basin (Data from TAFIRI Unpublished Reports)

Lake Malimbe. During the study period, 33 genera classified into 37 species of zooplankton were identified, among which 23 species were rotifers, six copepod species and eight species of Cladocera. The highest abundance of zooplankton was recorded in March 2001, with a density of 241,685.29 individuals per $m^2$, while the lowest density was recorded in January 2003, with a density of 64,879.75 individuals per $m^2$.

**Historical Information**

Zooplankton species identified during the early studies are shown in Table 5.2. In those studies, different authors identified 17 species of zooplankton. Among the 17 species, five have never been found in recent samples from the Tanzanian part of Lake Victoria (Table 5.2).

### *5.3.3 Macroinvertebrates*

A total of 17 species of molluscs were recorded in the two lakes. The results on species richness, density and the distribution of molluscs in Lakes Victoria and Burigi, as shown in Table 5.3, indicate that there were more molluscan species in Lake Victoria than in Lake Burigi.

In the Kenyan waters, the benthic macroinvertebrates' abundance in the main lake and in Winam gulf was composed mainly of Oligochaeta and Mollusca. Insecta groups contributed a very small portion. In polluted stations, oligochaetes, chironomids

**Table 5.2** List of planktonic Crustacea of Lake Victoria from historical data

| | Data source/stations/zone | | | | |
|---|---|---|---|---|---|
| Species | 1 | 2 | 3 | 4 | 5 |
| *Diaphanosoma excisum* Sars | + | – | + | – | + |
| *Ceriodaphnia cornuta* | + | – | | – | + |
| *Ceriodaphnia dubia* | + | – | | – | – |
| *Moina dubia* G. & R. | + | *Brachiata* spp. | + | – | – |
| *Moina micrura* | – | – | + | – | + |
| *Daphnia longispina* Leydig | + | – | + | – | + |
| *Daphnia lumholtzi* Sars | + | – | – | – | + |
| *D. barbata* Weltiner | – | – | *Jardinei* Var. *barbata* | – | + |
| *Chydorus sphaericus* (O.F. M.) | + | – | – | – | |
| *Bosmina longirostris* (O.F.M.) | + | – | *Stuhlmanni* | – | + |
| *Simosa vetulus* (O.F.M.) | + | – | *capensis* Sars | – | – |
| *Tropocyclops confinis* (Kiefer) | + | – | – | *T. prasinus* | + |
| *Mesocyclops leuckarti* Claus | + | – | – | + | + |
| *Thermocyclops neglectus* Sars | + | – | – | *Cyclops oithonoides* Sars | + |
| *Thermocyclops schuurmanae* Kiefer | + | – | – | | – |
| *Thermocyclops emini* Mrázek | + | – | – | + | + |
| *Thermodiaptomus galeboides* Sars | + | – | – | + | + |
| *Tropodiaptomus stuhlmanni* Mzárek | + | – | – | + | – |
| Total | 16 | 1 | 7 | 7 | 13 |

+ n = present; – = absent
Sources: (1) Rzóska (1957) – 9 stations, (2) Stuhlmanni (1891) – Mwanza Bay, (3) Weltner (1897) – 4 stations, (4), (5) Waya and Mwambungu (2004)

and gastropods dominated, whilst Ephemeroptera and Bivalvia were the most abundant groups in unpolluted stations.

A study conducted in Tanzanian and Ugandan waters of Lake Victoria by Ngupula and Kayanda (2010) revealed clear trends in macroinvertebrates temporal variations. In the July to August 2008 sampling, the benthic macroinvertebrates of the shallow nearshore, intermediate and deep offshore environments (n = 337) comprised mainly molluscs, insects and worms. Gastropods (44%, 122.97 ± 102.43 ind./$m^2$) and bivalves (47%, 133.68 ± 110.38 ind./$m^2$) made up a major part of the density of the macroinvertebrates, constituting 91% of the total abundance. Insects and worms

