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TEMPORAL AND SPATIAL DYNAMICS OF ZOOPLANKTON IN RELATION TO PHYTOPLANKTON VARIATION IN LAKE BABOGAYA (BISHOFTU GUDA), ETHIOPIA

BY

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Temporal and spatial dynamics of zooplankton in relation to phytoplankton in Lake Babogaya (Bishoftu guda), Ethiopia.

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Abstract

The zooplankton of a crater lake in Ethiopia, Babogaya, was sampled at 3 stations from June 2006 to April 2007 concurrently with phytoplankton numerical abundance. The spatial and temporal variation in abundance of the dominant crustaceans, Rotifera, Copepoda and Cladocera is discussed. Temporal (months, sampling dates) variation was larger than spatial (station) variation for the mean total zooplankton. All major zooplankton groups showed temporal variations in abundance, with highest densities during wet (June to August) and mixing period (November to January), minimum densities after the end of the big rain in October. Rotifers were the dominant group and made up almost 71% of the total zooplankton abundance. Rotifers showed a maximum density during the dry period and declined after the end of the big rains. Copepods and cladocerans also contributed 23% and 6%, respectively, of the major total zooplankton abundance of the lake. The maximum vertical distribution of total zooplankton was observed at the metalimnon region. The phytoplankton community was dominated by dinoflagllates during the dry season and there was a shift in dominance to diatoms during the long rainy period. The dominant phytoplankton showed distinct seasonality. This study is believed to give a baseline for further research on zooplankton seasonal variation and production that helps in the understanding of fish production and proper management in the study lake.

Key words: *Lake Babogaya, zooplankton, phytoplankton, temporal dynamics, vertical migration.*

1.Introduction

Ethiopia is gifted with a variety of aquatic ecosystems, especially a number of lakes that are of great scientific interest and economic importance. The total area of inland waters in Ethiopia is 8,800 square kilometers, representing 0.72 percent of the total surface area of the country (Greboval *et al.,* 1994).

The Rift valley and crater lakes may provide admirable opportunities for comparative limnology owing to the considerable variation in their morphometric, physical and chemical features. Among these are the Bishoftu lakes, which form an extensive series of volcanic explosion craters in the vicinity of the town of Debre Zeit (Zinabu Gebremariam *et al.*,2002).

Although Ethiopia is gifted with a variety of aquatic ecosystems, especially a number of lakes that have great scientific interest and economic importance, urbanization and human settlement in close proximity to the lakes are the greatest potential causes of changes in water quality and quantity. Certain human activities, like building resort facilities, washing clothes, gutting and filleting of fish caught from the lake, etc., tend to be concentrated on the shores of the lakes (Zinabu Gebremariam, 1994).

Zinabu Gebremariam *et al.,* (2002) have noted that the Ethiopian Rift Valley and crater lakes have been undergoing changes in their limnological features during the last two decades or so. The present study lake is no exception. Lake Babogaya is inside a fast growing city, Debre Zeit, and its shores are currently used for recreation, washing clothes, and watering livestock.

Zooplankton is an important component in the food chain as a major contributor of the food base for larval fish stocks and some adult fish species (Mavuti & Litterick, 1981). Zooplankton studies provide information that will lead to a better understanding of the trophic relationship in the lake (Bollens & Frost, 1989). It is an important link between primary production and planktivorous fish. They play an important role in trophic dynamics of planktonic ecosystems as they transfer energy from primary productivity to higher trophic levels (Davis, 1996). In addition, they have a potential importance as indicators of water quality in ecosystems function (Suzanne and Jeffery, 1997).

Zooplankton community in temperate and tropical inland waters undergo regular temporal and seasonal fluctuations in abundance and composition just as phytoplankton do, at different times of the year. Several factors are suggested to govern the species seasonal fluctuations in zooplankton community in temperate and tropical inland waters. Both biotic and abiotic factors are responsible for the seasonal dynamics of zooplankton species. Abiotic factors such as wind, precipitation, turbidity and hydrology have been identified as critical factors in seasonality of zooplankton in the tropics (Mavuty & Litterick, 1981; Tombly, 1983; Serruya& Pollinghr, 1983; Nilsson, 1984; Chutter, 1985).

Moreover, zooplankton consumes phytoplankton and bacteria then re-releasing nutrients or serving as prey for higher trophic levels (Hillbricht-Ilkowska, 1977). The rate nutrients are recycled (Lehman, 1984) and the availability of zooplankton as food for planktivores (Hampton & Gilbert, 2001) depends on the species present (Main *et al*., 1997).

Zooplankton community composition in shallow-water systems can be influenced by predation (Donald *et al*., 2001; Hampton & Gilbert, 2001), water chemistry (e.g. salinity) and hydrology (Moss, 1994), food source (Ghadouani *et al.*, 1998), and submerged aquatic vegetation (SAV) (Lauridsen *et al.*, 1998). The vast majority of studies of shallow-water systems have found predation by fish to be the factor most strongly influencing zooplankton composition (Rodriguez *et al*., 1993).

Moreover, species composition and abundance of zooplankton communities can be influenced by a number of physical, chemical and biological factors. In general, factors such as temperature (Edmondson, 1965), salinity (Egborge, 1994), pH (Spirules, 1975) and electrical conductivity (Mavuti, 1990) can affect this community with regard to both composition and population density. The size of the water bodies (Patalas, 1971), their trophic state (Gannon & Stemberger, 1978) and the successional stage (Hutchinson, 1967) also greatly influences the species composition of the zooplankton. However, the factors recognized as the most important by the majority of authors are temperature, quality and availability of food, competition and predation. In natural environments, these factors act simultaneously and may also interact to various degrees, modifying the zooplankton structure in different ways.

Temperature controls the reproductive rate, population size and metabolism of many species (Edmondson, 1965). Quality and quantity of food can alter species composition as well as the abundance of the species; since particular organisms are highly selective about the size and the type of phytoplankton they consume (Campbell & Haase, 1981). Long-term studies on zooplankton composition have indicated that in tropical regions, precipitation and wind are important physical factors affecting zooplankton structure (Matsumura-Tundisi & Tundisi, 1976; Nogueira & Matsumura-Tundisi, 1996). Intra and inter specific zooplankton competition can alter population abundance by reducing species fecundity or raising the mortality of juveniles (Smith & Cooper, 1982). Predation by invertebrates usually has a greater impact upon microzooplankton than on macro-zooplankton, frequently reducing the abundance of the former (Zaret, 1980). Predation by fish may affect zooplankton structure, in accordance with the fish feeding mode: selective feeders, by differential capture of organisms, tend to eliminate large species, which are replaced by less vulnerable small forms (Brooks & Dodson, 1965); filter-feeding planktophage fishes do not actively select their preys and therefore more evasive species avoid predation whereas small forms are captured, thus diminishing zooplankton densities (Drenner *et al.*, 1982).

In temperate regions, zooplankton undergo regular seasonal fluctuations in abundance and composition, with different species at different times of the years. Here, zooplankton dynamics is mainly governed by temperature, food availability, predation and their biological abilities to withstand adverse conditions in annual production cycles (Lampert, 1993).

In large tropical lakes, wind-generated seasonal mixing and the associated redistribution of nutrients stimulate zooplankton population increase, but the duration of the mixing (Lewis, 1983; Degenbol & Mpila, 1982) and the adaptation of zooplankton life cycles to such unstable periods (e.g.

Threlkeld, 1986) determine whether established populations collapse or are maintained for longer periods.

Biotic factors also play a major role towards seasonal variation in zooplankton structural composition at different times of the year. For example, at a time in lakes where there is a high abundance of planktivorous fish, size selective predation (i.e. fish selectively consuming larger prey) can lead to dominance of small-sized zooplankton species (Eshete Dejen *et al.,* 2004).

Dussart & Defaye, (1995), reported that most Calanoida are herbivorous, feeding on algae, whereas Cyclopoida tend to be more omnivorous, feeding additionally and even preferentially on other planktonic and also benthic micro invertebrates. Although the diet and the niche amplitude favour this group regarding resource allocation, the copepods have obligatory sexual reproduction and longer life cycles (Monakove, 2002) resulting in a reduced number of generations compared to those of rotifers and cladocerans.

As high temperature and light throughout the year allow for primary production to occur all year round in tropical lakes (e.g. Dusart *et al*., (1984), Lewis, (1974); Dumont, (1994), it was long reported that tropical plankton populations remain relatively constant over time. Indeed, contrary to temperate zooplankton (e.g. Burgis, 1971; 1973; Allan, 1976), tropical zooplankton can breed continuously (e.g. Melak, 1979), so that there would be little seasonal variation in production, biomass and species composition. However, as stressed by Twombly (1983a) and Agrawal (1998), when the population dynamics are examined in detail, this assumption of little seasonal variations in tropical plankton proved false. In particular, there is an important body of data, which documents seasonal variations in the abundance of zooplankton in large lakes of the African Rift Valley as Lake Tanganyika e.g. Hecky and Fee (1981) and Lake Malawi (Havens, 2002), as well as in smaller, shallow tropical lakes e.g. Seyoum Mengestou and Fernando, (1991). These temporal variations may depend on changes in the availability of edible phytoplankton and micro zooplankton, which often vary depending on physical processes that drive nutrient availability and depth of the mixed layer, which are known to be key factors determining primary production in tropical lakes (Beadle, 1981).

The limited seasonal variation in irradiance and the small vertical temperature gradients that develop in tropical lakes give the impression that zooplankton population fluctuations might also remain seasonally muted. Yet many studies have documented seasonal variations in abundance of several orders of magnitude (Gras *et al.*, 1967; Lewis, 1983; Hart, 1981; Degenbol & Mpila, 1982; Carmouze *et al.*, 1983). Although these works have conclusively documented zooplankton seasonality in tropical lakes, the causes and consequences of that seasonality have not been explored (e.g. Lewis, 1979; Saunders & Lewis, 1988; Seyoum Mengestou and Fernando, 1991; Semeneh Belay, 1988; Seyoum Mengestou, 1989; Eshete Dejen, *et al.*, 2004).

Moreover, freshwater zooplankton is less diverse in tropical regions than in temperate regions. The uniformly high temperature does not seem to favor diversity of zooplankton (Fernando, 1980a). On other hand, due to an extensive growing season, temporal and seasonal variability that result from temperature are not so pronounced as in temperate regions. Therefore, seasonal and temporal variations in zooplankton assemblages in tropical lakes have been attributed to environmental variables that result from hydrological conditions and meteorological events (Lewis, 1987).

Although, zooplankton is an important link between primary production and planktivorous fish, during the previous studies the knowledge of zooplankton cycles in tropical African lakes was meager. Some data comes from Lake George, Uganda (Burgis, 1973) and Lake Chad (Carmouze *et al*, 1983). Inadequate work was done on the zooplankton of the Horn of Africa compared to temperate lakes (Dumont, 1984).

In recent years, several useful investigations have been carried out regarding the zooplankton seasonality of Ethiopia on Lakes Abijata and Langano (Baxter *et al*, 1965; Wood *et al*, 1978; Kassahun Wodajo & Amha Belay, 1984; Lake Awasa, Seyoum Mengestou, 1989; Seyoum Mengistou & Green, 1991; Seyoum Mengestou' & Fernando', 1991; Lake Tana, Eshete Dejen *et al.*, 2004; Lake Ziway, Semeneh Belay, 1988; Tudorancea& Taylor, 2002; Getachew Beneberu, 2005; Lake Beseka (Metehara), Tesfaye Delelegne, 2006). While some older studies on the zooplankton of Lake Abiata (Lowndes, 1930) and Lake Langano (Cannicci & Almagia, 1947) have only limited significance.

Moreover, diel vertical migration (DVM) of many species of marine and freshwater zooplankton has often been observed in the mixing and summer-stratified waters in temperate regions (Zaret, 1980). The actual patterns of DVM can vary remarkably between and within species, and under different environmental conditions. In most instances, the normal pattern of ascent at dusk and descent at dawn is performed (Bayly, 1986). Many possible mechanisms underlying DVM have been proposed, among which the visual predator-avoidance hypothesis is generally accepted by experimental evidence and field observations. Some authors also found that predation from non-visual invertebrate predators can force prey to perform reverse DVM (e.g.Ohman *et al*., 1983). Besides predation, food may be the second important factor affecting the vertical distribution of zooplankton. When food availability is very low, even though under great predation pressure animals employ the policy ‘better dead than unfed’ and remain in surface waters until they have consumed sufficient food to stimulate the commencement of DVM (Flik and Ringelberg, 1993).