**Table 5.3** Density (No./m$^2$) and distribution of molluscan species from sediments sampled from Lake Victoria and Lake Burigi

| Species | Lake Victoria | Lake Burigi | | | |
|---|---|---|---|---|---|
| | Mara zone | Speke gulf | Mwanza gulf | Bukoba zone | |
| GASTROPODA | | | | | |
| Viviparidae | | | | | |
| *Bellamya unicolor* | 10 | 8.45 | 234 | – | – |
| *Bellamya constricta* | 13 | – | – | 43 | – |
| Thiaridae | | | | | |
| *Cleopatra bulimoides* | – | – | | – | – |
| *Melanoides tuberculata* | 182 | 175 | 130 | 17 | 893 |
| Bithnidae | | 113 | | | – |
| *Gabbiella humerosa* | 78 | | 13 | – | – |
| Planorbidae | | | | | |
| *Bulinus globosus* | – | – | – | – | 52 |
| *Bulinus forskali* | – | – | – | – | 26 |
| *Bulinus ugandae* | 9 | 17 | – | – | 121 |
| *Biomphalaria chaonomphala* | 17 | – | – | – | 9 |
| BIVALVIA | | | | | |
| Corbiculidae | | | | | |
| *Corbicula africana* | 173 | 52 | 104 | 329 | – |
| Unionidae | | | | | |
| *Caelatura acuminate* | – | | 26 | 35 | – |
| *Caelatura alluaudi* | 9 | 9 | 26 | – | – |
| *Caelatura hauttecoeuri* | 9 | 74 | – | – | – |
| *Caelatura monceti* | 9 | 56 | – | 9 | – |
| Sphaeriidae | | | | | |
| *Sphaerium stuhlmanni* | – | – | – | 89 | – |
| *Sphaerium nyanzae* | – | – | – | 156 | – |
| *Eupera parasitica* | 87 | 25 | – | 78 | – |
| Av. ind. per zone | 686 | 1,366 | 585 | 756 | |
| Av. ind. per lake | 679 | 1,101 | | | |
| Shannon-Weaver diversity index | 0.8587 | 0.2973 | | | |

Source: Mwambungu (2004)

contributed about 6% (16.67 ± 10.22 ind./m$^2$) and 3% (7.75 ± 6.34 ind./m$^2$), respectively (Fig. 5.9a). In the February to March and August to September 2008 surveys benthic macroinvertebrates (n = 156) showed similar composition to that of the July to August 2008 survey with gastropods (57%, 109.73 ± 86.85 ind./m$^2$) and bivalves (38%, 74.01 ± 42.73 ind./m$^2$) being the dominant groups. The two groups accounted for 95% of the total abundance, while worms and insects accounted for 3% (5.23 ± 3.21 ind./m$^2$) and 2% (4.65. ± 3.34 ind./m$^2$), respectively (Fig. 5.9b).

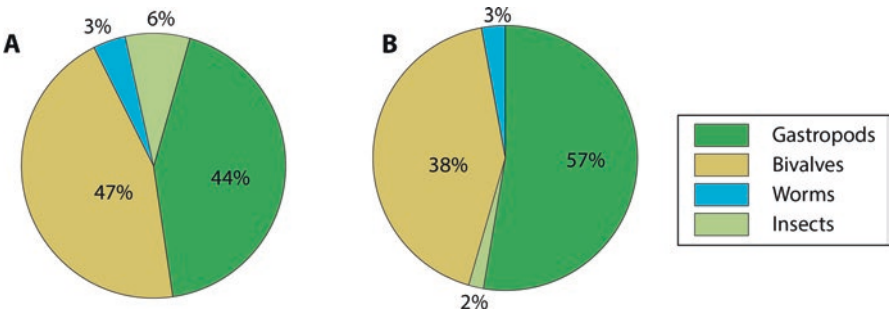



**Fig. 5.9** Percentage composition of benthic macroinvertebrate groups in the Tanzanian waters of Lake Victoria during the July to August 2008 survey (**a**) and in the Tanzanian and Ugandan waters conducted during the February to March and August to September 2008 surveys (**b**) (Redrawn from Ngupula and Kayanda 2010)