Even though, many Ethiopian lakes were studied very well, there is a need to get adequate information about quantitative studies on zooplankton species composition, seasonal and temporal abundance in Ethiopian freshwater lakes. Likewise, in Lake Babogaya, although, Yeshimebet Major, (2006) studied temporal and seasonal variation of phytoplankton and Lemma Abera (personal communication) studied the reproduction, food, length-weight relationship of African catfish (*Clarias gariepinus*), the species composition, seasonal and temporal abundance of zooplankton study was absent. Hence, more information is necessarily to understand the influence of biotic factors on zooplankton communities. Therefore, the purpose of this study was to provide baseline information for future studies about the temporal and spatial dynamics pattern of the zooplankton in relation to phytoplankton dynamics in Lake Babogaya, Ethiopia.

2.Objectives of the study

General objectives

The general objective of this study is to investigate the temporal and spatial dynamics of zooplankton in relation to phytoplankton dynamics in Lake Babogaya.

Specific Objectives

- To determine zooplankton structure and abundance at the shore and in the open water of Lake Babogaya.
- To assess the diurnal vertical migration of zooplankton at some depth profiles in Lake Babogaya.
- To determine the interaction of algal composition with zooplankton structure and abundance in Lake Babogaya.
- To provide further baseline data for proper management and sustainable utilization of Lake Babogaya.

3. Description of the study area

A. Physical and climatic features

Lake Babogaya (Bishoftu Guda) (Fig.1) is one of a number of volcanic crater lakes found in and around the town of Debre Zeit in Eastern Showa which is situated 47 km South East of Addis Ababa at an altitude of 1870m, at about 9^0N and 39^0E (Prosser, *et al*., 1968; Wood, *et al*., 1984). Like all the other volcanic crater lakes in this area, Lake Babogaya is a closed system surrounded by very steep and rocky hills and cliffs. The catchment of the lake is formed from volcanic rocks of basalt, rhyolite and tuff. The lake is substantially sheltered from wind by its deep well-preserved crater (Wood *et al.*, 1976).

The climatic condition in Lake Babogaya area is characterized by a moderate rainfall, varying around 850 mm per annum (Rippey and Wood, 1985) and maximum heat content in September. There are generally two rainy seasons, the minor one extending roughly from February to April and the major one from June to September. Lake Babogaya was found to be stratified from March to November and mixing from November to February. Baxter and Wood (1965) reported that, Lake Babogaya has two rainy periods, the minor one extending roughly from February to April and the major one between June and September. It is fed directly by rain and water flowing down from the crater rims (Wood, *et al.,* 1976).

The temperature of its surface water was frequently found to be about 22^0C with a maximum of 24.5^0C and a minimum of 19.2^0C, while the bottom temperature was almost constant (19.2^0C-19.4^0C) (Wood, *et al.,* 1976).

Previous limnological studies made on Lake Babogaya described bathymetry (Prosser *et al*., 1968), water chemistry (Prosser *et al*., 1968;Wood *et al.*, 1984; Rippey and Wood, 1985; Zinabu Gebre-Mariam, 1994; Baxter, 2002; Zinabu Gebre-Mariam *et al.*, 2002), thermal stratification and mixing (Baxter and Wood, 1965; Baxter *et al*., 1965; Wood *et al*., 1976; 1984), chlorophyll a and phytoplankton (Wood and Talling, 1988; Zinabu Gebre-Mariam, 1994; Zinabu Gebre-Mariam and Taylor, 1997), bacterial abundance and zooplankton associations (Green,1986) temporal and seasonal variation of phytoplankton,(Yeshimebet Major,2006) and studies on reproduction, food, length-weight relationship of African cat fish (*Clarias gariepinus*), Lemma Abera, (personal communication).

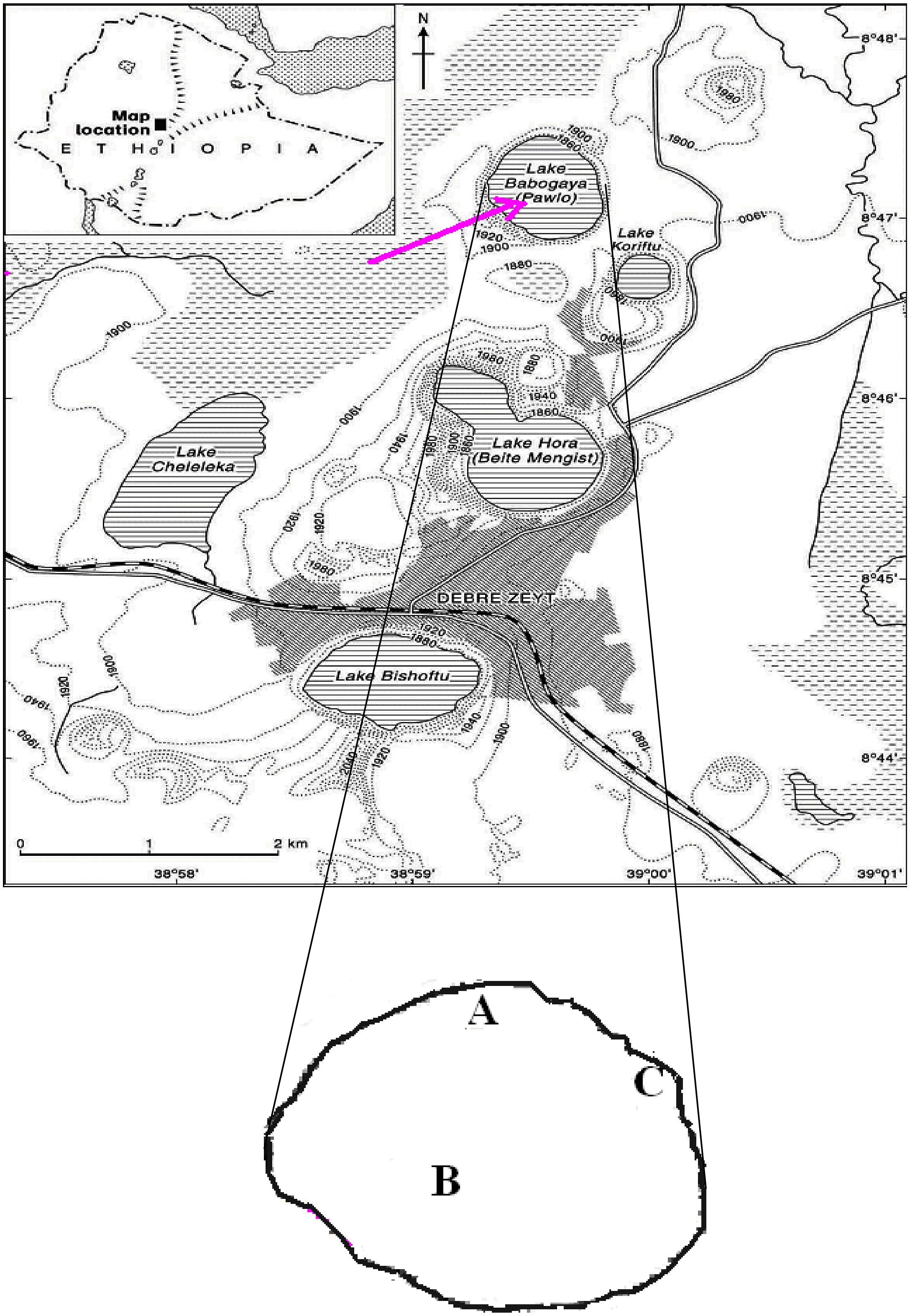


Fig.1. Location of the study Lake Babogaya (sampling sites: A, B and C) in relation to other Bishoftu Crater Lakes (After Lamb, 2001).

The lake is alkaline, with Na^+ as the dominant cation and carbonate bicarbonate as the dominant anion. The erosion of basaltic and hyper-alkaline rocks surrounding the lake has an important role in increasing the alkalinity of the water (Wood and Talling, 1988). Some liminological feature of the lake is given in Table.1.

Table1. Some liminological features of Lake Babogaya (Bishoftu Guda). Chemical data from Tudorancea and Taylor, (2002). Morphological data from Prosser *et al.*, (1968).

Parameters	**Value**
Altitude (m)	1870
Surface area (Km^2)	0.58
Volume (Km3)	0.022
Maximum depth (m)	71
Mean depth (m)	38
Conductivity K_{25}, μscm^{-1})	900
Alkalinity (meq l^{-1})	10.2
p^H	9.2
Salinity (gl^{-1})	0.9
SiO_2 (meq l^{-1})	< .1
Na+ (meq l^{-1})	5.50
Cl^- (meq l^{-1})	0.90
Sum of cations (meq l^{-1})	11.7
Sum of anions (meq l^-)	11.4

B. Biology of the lake

The phytoplankton is dominated by blue green algae, green algae, eugleniods, Cryptomonas and particularly diatoms and dinoflagllates, (Yeshimebet Major, 2006). According to Green, (1986), the dominant zooplankton species are *Afrocyclops gibsoni, Asplanchna sieboldi, Brachionus calyciflorus,* and *Hexarthra jenkinae*. The major fishes species found in the lake are *Oreochromis niloticus, Clarias gariepinus and Tilapia zillii,* where *C.gariepinus* is the most dominant species next to *O.niloticus* (Lemma Abera personal communication) and in recent years intensive fishing activities are commonly observed.

C. Meteorological Data

Data on mean monthly maximum and minimum air temperature, and monthly total rainfall of the lake region were obtained from the National Meteorology Agency, Addis Ababa. According to the data, (Figure 2) mean monthly minimum air temperature ranged from 8.4^0C in November, 2006 to 13.8^0C in August, 2006, while the maximum mean monthly air temperature varied from 23.6^0C in September, 2006 to 29.3 ^{0}C in March, 2007. Monthly total rainfall varied from 5.2 mm November, 2006 to 329 mm July 2006. Although the region was described by Baxter and Wood (1965) as having two rainy periods, the minor one extending roughly from February to April and the major one between June and September. Appreciable quantities of rainfall were recorded from June to October 2006. The peak value was in July 2006. Rippey and Wood (1985) also documented that the lake area has moderate rainfall, varying around about 850 mm per annum. The present meteorological data also show an annual mean rainfall of about 896.9 mm. Surface water temperature of the lake is reported to be mostly between 22^{0}C and 24.5^{0}C while the bottom temperature was almost constant (19.2^{0}C-19.4^{0}C) (Wood, *et al.*, 1976 and 1984). In a recent study (Yeshemebet Major, 2006), the water temperature and dissolved oxygen of the lake range from 23^{0}C to 27^{0}C and 7 mg l^{-1} to 14 mgl^{-1}, respectively.

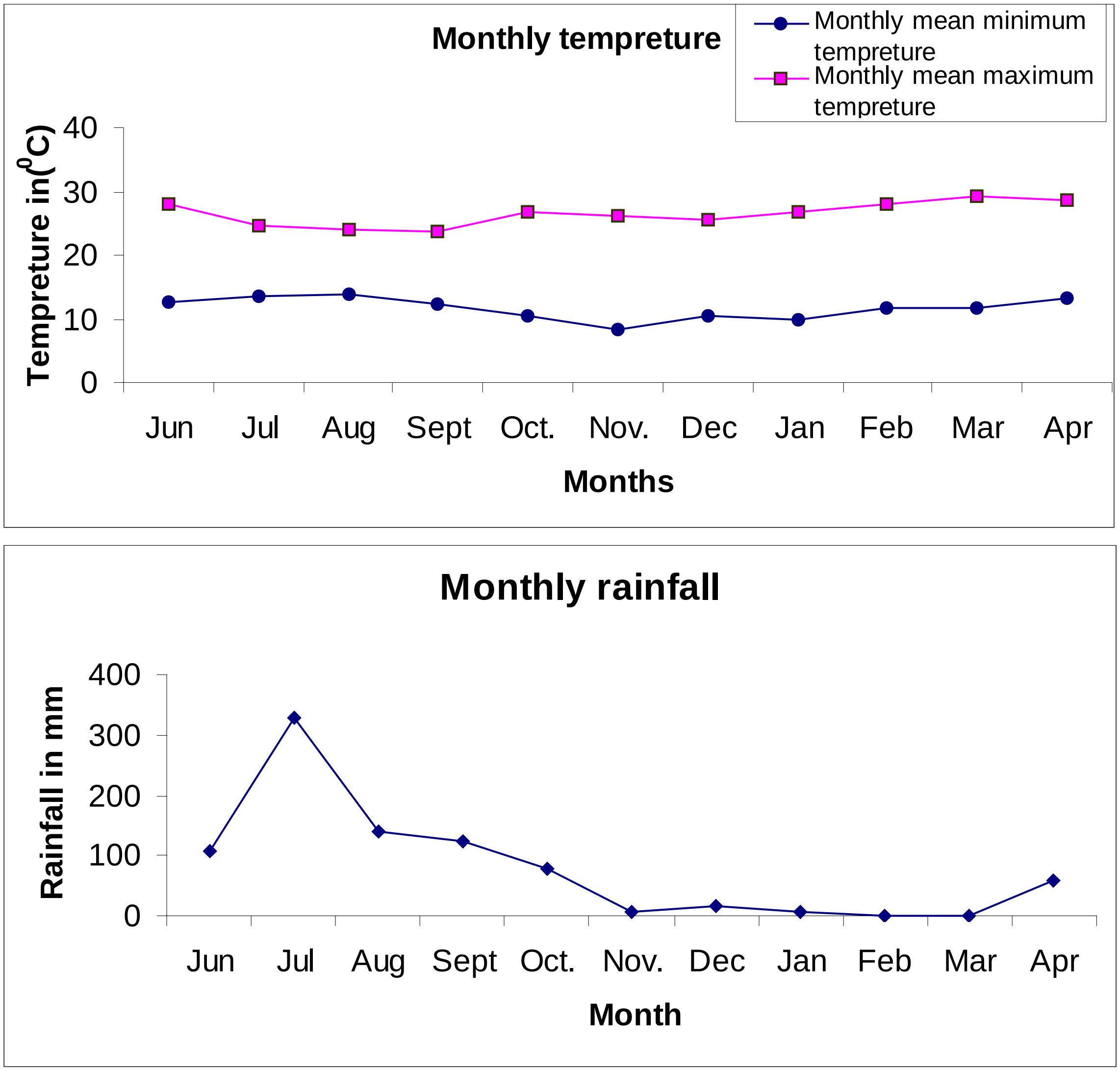


Fig.2. Monthly mean minimum and maximum temperature and monthly rainfall of the study area from June 2006 to April 2007.

4. MATERIALS AND METHODS

4.1 Sampling sites

Three sites were selected based on their unique physical and biological characteristics for the entire sampling period (hereafter referred as station near shore, center and shore. They were sampled monthly throughout the study period (June 2006 to April 2007). Sites shore, near shore and center had a maximum depth of 0.7, 38 and 65 meters respectively.

4.2 Phytoplankton sampling

Phytoplankton samples were taken from euphtic depth (Z_{eu}=3x Z_{SD}) of the two sites (near shore and center) and from 0.7m at shore by using a mesh size of 25µm phytoplankton net and poured into bottles with a few drops of Lugol's iodine.

The phytoplankton taxa were identified to the species level using references such as Whitford and Schumacher (1973); Jeeji-Bai (1977); Durand and Leveque (1980); Gasse (1986); Talling (1987); Rot and Lenzenwger (1994); Hindak (2000); Komarek and Cenberg (2001); Komarek and Komarokova (2002) and John *et al.*, (2002). Each phytoplankton sample was allowed to settle in a 50ml graduate cylinder for more than 24 hours. Excess water was gently siphoned off to leave 5ml of the sample water in the graduated cylinder. From the concentrated sample, 1ml of sub sample was taken with a pipette and Phytoplankton abundance was determined from cell counts of algal units using Sedgwick rafter cell under an inverted microscope (40x and 100x) following Hotzel and Croome, (1999). Cells per one ml of sub sample Was computed using the following formula.

Cells in one ml of sub sample were computed using the following formula;

$$C\ (\text{cells ML}^{-1}) = \frac{N \times 1{,}000\text{mm}^3}{A \times D \times F}$$

Where:

N= number of cells or units counted

A=area of field (mm^2)

D=depth of a field (Sedgwick-Rafter chamber depth) (mm)

F= number of field counted

4.3 Zooplankton sampling

4.3.1 Sampling procedure

Zooplankton samples were collected monthly with No. 25 (64µm mesh) plankton net with mouth diameter 30cm at the depth of 4m, 9m,and 15m at near shore, at 4m, 9m, 15m, 30m and 50m at open water and at 0.7m at shore. Immediately after sampling, zooplankton samples were preserved with 4-6% neutral formaldehyde in 200 ml plastic bottles. For the estimation of abundance, a sub-sample of 20ml was drawn from each well-mixed sample using a wide- mouthed pipette. The sub-sample was poured into a girded petridish (15grids) and counted at 50X magnification using WILD dissecting stereomicroscope. Three grids were counted and the average value was taken. Adult Cladocera, Cyclopoida, Calanoida, Rotifera, were counted as separate groups at species level.

4.3.2 Identification of zooplankton species and estimation of abundance

Zooplankton species were identified using standard methods and references, mainly, keys of Vogit and Koste, (1978), Van de Velde, (1984), Defaye, (1988) and Fernando, (2002). Abundance of zooplankton population was estimated as individual m^{-3} following Edmondson & Winberg (1971).

$$V = \pi r^2 h$$

Where, V is the volume of the water filtered,

r is the radius of the net, and

h is the length of the course of the net through the water

The total number counted (N) in the sub-sample was multiplied by the sub-sample factor (SSF) and divided by the total volume (V) of water strained, (N×SSF)/V, to find the density in numbers per cubic meter (m^3). SSF (sub sample factor was computed by dividing the volume of the total sample by the sub sample. Based on this, the number of organisms per m^3 of the lake was calculated and the number of each category of zooplankton of the lake was expressed as number per m^3.

4.3.3 Assessing diurnal vertical distribution of zooplankton

Diurnal Vertical distribution of zooplankton was assessed at the center by taking samples using Schindler sampler of 10-liter capacity (0.14m^3) at the selected depth profiles from surface up to 50m within 10m intervals. Immediately after collection, the samples were fixed with 4-6% neutral formaldehyde.

Numerical density was computed as individual per liter, following Tesfaye Wudneh (1998) and Wetzel and Likens (2000).

N_w=N_a*400/V

Where:

N_w= number of organisms of each species /age class per liter of lake water.

N_a= number of organisms in concentrated (filtered) sample

V=volume of water filtered in ml. and

The density of concentrated sample was calculated as:

Na= N_c/N_g *N_G

Where: N_c=Number of organisms in grids counted

N_g = Number of grids counted

N_G= Number of grids in the counting chamber

4.4 Data Analysis

To estimate the relative abundance of a species or group at a given station and month, the percentage abundance of each species and each group of zooplankton was calculated out of the total zooplankton number at that station. Data obtained was recorded at each station at different months. To determine if changes in abundance between stations and months were statistically significant, a one-way classification analysis of variance (ANOVA) was performed. Regression was done depending on the nature of data available using Minitab 1-4 version. Values were considered significant at 0.05 levels as indicated in Sokal and Rohlf (1981).

5. Results and discussion

5.1 Phytoplankton species composition

Seven phytoplankton taxa namely, dinoflagellates, diatoms, blue green algae, green algae, cryptomonads, euglenoids and haptophytes and 28 species were identified in the present study (Table 2). Dinoflagellates and diatoms contribute the greatest proportion in terms of % numerical density than other phytoplankton groups in Lake Babogaya. Diatoms are represented by 8 species, dinoflagelates, blue green algae and green algae are each represented by 6 species and the remaining three groups cryptomonads, euglenoids and haptophytes are represented by 3,2,and 1 species, respectively.

Peridinium aciculiferum and *Peridinium bipes* were the most common contributers of Dinophyceae (dinoflagllates) throughout the study period, whereas diatoms were represented by *Nitzschia vermicularis* and *Nitzschia nyassensis*. Others, which were present in the phytoplankton community of Lake Babogaya, included blue-green algae (*Cyanophyceae*), green algae (*Chlorophyceae*) and euglenoids (*Euglenophyceae*).

Table 2. List of phytoplankton species/taxa identified in samples collected from Lake Babogaya (Bishoftu guda) (June 2006-April 2007). ++ = Dominant

Bacillariophyceae (diatoms) a, *Cyclotella planctonica*(Brunthaler) ***b***, *Cymbella cistula* (Hemp.) Grun ***c***, *Fragilaria capucina* (Desm) ***d***, *F. ulna* ***e***, *Nitzschia nyassensis* O. Muller++ ***f***, *N. vermicularis* (Kutz.) Grun.++ ***g***, *Surirella linearis* var. spendid (Ehr.) ***h***, *Synedra dorsiventralis* O. Muller	C*hlorophyceae* (green algae) ***a***, *Cosmarium depressum* (Nag.) Lund. ***b***, *Pediastrum duplex* Meyen. ***c***, *Pediastrum cf. Integrum* d, *Scenedesmus arcuatus* ***e***, *Tetraedron minimum* (A.Br.) Hansg. ***f***,*T. triangulare* Korsch. ***g***, *Tetrastrum hetercanthum*
Cryptophyceae (cryptomonads) ***a***, *Cryptomonas marssonii* (Marss.) Skuja ***b***, *C. obovata* Skuja ***c***, *C. ovata* Ehr.	*Cyanophyceae* (blue-green algae) ***a*** ,*Chroococcus limneticus* Lemm. ***b***, *C. turgidus* (Kutz.) ***c***, *Cylinrospermopsis sp* ***d***, *Microcystis aeruginosa* (Kutz.) Kutz.) ***e*** , *Merismopedia glauca* (Eher.) f, Rhaphidiopsis *mediterraneae* (Skuja)
Dinophyceae (dinoflagellates) ***a*** , *Gymnodinium aeruginosum* Stein. ***b***, *G. limneticus* Lackey ***c***, *Peridinium aciculiferum* Lemm.++ ***d***, *Peridinium bipes* stein++ ***e***,*Ceratium carolineanum* (Bailey) Jörgensen	*Euglenophyceae* (euglenoids) *Euglena cf. deses* Ehr. *Haptophyceae* (haptophytes) *Chrysochromulina cf. parva* Lack

5.2 Seasonal dynamics of phytoplankton

In Lake Babogaya (Bishoftu Guda), dinofllagelates and diatoms contribute the greater proportion in numerical density than other phytoplankton groups. Temporal changes in the dominance of algal groups were observed in the phytoplankton community in Lake Babogaya. The dinofllagelates persisted in appreciable numbers for a relatively longer period of time in all sites. In June (2006), they contribute most in all sites (See Fig. 3 also Appendix .1). At this time the diatoms; green algae and others contributed less. On the other hand, the diatoms became the most dominant groups among others in all sites from August to October, 2006, indicating that there was a shift in dominance from dinoflagellates to diatoms. The reason may be that during this period heavy precipitation seems to change the thermal stability and nutrient-status of the water column and the heavy rainfalls thicken the mixed layer depth by eroding at least the upper part of the metalimnetic region and injecting nutrients into the water column (Talling and Lemoalle, 1998). Baxter and Wood (1965) reported that the region around Lake Babogaya has a major rain extending between June and September, which supports the present study where appreciable quantities of rainfall were recorded from June to October 2006. The peak value was in July 2006.

Moreover, Diatoms are planktonic algae, whose maintenance in suspension depends on turbulence (Reynolds, 1984) and which are able to exploit temporarily favourable conditions and build up their populations because of their intrinsically high growth rates. They commonly dominate in cold nutrient rich waters (Paasche, 1975).