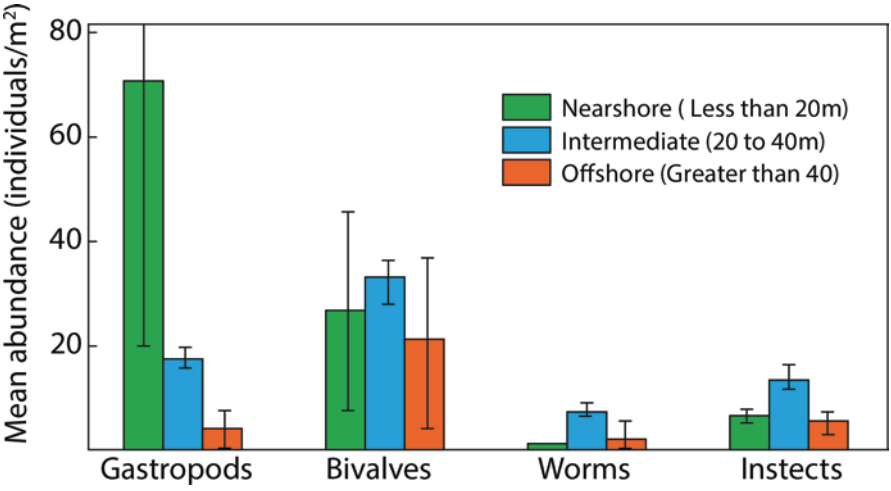



**Fig. 5.10** Mean abundance of different macroinvertebrate groups in nearshore, intermediate and deep offshore waters of Lake Victoria. Error bars denote ± SD (Redrawn from Ngupula and Kayanda 2010)

### Macroinvertebrates Vertical Distribution

The vertical distribution of macroinvertebrates abundance indicated that, gastropods had a declining trend with increasing water depth, whereas bivalves had a contrasting trend and worm abundance indicated no clear trend. *Chaoborus* spp. was largely encountered in the deep offshore waters, as opposed to most insects, which were abundant in the nearshore waters (Fig. 5.10). Quasi-likelihood showed a significant positive relationship between depth and macroinvertebrate abundance ($p = 0.0014$).

**Macroinvertebrates Distribution by Taxon**

Molluscs were dominated by two gastropod species, namely *Bellamya unicolor* (Olivier 1804) (Viviparidae) and *Melanoides tuberculata* (Müller 1774) (Thiaridae); and by two families of bivalves (Ngupula and Kayanda 2010). The gastropods, *Bellamya constricta* (Martens 1889) and *B. costulata* (Martens 1892), were less abundant. The *Sphaerium nyanzae* (Smith 1802) (Sphaeridae) and *Coelatura monceti* (Bourguignat 1883) (Unionidae) were both abundant. The other bivalves, *Sphaerium stuhlmanni* (von Martens 1897) (Sphaeridae), and two pelecypods, *Coelatura acuminata* (H. Adams 1866) and *C. alluaudi* (Dautzenberg 1908) (Unionidae), were less abundant. Insects were dominated by Chironomidae and Chaoboridae, while the families Culicidae and Tipulidae were less dominant (Ngupula and Kayanda 2010). Worms were dominated by oligochaetes and turbelarians. Gastropods from the family Planobirbidae, i.e. *Bulinus transversalis* (Martens 1897), *B. ugandae* (Mandahl-Barth 1958) and *Biomphalaria choanomphala* (Martens 1879), were not encountered during the July to August survey in the Tanzanian waters, but were encountered during the February to March and August to September surveys in the Ugandan waters (see Ngupula and Kayanda 2010).

## 5.4 Discussion

The study found a shift in algal composition from communities dominated by diatoms such as *Aulacoseira* spp. and green algae to cyanobacteria in response to increased phosphorus loading into the lake and a high nitrogen-demand (Sitoki et al. 2012; Gikuma-Njuru et al. 2013). The elimination of *Aulacoseira* spp. was also noted by Kling et al. (2001), which matched with the increased occurrence of a massive cyanobacterial bloom. The shift in phytoplankton species composition is interpreted as an evidence of silicon limitation and increased phosphorus loading which favour cyanobacteria growth. Diatoms and chemical stratigraphy of a sediment core confirmed the disappearance of *Melosira* spp. by the end of 1960s (Hecky 1993). This core study showed that the changes in phytoplankton were accompanied by increased deposition rates of nitrogen (starting in the 1920s) and phosphorus (starting in the 1950s). During the 1960s the biogenic silica deposition started to decrease, causing low concentration of silica in the surface waters. This is believed to have led to the disappearance of *Melosira* spp. from the open waters (Akiyama et al. 1977). Generally, the disappearance of *Melosira* spp. in the 1960s was unique in the recent history of the lake, as the representatives of this genus were present in all the examined sediment intervals deposited over the past 10,000 years (Stager 1984). Thus, the high nitrogen-demand in the lake favours the dominance of cyanobacteria some of which are capable of fixing $N_2$ to meet their nitrogen requirements.

It should also be noted that the shift in algal composition towards cyanophytes is an indication of changes in the trophic status of the lake, which could have led to eutrophication. The eutrophication conditions favour the growth of cyanobacteria

dominated by *Planktolyngbya* spp., *Anabaena* spp. and *Microcystis* spp. Some of the cyanobacteria produce toxins that can be dangerous to aquatic life, human health (Sekadende et al. 2005b; Dittmann et al. 2013; Komárková et al. 2016), and land-based animals that use the water from the lake. Studies show that, cyanobacteria vary both spatially and seasonally in Lake Victoria with the highest concentrations found in bays and during the rainy season, respectively (Haande et al. 2011; Cornelissen et al. 2014). Recent studies also show that *Anabaena* spp. and *Microcystis* spp. dominate in various months and sites (Sekadende et al. 2005b; Haande et al. 2011; Cornelissen et al. 2014), especially in closed bays (Mbonde et al. 2015). Despite the fact that cyanobacteria may bloom all year-round (Luyiga et al. 2015), Lake Victoria has a seasonal succession in species composition of algae with increasing dominance of nitrogen fixing cyanobacteria during the early stratified period followed by non-fixers later in the stratified period and during the deepest mixing period between June and July.

Notwithstanding the shift in algal composition, the phytoplankton species composition from the studies published on the Tanzanian waters of Lake Victoria between 2000 and 2017 (Mbonde et al. 2004, 2015; Machiwa et al. 2005; Sekadende et al. 2005a; Ngupula et al. 2011; Cornelissen et al. 2014, Waya et al. 2017) reveal some similarities with other reports (Cocquyt et al. 1993; Lung'ayia et al. 2000; Hecky et al. 2010; Haande et al. 2011; Sitoki et al. 2012) in the other countries bordering the lake. The major similarity is the predominance of cyanobacteria during thermal stratification of the lake and predominance of diatoms during isothermal mixing of the whole water column. Lake Victoria undergoes thermal stratification during October to March and isothermal mixing in June to August (Lung'ayia et al. 2000; Kling et al. 2001). During thermal stratification, the phytoplankton distribution pattern is a function of the excess density of the organisms. Cyanobacteria have buoyant vesicles that enable them to remain in the surface waters during thermal stratification (Reynolds et al. 1987). This in turn assists the cyanobacteria to trap more sunlight for photosynthesis than other phytoplankton groups; and in addition to that they are more efficient light harvesters than eukaryotic algae, thus explaining their predominance.

The success of some species of cyanobacteria in Lake Victoria especially *Microcystis* spp. and *Anabaena* spp. may also be linked to the high fertility (eutrophication) of the lake (Hecky 1993; Cózar et al. 2012; Schindler 2012). Based on the Carlson and Simpson's (1998) eutrophication guide, lakes containing chlorophyll-*a* concentrations between 20 and 56 $\mu gL^{-1}$ are deemed eutrophic. Indeed, a recent study by Waya et al. (2017) recorded chlorophyll-*a* ranging from 7.57 ± 0.01 to 69.14 ± 0.87 $\mu gL^{-1}$ with an average of 22.14 ± 5.14 $\mu gL^{-1}$, indicating eutrophic conditions. Eutrophication favours the preferential thriving of cyanobacteria species through a competitive advantage for light as explained above.

In a similar pattern to the main lake, a general pattern of an increasing dominance of N-fixing types (e.g., *Anabaena* spp.) in inshore waters of Lake Victoria has been confirmed by earlier findings (Kling et al. 2001; Gikuma-Njuru and Hecky 2005; Tamatamah et al. 2005). Biological nitrogen fixation has at some period emerged as one of the largest single source of nitrogen during which it accounted for over 80% of the total nitrogen loading to Lake Victoria, exceeding dry atmospheric and rivers inputs (Mugidde et al. 2003).