The dinofllagelates flourish again from November (2006) to April (2007), (Fig. 3), the reason for the dominance of dinoflagellates in Lake Babogaya over an extended period of time seems to be linked to the hydrographic conditions of the lake (physical stratification/mixing), which are regarded as factors of over-riding importance in determining the seasonal dominance of algal groups in tropical lakes. In addition, Lake Babogaya is a deep lake, which is moderately protected from wind by crater walls and natural as well as managed vegetation (Fig. 1). The ability of dinoflagellates to migrate vertically to great depths is of immense competitive importance in lakes like Babogaya, where epilimnetic waters are nutrient-poor and in which deep parts of the water column may have as high concentrations of phosphorus as over 800 μgl $^{-1}$ (Wood *et al.*, 1984). It is this nutrient-acquisition ability, which allows dinoflagellates to occupy notoriously nutrient-poor tropical and sub-tropical open- waters (Graham and Wilcox, 2000).

Previous report of Yeshimebet Major (2006) also showed the dominance of dinoflagellates in Lake Babogaya. Moreover, Yeshimebet Major (2006) reported that there were heterogeneous vertical distributions of chemical and biological parameters observed in the same lake due to stable thermally stratified over extended periods. Talling (1986) has also emphasized the importance of hydrological and hydrographic factors to the temporal variations in the species composition, biomass and primary production of phytoplankton in African lakes. Furthermore, (Pollingher, 1988) reported that the dominance of dinoflagellate is very common in freshwater lakes. The apparent success of these organisms is attributed to a number of adaptive features that improve their ability to compete with other phytoplankton (Pollingher, 1987; 1988), which include luxury consumption of phosphorus and nitrogen, vertical migration that maximizes nutrient uptake from nutrient-replete hypolimnetic waters (James *et al.*, 1992) and reduces sinking losses (Levandowsky and Kaneta, 1987).

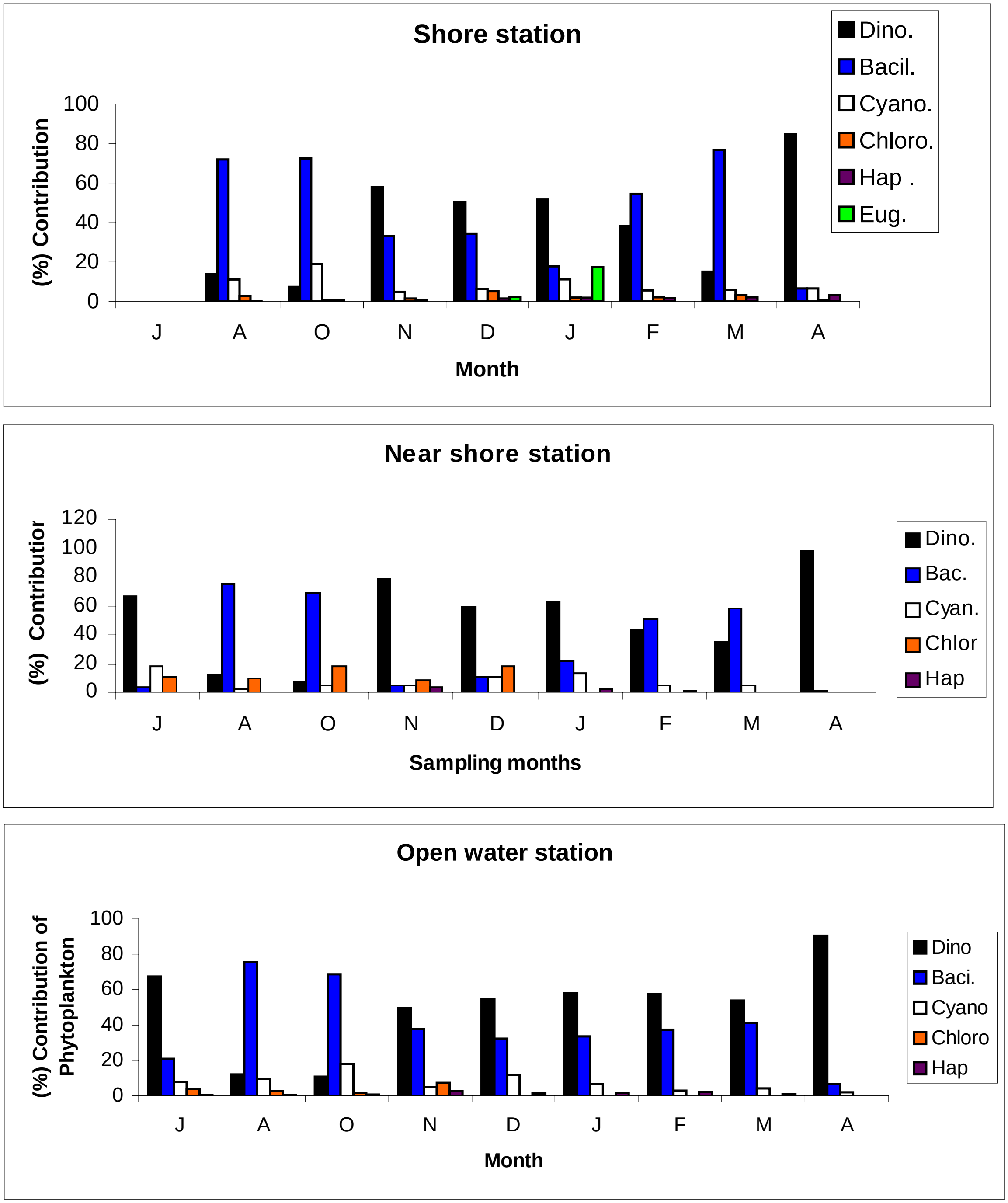


Fig.3 Percentage contribution in terms of numerical density of different phytoplankton groups at the 3-sites in Lake Babogaya (June 2006-April 2007).

5.3 Zooplankton species composition and dynamics

5.3.1 Zooplankton species composition

A total of four cyclopoid, one calanoid copepod, three cladocerans and twenty-eight rotifers were identified in Lake Babogaya (Bishoftu Guda) during the present study (Table. 3). The copepods were the cyclopoids *Mesocyclops aequatorialis similis*, *Thermocyclops consimilis*, *Afrocyclops gibsoni ondoensis*, *Ectocyclops rubescens* and the Calanoid *Paradiaptomus (Lovenula) africana***.** Whereas the cladocerans were *Diaphanosoma excisum, Moina dubia, Ceriodaphnia conuta,* and 28 species of Rotifers that are listed in Table 3.

The most interesting result in this study was the dominance of rotifers, which were higher by 21 species, the presence of *Mesocyclops aequatorialis similis*, *Thermocyclops consimilis***,** *Ectocyclops rubescens (cyclopoid)* and *Diaphanosoma excisum*, *Moina dubia*, *Ceriodaphnia cornuta* (Cladocera), which were not recoreded by Green, (1986). Rotifers were numerically dominant throughout the study period followed by copepods and cladocera. The genus *Keratella* has more species followed by *Branchionus* species.

Table.3 List of crustatian zooplankton species identified in Lake Babogaya (Pawlo). The zooplankton species not described in earlier work (Green, 1986) are indicated (*) and the most abundant (+)

COPEPODA	*Paradiaptomus (Lovenula) africana* Dady,1908 *Afrocyclops gibsoni ondoensis* Brady, 1904+ *Ectocyclops rubescens* Brady, 1904* *Mesocyclops aequatorialis similis* Van de Velde, 1984*+ *Thermocyclops consimilis* Kiefer, 1934*
CLADOCERA	*Diaphanosoma excisum* Sars* *Moina micrura* Kurz (= *Moina dubia* De Guerne & Richard)* *Ceriodaphnia conuta* Sars*
ROTIFERA	*Anuraeopsis fissa* Gosse* *A.coelata*(De Beauchamp)* *Asplanchnia priodonta* Gosse* *A. brightwelli* Gosse* *Asplanchna(Asplanchnella)girodi* DE GUERNE* *Brachionus angularis* Gosse* *B. calycifloris* Pallas+ *B. urceolaris* ROUSSELET *B. quadridentatus* Hermann* *Cephallodella gibba** *C. exigua* Gosse * *Filina longiseta* Gosse * *Hexarthra jenkinae* Hudson *Keratella tropica* Apstein*+ *K.. quadrata* Muller* *K..cochelaries Gosse** *K.. vulga Ehrbg** *K .tecta* Koste* *Lecane bulla Gosse** *L..luna Koste** *Proales indirae* Wulf *Polyarthra vulgaris* Carlin *P. dolichoptera* Idels* *Synchaeta longipes* Gosse* *Trichocerca cylinderica* Imhof * *T .capunica Wierz** *T. pusilla* Jenninings* *T.rousseleti* Voigt*

5.3.2 Spatial and temporal dynamics of the major zooplankton groups

The abundance of the zooplankton species in Lake Babogaya studied was quite variable at different sampling months at the three sites (near shore, center and shore). (Fig 4, 5, and 6).

Copepoda

The abundance of copepods over the study period in Lake Babogaya varied from 0.2 - 8.9, 0.3 - 29.7, and 0.4 - 9.4 $x10^4$ individual per m^3 at the near shore, open water, and shore sites, respectively (Fig. 4). Even though, copepod density was high in the open water than the near shore and shore sites, the variation among the sampling sites for (mean monthly total) copepod was not statistically significant (ANOVA, F=2.09, P=0.13). The density of copepods was higher from June to August (2006) and from November (2006) to January (2007) with the peak value ($29.7x10^4$) individual per m^3 in December (2006) recorded at open water site in Lake Babogaya.

Moreover, there was a clear seasonal variation in the abundance of copepods in Lake Babogaya, i.e. the abundance of copepods was extremely low and fluctuated irregularly during dry seasons; however the conditions reversed and relatively high in the wet season and mixing periods. This could be associated with food conditions and predation (Table. 4 ANOVA, $P<0.05$). During the wet season diatoms dominated the phytoplankton community. The reason for the relative increase of copepods (calanoid and cyclopoids) during this period may be due to the increasing diatoms and other small phytoplanktons during the rainy months that was caused by runoff and partial mixing due to the cold runoff introduced into the lake. Similar results were reported from other Ethiopian lakes such as Langano and Abijata (Kasshun Wodajo and Amha Belay, 1984; Ziway, Getachew Beneberu, 2005 and Lake Beseka, Tesfaye Delelegne, 2006).

The copepods declined in numerical density in October (2006) at all stations; during this time diatoms dominated the phytoplankton community. So that, since cyclopoids are omnivorous and raptorial feeders and calanoids use a mixture of passive and active collection for small and large particles respectively (Vanderploeg, 1990), the reason for the decline of copepods may be due to intense predation pressure as juvenile fishes increase in density during this period (Lemma Abera personal communication).

Generally, in Lake Babogaya the relative importance of resource and predator control in shaping zooplankton community structure was observed. The relative importance of resource and predator control in shaping zooplankton community structure is viewed as complementary, not contradictory. Even though, the zooplankton community is expected to respond to changes both in available food resources and in predation pressure, reflecting the “sandwiched” role of zooplankton in aquatic food webs (Gliwicz 2002; Jeppesen *et al*., 2002a), the two forces operate at different time scales. The effect of predation is immediate, while it requires more time to transform enhanced productivity into new biomass and this time lag is dependent on the generation time of organisms (Reynolds, 1994; Kairesalo *et al*., 1998; Gliwicz, 2002). Therefore, during this period the response of the zooplankton community tends to be more vigorous to manipulations of fish than food in Lake Babogaya.

In addition, another higher density of copepods was observed from (November 2006 to January 2007) with a peak value in December 2006, in all sites. It was coincided with the mixing periods of the Lake, as Wood, *et al.*, (1976), reported that Lake Babogaya has a period of mixing from November to February. The reason for the maximum density of copepods in the study lake may be associated with seasonal mixing of the water column, which distributes nutrients that enhance primary production, as sufficient light is available throughout the year. Lewis, (1983); Degenbol and Mapila, (1982), also reported that wind associated seasonal mixing and the associated redistribution of nutrients stimulates zooplankton population increases. Generally, crater lakes have a small surface area relative to their great depth and are often stratified. Despite the sheltering-effect of the crater rims, special weather conditions can cause complete mixing of lake contents (Jamie Bartram and Richard Balance, 1996). Furthermore, Seyoum Mengistu and Fernando (1991) also reported that, in Lake Awasa zooplankton density increased during mixing periods of the lake whereas they show low number in period of stratification. Moreover, in Lake Babogaya (Bishoftu Guda) during this period the abundance of planktivores fishes like *Oreochromis niloticus* and *Tilapia zillii* was very low as compared to the other sampling periods (Kemal Mohammed personal communication), so that the predation pressure on zooplankton groups was low during these periods that may cause to the increase of the density of copepods.