In satellite lakes of the Kagera River basin, higher species diversity and richness existed during the dry season than the rainy season. Theoretically, in the dry season nutrient fluxes into the lakes are expected to be low due to reduced terrestrial runoff. In less fertile waters the growth rate of phytoplankton is low hence allowing a greater number of species with reasonably similar requirements to coexist than would be found in the more fertile main lake. It is worth noting that, some phytoplankton species that are believed to have gone extinct in the main lake occur in the satellite lakes. For instance, large colonies of *Pediastrum* spp. and *Aulacoseira* spp., which were abundant during the 1960s, are now rarely found in Lake Victoria (Kling et al. 2001) where they exist in inshore areas and some satellite lakes.

The trends in the dynamics of the zooplankton from the studies referred to in this chapter, have shown some changes in both abundance and diversity over the years. However, the community structure of zooplankton still comprised three groups, namely the rotifers and two subclasses of the Crustacea, the Cladocera and Copepoda (Worthington 1931; Rzóska 1957; Akiyama et al. 1977; Mavuti and Litterick 1991; Mwebaza-Ndawula 1994; Waya and Chande 2004; Waya and Mwambungu 2004; Ngupula et al. 2010; Vincent et al. 2012). Prior to the introduction of *L. niloticus* the relative proportions of the major taxa ranked as cyclopoids > calanoids > rotifers and Cladocera in terms of density (No./$m^2$) in the near shore stations, but in the open water stations the diaptomids became equal or even dominant over cyclopoids (Rzóska 1957).

Historically, the planktonic crustaceans of Lake Victoria have been studied since 1888 when Emin Pasha and F. Stuhlmann collected the first sample in the lake. From that time, different studies have been carried out on the planktonic crustaceans of Lake Victoria but most of them, with the exception of Daday (1910), were dealing with only few species (Daday 1907; Sars 1909; Verestchagin 1915; Delachaux 1917; Gurney 1928). The works that dealt with the general aspects of zooplankton are those by Worthington (1931) and Rzóska (1957). Past historical data show that the zooplankton community of Lake Victoria is dominated by cyclopoid copepods and their developmental stages in terms of abundance and biomass while Rotifera have the highest diversity (Akiyama et al. 1977; Mavuti and Litterick 1991; Mwebaza-Ndawula 1994; Branstrator et al. 1996; Ngupula et al. 2010; Waya et al. 2014). Currently, food availability and predation, among others, seem to be the important factors affecting zooplankton density and biomass in time and space in Lake Victoria (Goudswaard et al. 2006; Budeba and Cowx 2007). The role of zooplankton in secondary productivity is directly related to production of zooplanktivorous fish (e.g., haplochromines, silver cyprinid (dagaa), juvenile stages of the Nile perch and other fish species). Shifts in the relative abundance of zooplankton species can be directly related to availability of fish.

The results have shown a shift in macroinvertebrate abundance from an oligochaete- and insect-dominated community in 1984 to a community dominated by molluscs in 2008 (Mwambungu 2004; Muli 2005; Ngupula and Kayanda 2010). Molluscs, insect larvae and nymphs dominated the benthic fauna of Lake Victoria, while oligochaetes, leeches, nematodes, ostracods and other crustaceans are also present though in minor proportions (Wakwabi et al. 2006). A study conducted by

Ngupula and Kayanda (2010) indicated an increase in the abundance of gastropods and bivalves while that of insects and worms decreased. These results are in agreement with those obtained by Mbahinzireki (1994) and Ligtvoet and Witte (1991) in the lake. This is probably due to the current eutrophication and deoxygenation in the lake (Hecky 1993, Hecky et al. 1994). Since 1986, it has also been noted that the abundance of macroinvertebrates such as *Chaoborus edulis*, the atyid prawn *Caridina nilotica*, oligochaetes, ostracods, molluscs, *Chironomus* spp., nymphs of Anisoptera and Ephemeroptera, have increased compared to the past (Budeba and Cowx 2007; Ngupula and Kayanda 2010) as a result of increasing anoxia in Lake Victoria (Goldschmidt et al. 1993; Njiru et al. 2012).