Conversely, in Lake Babogaya copepods were not observed in February and March, (Fig.4) the reason might be their mode of reproduction. The copepods have obligatory sexual reproduction and longer life cycles resulting in a reduced number of generations compared to those of rotifers and cladocerans (Monakove, 2002). According to Dussart and Defaye (1995), most Calanoida are herbivorous, feeding on algae, whereas Cyclopoida tend to be more omnivorous, feeding additionally and even preferentially on other planktonic and also benthic micro invertebrates. Although the diet and the niche amplitude favour this group regarding resource allocation, the copepods have obligatory sexual reproduction and longer life cycles resulting in a reduced number of generations compared to those of rotifers and cladocerans.

Table. 4 One-way analysis of variance for Copepods abundance between sampling stations and months. **Note:** E+11=10^{11}

Between sampling months

Source	DF	SS	MS	F	P
Month/year	8	3.24486E+11	40560736731	11.35	0.000
Error	68	2.42982E+11	3573258568		
Total	76	5.67467E+11			

Between sampling sites

Source	DF	SS	MS	F	P
Site	2	30351558213	15175779107	2.09	0.131
Error	74	5.37116E+11	7258323220		
Total	76	5.67467E+11			

Note: site A=near shore, site B=center, site C =shore

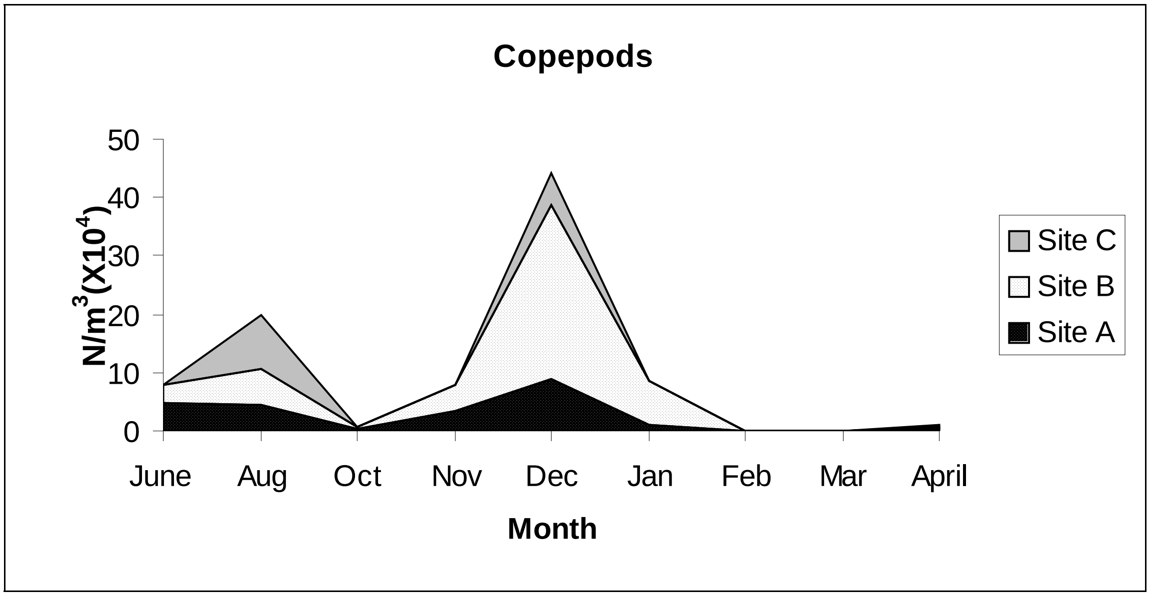


Fig.4 Mean monthly abundance (N/m^3) of copepods at the three sites (From June 2006-April 2007).

Cladocera

Diaphanosoma exisum was the dominant species among the cladocerean groups in Lake Babogaya. Cladocerans community contributed less when compared to the numerical density of rotifers and copepods. Cladocerans exhibited a significant seasonality in their abundance in Lake Babogaya. The variation in seasonality (mean monthly total) of cladocera was highly significant (ANOVA, P< 0.001), but the variation among the sampling sites for the mean total cladocera was not statistically significant (P=0.12), (Table.5). The number of cladocerans in Lake Babogaya showed irregular fluctuations patterns in the dry season. This pattern, however, was changed during the wet and mixing periods when the number increased drastically at all sampling stations.

The cladocerans community was observed in high numbers during the wet season (June and August) (Fig. 5). In Lake Babogaya the big rain extends from June to September. The increase in density of cladocerans during the wet season might be associated with allochthnous organic matter input into the lake that is favoring the growth of some phytoplankton. Consequently, phytoplankton species in the lake may be shifted to edible phytoplankton by filter-feeder cladocerans. The dominant phytoplankton during this season was small size diatoms, which are edible by filter feeder cladocerans. In addition, the particulate organic matter serves as a medium for the growth of bacteriophytes that are a good source of food for cladocerans.

Eshete Dejen, (2004), also reported that, in Lake Tana the allochthonous dissolved nutrients washed into the lake combined with the higher water temperature prevalent at the wet period, should induce higher phytoplankton production which in turn could supports higher cladocera production (Morgan *et al*., 1980), In Lake Langano and Abijata, Kasahun Wodajo and Amha Belay (1984), Lake Awasa, Seyoum Mengistu and Fernando (1991), Lake Zeway, Getachew Beneberu (2005), Lake Beseka, Tesfaye Delelegne (2006), also reported that there was cldoceran increase during the wet season.

The density of cladocerans declined after the big rain i.e. in October, (2006). The reason for the decline of cladocerans may be heavy predation by juvenile and planktivores fish as juvenile fishes increase in density during this period (Lemma Abera personal communication).

Generally, seasonal variation of resources and top-down control by predators affect cladoceran structure and biomass (e.g. Gliwicz and Pijanowska, (1988); Carpenter and Kitchell, (1993), Plath & Boersma, (2001), also reported that, Daphnids and cladocerans in general are important organisms in the food web of a lake, as they are herbivores and one of the main food sources of planktivorous fish. predation pressure can be one of the most important factors that influence population size and structure.

During this period there was also significant number of colonial blue-green algae that cannot be effectively grazed upon by the filter-feeding Cladocera. Generally, Cladocera have problems with manipulation and consumption of blue-green algal bundles (Dumont, 1977; Edmondson, 1974). Quality and quantity of food can alter species composition as well as the abundance of the species, since particular organisms are highly selective about the size and the type of phytoplankton they eat (Campbell & Haase, 1981).

Burgis (1973) suggested that the lack of small algal particles restrict Cladocera in blue-green algal-rich Lake George, Uganda, and this would apply to most Cladocera (Fernando, 1980b). Arnold (1971) has also shown that blue-green algal cultures fed to Cladocera have an adverse effect on their reproductive rate and longevity. Moreover, daphnids, due to their small size and short generation times, respond rapidly to changes in algal food densities. One of the most important variables affected by changing food is the reproductive rate, influencing the population growth (Nandini & Sarma, 2003). Agrawal, (1998) also reported that, phytoplankton can be poor-quality food because of digestion resistance, chemical deterrents, or constraints on ingestion due to particle size or shape.

On the other hand, another high numerical density of cladocerans was observed from November (2006) to January (2007) with a peak value in December 2006 (Fig.5). The reason for the maximum increase of cladocerans may be associated with the seasonal mixing of Lake Babogaya during this period that distributes the nutrients and enhance the primary production, which contributed better increase in primary production that may be the cause for cladoceran increase. The dominance of dinoflagllates during this period may be due to size –dependent predation upon the food collectors (the herbivorous zooplanktons) Brooks and Dodson (1965). Beadle (1981) argued that the major determinant of circulation and hence production in tropical lakes is wind rather than seasonal fluctuations of illumination and atmospheric temperature since some small sheltered lakes, deep relative to their area in tropical regions are the least productive. Further more, the second reason for cladoceran increase may be their mode of reproduction they have parthenogenetic mode of reproduction i.e. high growth rate within a short period of time (r-strategists).

Table.5 One-way analysis of variance for Cladocera abundance between sampling stations and months. **Note**: (E+12=10^{12},E+11=10^{11})

Between sampling months

Source	DF	SS	MS	F	P
Month/year	8	3.20709E+12	4.00886E+11	10.05	0.001
Error	69	2.75320E+12	39901466509		
Total	77	5.96029E+12			

Between sampling sites

Source	DF	SS	MS	F	P
site	2	3.27565E+11	1.63783E+11	2.18	0.120
Error	75	5.63272E+12	75102948104		
Total	77	5.96029E+12			

Note: Site A= Shore, Site B= center, Site C=Shore

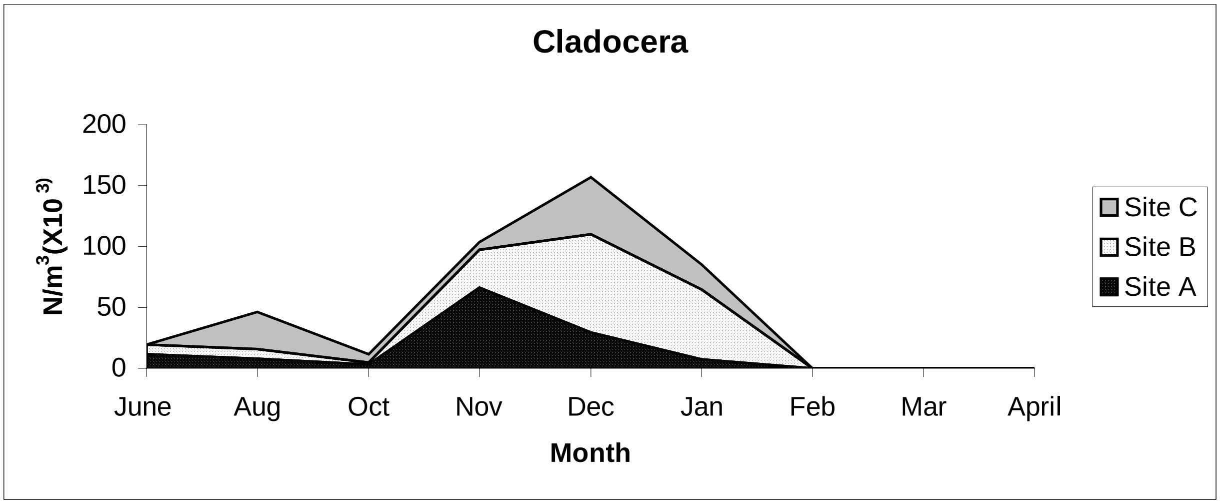


Fig.5 Mean monthly abundance (N/m^3) of cladocerans at the three sites during (June 2006-April 2007).

Rotifers

Rotifers dominate the zooplankton community in Lake Babogaya, in terms of both density and species richness. Rotifers exhibited significant spatial and temporal variation in population density i.e. ($p<0.05$), (Table.6). Their density varied from ($9.3X10^3$) ind/m^3 in November (2006) to ($9.9X10^5$) ind/m^3 in March (2007) at near shore, ($6.1X10^4$) ind/m^3 in January (2007) to ($1.9X10^6$) ind/m^3 at shore in March (2007). (Fig.6)

The peak density was observed in March 2007 at shore site (See Fig. 6). Many authors reported that the seasonality of rotifers in tropical lakes has been ascribed due to a number of climatological and biological factors. During this period the dominant phytoplankton were diatoms in shore and near shore sites. Despite disparity in opinions on the nutritive value of diatoms, there are many field observations supporting that diatoms are excellent food for the growth of herbivores zooplankton (Porter, 1977; Elser, *et al.*, 2001; Jonsen, 1987). The high rotifer numbers during this period may be associated with increasing in the density of edible phytoplankton. Moreover, Yeshimebet Major, (2006), reported that maximum algal biomass was recorded during this period in the same lake. The second reason for the high population density of rotifers may be due to their parthenogenetic reproductive pattern and short developmental rates under favorable conditions and typical r-strategists (Herzig, 1987). Several factors including life cycle traits, feeding mechanisms and metabolism, favor the Rotifera, which have competitive advantages over the other main zooplankton groups such as Cladocera and Copepoda (Allan, 1976; Dumont, 1984).

The third possible reason may be due to the absence of calanoid and cyclopoid copepods, which feed on rotifers. Rotifer and copepods densities appeared to be negatively correlated with each other during this period. In addition, the decline of *Oreochromis niloticus* (planktivorous fish) and juveniles during this period (Kemal Mohammed, personal communication) may fever high rotifer abundance, as rotifers are highly nutritive to planktivorous fish, its protein supports fast growth of fish larvae and juveniles and as such is a booster to fish farmers (Kitto and Bechara, 2004). The dominance of the Rotifers in Lake Babogaya has been documented by Green, (1986). The present study was consistent with Green (1986) in the same lake, Lake Zeway, (Getachew Beneberu, 2005), Lake Hora, (Tamiru Gebre, 2006).

Generally, the maximum abundance of rotifers was in agreement with many authors (e.g. Burgis, 1974) who reported that, the seasonality of rotifers in tropical lakes has been ascribed to a number of climatological factors; rotifers number are highest during the warm, dry months and lowest during the cold period) or during periods of high water transparency (Egborge, 1981). Whereas, in non-eutrophic lakes in temperate regions, the zooplankton are usually dominated by Cladocera species belonging to the family Daphnidae. Where as, In tropical regions the Rotifera have been observed to be dominant irrespective of the level of eutrophication thus suggesting that other factors and particularly the zooplanktonic interactions (competition and predation) may be more important (Rocha *et al*., 1999).

Table.6 One-way analysis of variance for rotifers abundance between sampling stations and months. **Note:** (E+15=10^{15})

Between sampling months

Source	DF	SS	MS	F	P
Month/year	8	2.36973E+15	2.96216E+14	5.97	0.000
Error	69	3.42178E+15	4.95910E+13		
Total	77	5.79151E+15			

Between sampling sites

Source	DF	SS	MS	F	P
Site	2	8.19735E+14	4.09867E+14	6.18	0.003
Error	75	4.97178E+15	6.62904E+13		
Total	77	5.79151E+15			

Note: **Site A = Shore** **Site B= center** **Site C= Shore**

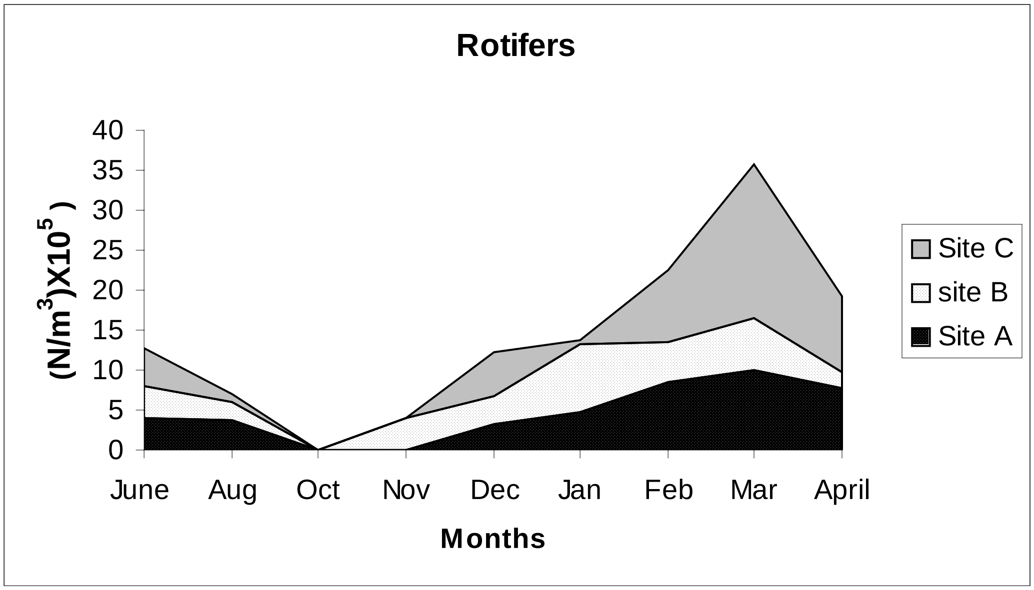


Fig.6 Mean monthly abundance (N/m^3) of rotifers at the three sites during (June 2006 - April 2007).

5.4 Vertical distribution of total zooplankton

The vertical distribution of total zooplankton in Lake Babogaya showed statistically significant variation among the sampling depths ($P<0.05$). (Table.7). In Lake Babogaya (Bishoftu guda), the highest density of zooplankton was registered at 9 and 15 meter depths in both near shore and open water stations during the rainy season (June and August, (2006) (See Fig.7). In this period the peak value of total zooplankton was coincided with the rainy season. The wet season seems to be associated with massive inflow that raise the water level and increase food supplies directly by allochthonus organic matter (Hart, 1985).

Gliwicz and Pijanowska (1988) reported that zooplankton migration into surface waters has usually been thought to reflect a trade-off between improved food conditions and increased risk of fish predation. However, resources from a metalimnetic peak in chlorophyll supported better zooplankton reproduction than resources from surface waters and the subsurface maxima in algal abundance are common, especially in less productive waters (Williamson *et al*., 1996). Likewise, since Lake Babogaya is a relatively deep lake that has a maximum depth of about 71 meters and has relatively higher euphotic depth measurement about 7 meter (see appendix.2), during the wet season, the increasing density of zooplankton towards the lower part of the water column may be due to the presence of high phytoplankton peak.

On the contrary, the abundance of total zooplankton decline at all depths at all stations in October, 2006. Diatoms were dominant to other phytoplankton groups during this period. Despite disparate opinions on the nutritive value of diatoms, there are many field observations supporting that diatom are important to excellent growth for herbivorous zooplankton (Larson *et al.*, 1986). Therefore, the decline in density of the total zooplankton during this period in Lake Babogaya may be due to higher predation pressure (top-down) effect by Juvenile fishes particularly at shallow depths of the shore and near shore stations, and the presence of O*rieochromis niloticus* and *Tilapia zillii* (Planktivores fishes) and *Clarias gariepinus* (omnivores fish) in the open water. Zooplanktons in general are important organisms in the food web of a lake, as they are one of the main food sources of juvenile and planktivorous fish. Predation pressure can be one of the most important factors that influence population size and structure. (Lass & Spaak, 2003; Tollrian & Dodson, 1999).

Moreover, Lemma Abera (personal communication) also reported that zooplankton is the most important diet for *C. gariepinus* in Lake Babogaya (Bishoftu Guda) that contributed 88.2% of the total food ingested indicates that the possible cause for the decline of zooplankton during this period may coincide with predation pressure. Zaret, (1980), reported that predation can be an important force in structuring zooplankton community considering the high mortality rates imposed to their prey.

The second maximum peak of total zooplankton density in Lake Babogaya was observed from December 2006 to March 2007 with the maximum density in January, February and March at 9 and 15-meter depth at near shore station and from 15 to 50meter depth from December to March at the central station. It showed a decline in density at epilimnotic region. (See Fig.7). This decline at the epilimnon region could be due to food limitation, since Lake Babogaya is a nutrient deficient lake with low primary productivity (Yeshimebet Major, 2006). Likewise, Tessier *et al.*, (2001), also reported that food limitation is much stronger in the surface waters of deep stratified lakes than in shallow lakes of similar productivity.

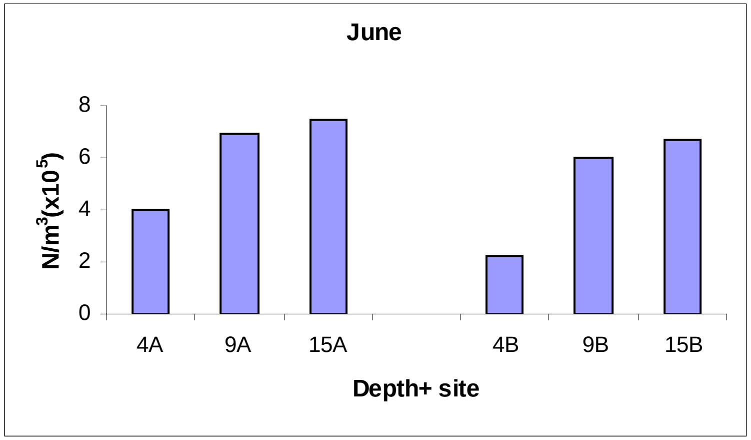
Moreover, the depth selection behavior of zooplankton, which includes some period of diurnal vertical migration, results in the exposure of the animals to a given set of environment variables such as, food, light, temperature, and oxygen concentration. Furthermore, the numerical increase in density towards the lower part of the water column coincided with seasonal mixing of the lake, which may be the cause to increase phytoplankton biomass during this period. In addition, in the same lake, Yeshimebet Major, (2006) reported that, the peak phytoplankton biomass was recorded in March, 2005.

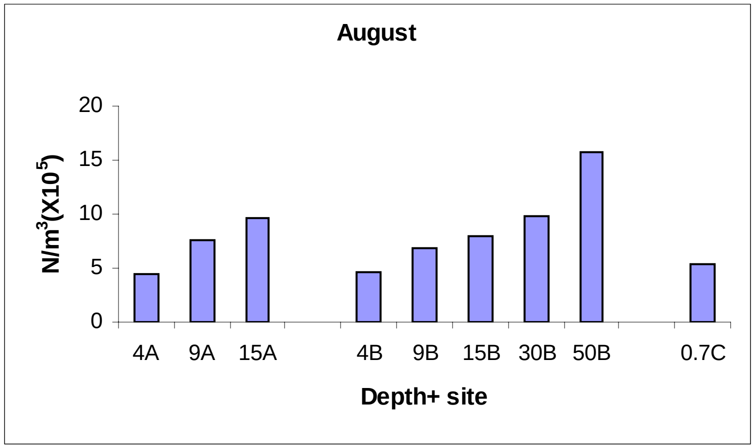
Table.7 One-way analysis of variance for zooplankton abundance in different depth profiles at the three sites

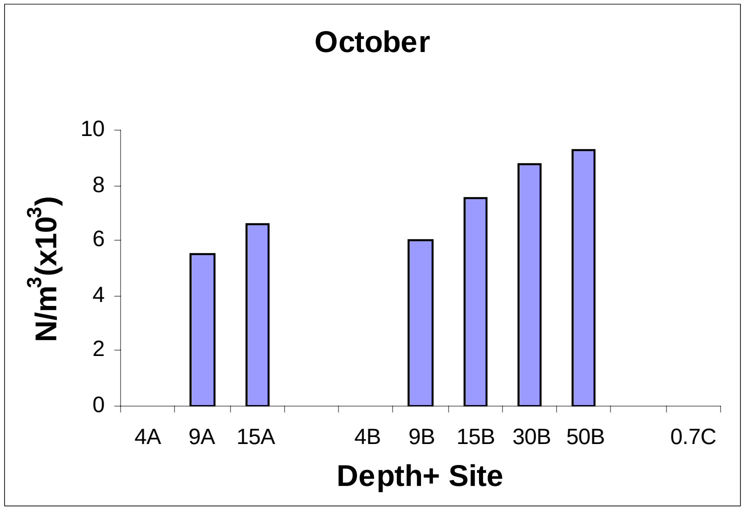
Between sampling depths

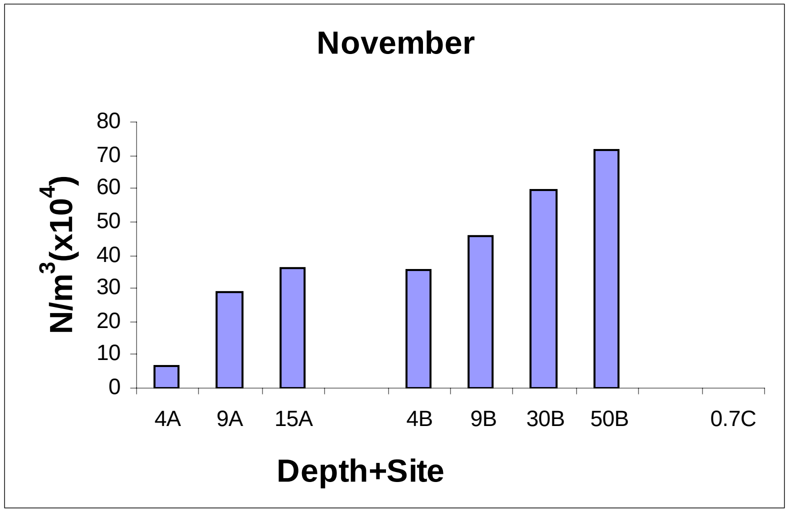
Source	dF	SS	MS	F	sig
Between groups	**12**	**91847857930**	**901488161**	**2123.215**	**0.000**
Within groups	**22**	**8187240**	**3721473.146**		
Total	**34**	**94899730339**			