The obtained differences in macroinvertebrates composition compared to the situation before 1984, are attributable to the different environmental conditions that existed by then and the changes in fish composition after the introduction of Nile perch into the lake. The pre-Nile perch food web in Lake Victoria was dominated by haplochromines, encompassing many trophic specialisations including molluscivory by species like *Synodontis victoriae, Protopterus aethiopicus, Barbus altianalis* (Witte et al. 1995). The molluscs, however appear now to be largely unexploited following the upsurge of the Nile perch resulting in the disappearance of the haplochromine molluscivores and a decline in the abundance of *Protopterus aethiopicus* (Mwambungu 2004).

The results on macroinvertebrates from all the three countries showed that, shallow nearshore environment had the highest abundance than offshore areas. This is attributed to the presence of abundant detritus, and macrophytes, which provide refuges in the shallow nearshore environment. Of the macroinvertebrate groups, gastropods and insects were more abundant in the shallow nearshore waters than bivalves, *Chaoborus* spp. and worms. Bivalves were dominant in the offshore waters, and *Chaoborus* spp. was encountered only in these waters implying variations in feeding habits, tolerance to environmental conditions, species behaviour and competition among different species. The distribution indicates that gastropods and insects are more tolerant to high organic pollution and high turbidity levels, but less tolerant to low oxygen levels, than the bivalves, *Chaoborus* spp. and oligochaetes (Ngupula and Kayanda 2010).

Similar to plankton results, some species of macroinvertebrates obtained highlight the existence of eutrophic conditions in the lake. The oligochaete species obtained, such as *Alma emini*, *Branchiura sowerbyii* and *Tubifex* spp. are known to tolerate low dissolved oxygen concentration (Muli 2005). Tubificidae species such as *Branchiura sowerbyii* and *Tubifex* spp. are known worldwide as indicators of high organic pollution in water bodies. On the other hand, molluscs of the family Ancylidae and insects of the orders Ephemeroptera and Plecoptera are known worldwide to indicate unpolluted water bodies (Muli 2005). Similarly, *M. tuberculata* and *B. unicolor* are tolerant to environmental variations. The absence of the bivalves *Corbicul*a spp. and *Mutela* spp. indicate possible disappearance of these species, although they were once dominant in the lake (Mothersil et al. 1980). However, the dominance of Sphaeridae family among the small bivalves has survived the lake changes because it was reported by Hoogerhoud (1986) in Mwanza

Gulf area. Thus, the existence of rich and diverse benthic macroinvertebrate fauna is expected to provide food for demersal fish species in the lake.

## 5.5 Conclusions and Recommendations

- The present dominant cyanobacteria species in the lake are less digestible and provide poor quality food for the fish; this may have contributed to the reduction or loss of planktivorous haplochromines and tilapiines that once flourished in Lake Victoria. There is a need for reduction in nutrient loads and pollutant inputs into the lake.
- The zooplankton community in the lake is dominated by rotifers and cyclopoid copepods, in both inshore and offshore areas. This has implications on the production and sustainability of fishes (i.e. *R. argentea,* some haplochromines, larval fishes etc.) that utilize these organisms as a food base. There is need to investigate further on the ecology of the major zooplankton groups and their relative importance as food items of commercial fish species. Moreover, research on the zooplankton community structure should be focused towards developing bioindicators of environmental and water quality.
- The occurrence of a relatively high abundance of low-oxygen tolerant zooplankton taxa at inshore stations is an indication of deteriorating water quality due to eutrophication and pollution processes especially around near-shore areas of the lake. The identification and mapping of sources of pollutants needs to be carried out and control measures (i.e. provision and enforcement of chemical/nutrient standards of effluents to waterways and the lake) must be instituted in order to mitigate the pollution of the lake waters and thereby protect the valuable living resources in the main lake and satellites in the basin.
- Molluscs occur in relatively high abundance in both offshore and inshore areas. This has implications on fisheries production (i.e. juvenile fishes, the lungfish, *Protopterus aethiopicus*, *Synodontis* spp., and *Mormyrus* spp. that use these organisms as a food base). Molluscs and other macroinvertebrates should be thoroughly investigated in terms of batho-spatial distribution, suitability as indicator species of environmental quality and fish food, among others.

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