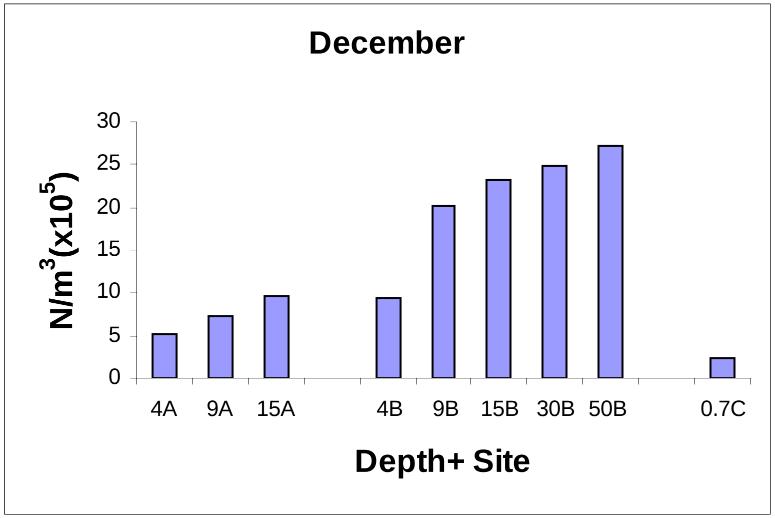
Note: 4A=site A-4meter depth, 9A=Site A-9meter depth, A15=siteA-15meter depth, 4B= siteB-4 meter depth, 9B=Site B-9meter depth, B15=Site B-15 meter depth, B30= siteB-30meter depth, B50=SiteB-50meter depth

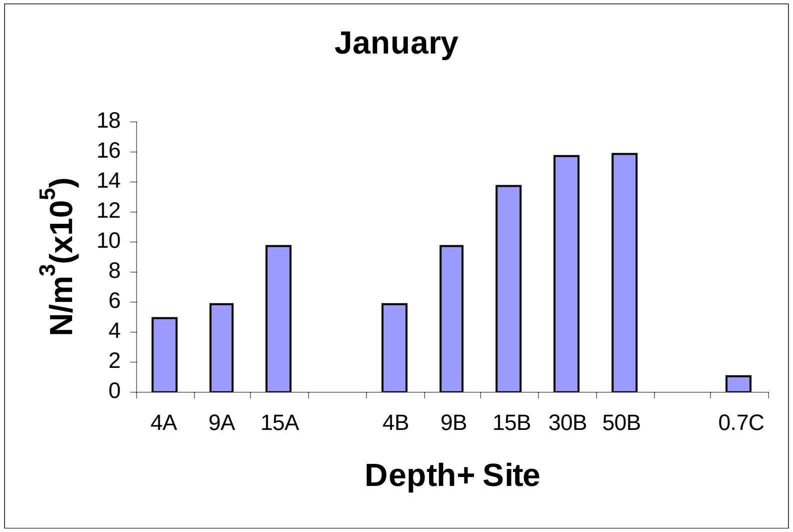









December
N/m^3(x10^5)
0
5
10
15
20
25
30
4A
9A
15A
4B
9B
15B
30B
50B
0.7C
Depth+ Site


January
N/m^3(x10^5)
0
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30B
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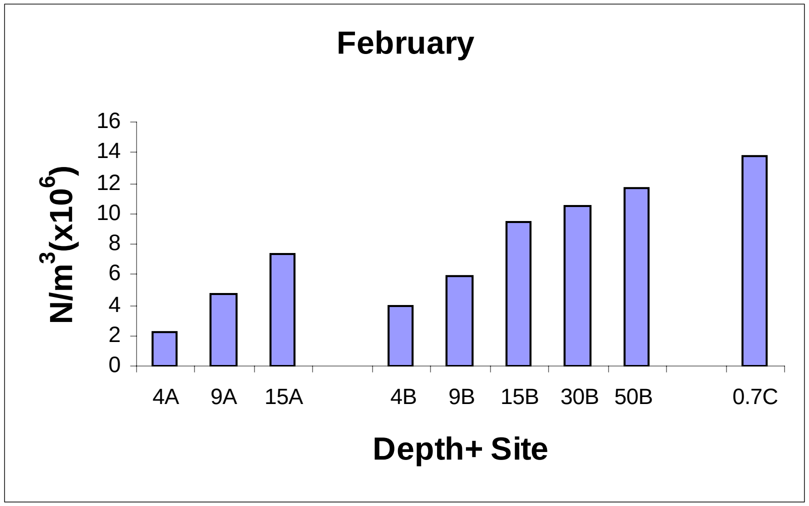
Depth+ Site


February
N/m^3(x10^6)
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30B
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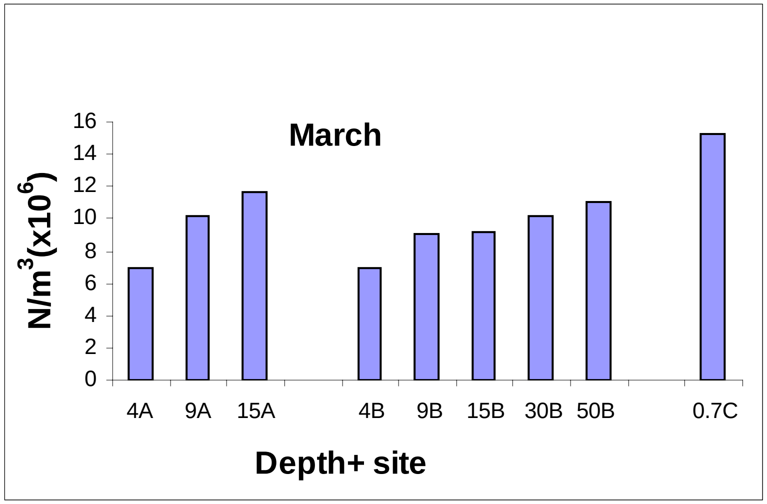
Depth+ Site


March
N/m^3(x10^6)
0
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Depth+ site

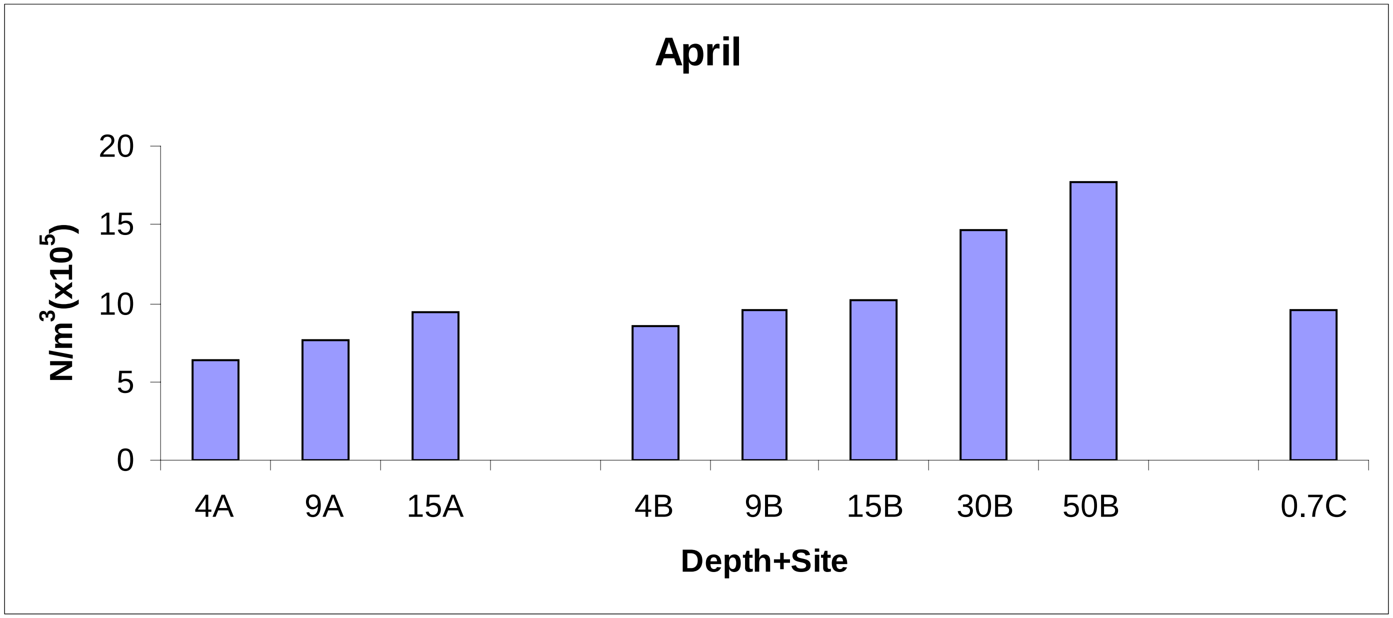

Fig .7 Vertical distribution of the total zooplankton in Lake Babogaya (Bishoftu guda) at the three sites with different depth profiles from (June 2006 to April 2007).

5.5 Diurnal vertical distribution of the major zooplankton groups

The shape of diurnal vertical distribution of the major zooplankton groups (Copepods, Cladocera and Rotifers), in Lake Babogaya (Bishoftu Guda) was observed in the open water station from 0 to 50 meters within 10-meter intervals in December (2006) (Fig.8) and March (2007) (Fig.9).

The presence of diurnal vertical distribution in so many taxa suggests that it has adaptive value. Predator-avoidance is commonly accepted as the ultimate reason for diurnal vertical distribution (Lampert, 1993). The decisive 'benefit' of vertical distribution is a reduction in the risk of predation by visual predators, whose effectiveness is reduced in darker, colder, often hypoxic, deeper waters (Ohman, *et al*., 1983). Although there is no reason to believe the same ultimate factor drives migration in all taxa, it is interesting that all migrating filter feeding zooplankton experience similar disadvantageous of environmental conditions. Migrating animals spend the night in warm food rich surface waters but they leave this advantageous environment during the day to stay in the cold hypolimnion where quality and quantity food are low (Lampert, 1993). Thus several costs are associated with migration. Reduced food availability results slower growth and lower fecundity. The developmental time of eggs carried by females is prolonged at lower temperatures. Moreover swimming up and down the water column needs energy.

In the present study, the vertical distribution of zooplankton was in agreement to normal diurnal vertical distribution. The major zooplankton in Lake Babogaya Rotifers, Copepods and Cladocera did exhibit normal movement patterns. Copepods were highly concentrated at the depth of 10 to 20 m (below euphotic depth) i.e. (208 to 240) ind/liter whereas the concentration decreases towards the lower part of the water column i.e. 30 meter to 50 meter (120 to 56) ind/liter during December 2006 (Fig.8). Similarly, Cladocearans, and rotifers also showed vertical distribution below the euphotic depth. The reason for the maximum abundance of zooplankton below the euphotic depth may be associated with avoidance of predators at the surface water, whose effectiveness is reduced in darker, colder, often hypoxic, deeper water (O'Brien & Vinyard, 1978).

The second reason may be the seasonal mixing of the lake starting from November to February; that cooling and mixing are more likely to follow cloudiness periods (Wood, *et al.,* 1976). Particularly on the sampling date there was high cloud cover with some amount of rain and high amount of wind turbulence. Long-term studies on zooplankton composition have indicated that in tropical regions precipitation and wind are important physical factors affecting zooplankton structure (Matsumura-Tundisi and Tundisi, 1976; Nogueira & Matsumura-Tundisi, 1996).

In addition, many authors reported that, the pelagic habitat of lakes is characterized by pronounced vertical gradients in light, temperature, resources, competition strength and predation risk (Zaret, 1980; DeMott, 1995; Gliwicz, 2002). The vertical stratification of these factors strongly affects the vertical distribution of zooplankton. Many zooplankton species avoid the surface layers during daytime, migrating downward to deep layers and returning to surface waters at night (Gliwicz, 1986; Lampert, 1989; Ringelberg, J.1993; Jeppesen *et al*., 2002).

On a short time scale (e.g. a diel cycle), DVM performers must behave on the basis of their instantaneously acquired information from checking environmental parameters. For example, experimental evidence indicates that animals have good abilities to sense their predators by chemical (Ringelberg, 1991) and mechanical or visual cues (Bollens *et al*., 1994) and can respond behaviorally in as little as a few minutes. Changes in life history traits (e.g. size, energy reserve storage) are the end products shaped gradually by these immediate flexible behaviors, which transform the variations of external factors into physiological adjustment. Thus, in this contribution, animals built a new framework for a DVM performer to immediately trade-off the two major potentially conflicting factors affecting its survival: food uptake and risk avoidance. Moreover Huntley and Brooks (1982) reported that, when food is scarce in the surface waters, the usual DVM performers cease vertical migration until food concentrations attain levels high enough to support it.

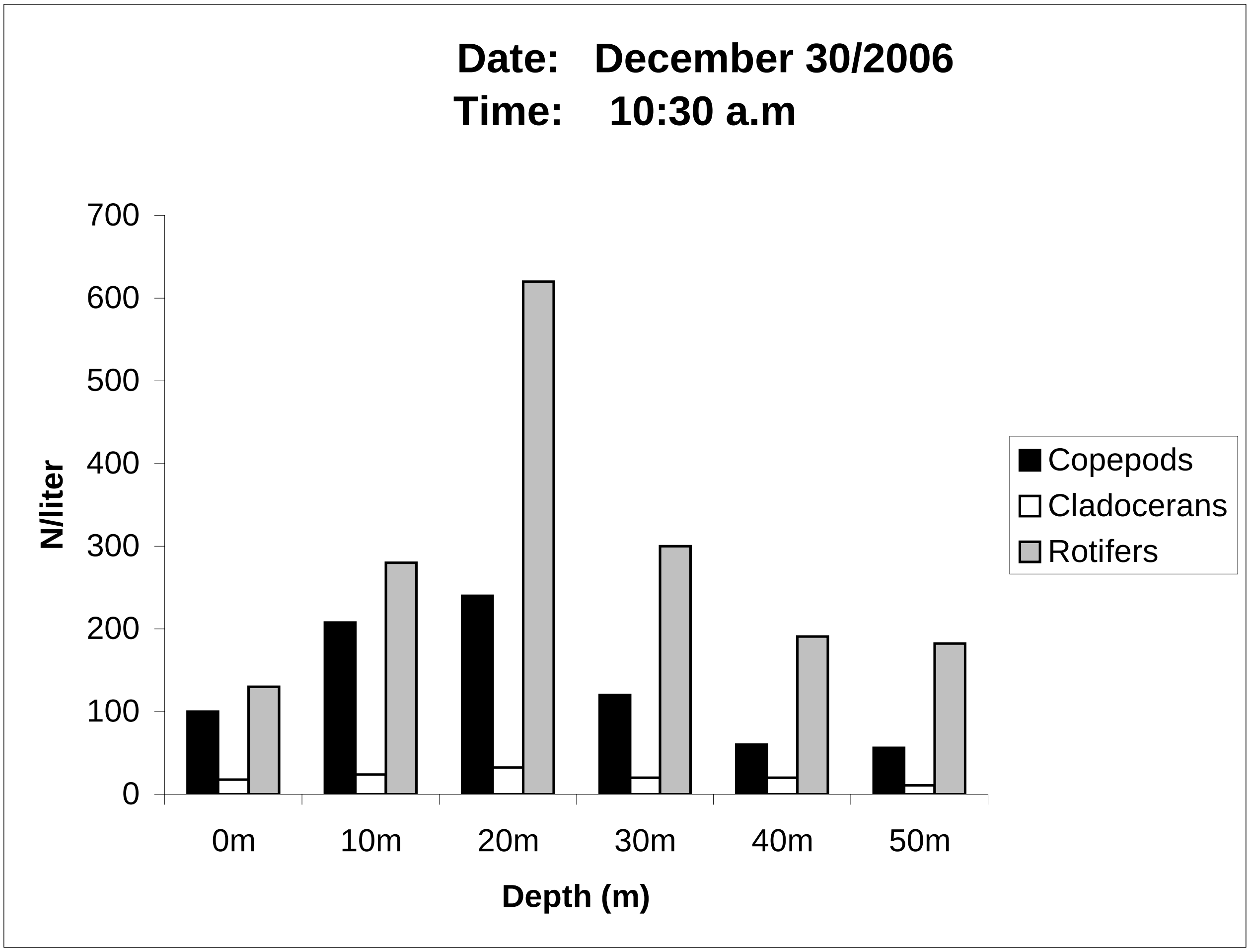

Fig.8. Diurnal vertical distribution of the three major groups of zooplankton copepods, cladocera and rotifers, at central station in December 2006 at 10:30 a.m.

Furthermore, rotifers in (March 2007) were observed in their highest density (6,785ind /lit) concentrated at 20-meter depth to the lowest density (1,256ind/liter) at 50-meter depth (Fig.9). It may be associated to oxygen depletion towards the hypolimnon. Wood *et al.,* (1965) reported that, during the period of stratification there was a sharp fall in oxygen concentration in Bishoftu crater lakes. Particularly, in Lake Babogaya the hypolimnetic water was always anoxic. Hypoxia is widespread in tropical freshwaters particularly in systems characterized by low light and reduced mixing such as heavily vegetated swamps, flooded forests, stagnant pools (Chapman & Kramer, 1991), floodplain lakes and ponds (Welcomme, 1979), and deep waters of some lakes (Wetzel, 1975; Beadle, 1981).

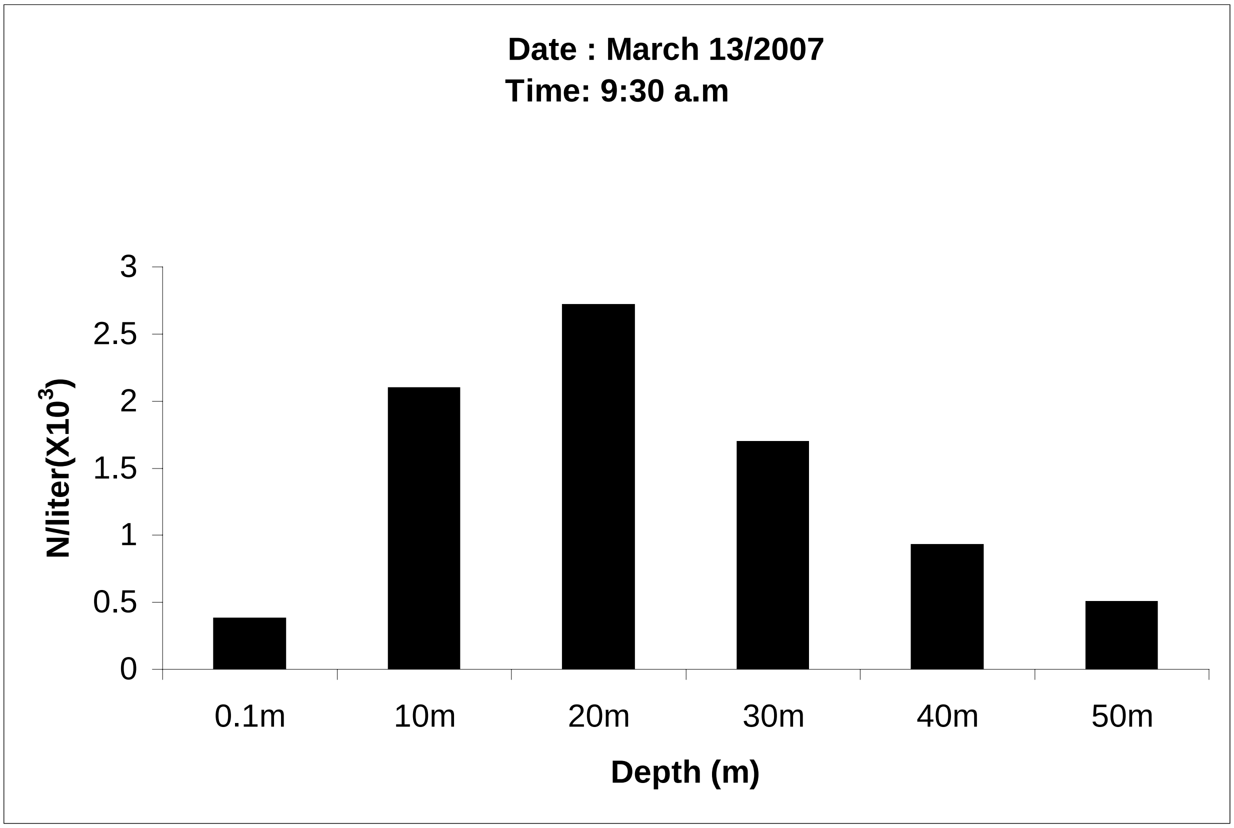

Fig.9 Diurnal vertical distribution of rotifers at central station in March 2007 at 9:30 a.m.

General discussion

The phytoplankton community in Lake Babogaya was constituted for most of the study period largely by dinoflagellates and diatoms whose dominance was favoured by the hydrographic conditions of the lake (physical stratification/mixing), which are regarded as factors of over-riding importance in determining the seasonal dominance of algal groups in Lake Babogaya. Lake Babogaya has low algal biomass and primary production which are associated with unusually low concentrations of nitrate and phosphate, which must have resulted from their low external and internal input into the trophogenic zone (Yeshimebet Major, 2006). The hydrological conditions (water input-output through runoff from precipitation and evaporation) are contributory factors for the marked temporal fluctuations in the abundance, biomass and photosynthetic activity of phytoplankton.

The zooplankton community composition in Lake Babogaya is determined to be a typical of tropical inland water populations. Seasonal variation in zooplankton density and composition (Figs. 4, 5 and 6) was related to some extent to alternating wet and dry season conditions, changes in the density and composition of the phytoplankton and with the change in abundance of juvenile and planktivores fish.

Generally, in Lake Babogaya, both top-down and bottom- up effect control shape the numerical density of zooplankton community. Even though, the zooplankton community is expected to respond to changes both in available food resources and in predation pressure, reflecting the “sandwiched” role of zooplankton in aquatic food webs (Gliwicz 2002; Jeppesen *et al*. 2002a), the two forces operate on different time scales. The effect of predation is immediate, while it requires more time to transform enhanced productivity into new biomass and this time lag is dependent on the generation time of organisms (Reynolds, 1994; Kairesalo *et al*., 1998; Gliwicz, 2002).

The crustacean zooplankton community is dominated by a few species (Table 3.), as in most tropical African lakes studied so far. Furthermore, Rotifera, the dominant group has the highest density with values up to ($1.9X10^6$) ind/m^3 at their maximum in March. The dominance of the Rotifers in Lake Babogaya has been associated with decline of planctivores and juvenile fish, decline of copepods (cyclopid and calanoid), associated with increasing in primary production and maximum algal biomass and probably due to the presence high amount of bacteria which is an important food of rotifers. Yeshimebet Major, (2006) also reported that maximum increase in primary production & maximum algal biomass was recorded during this period. Another reason for the high population density of rotifers may be due to their parthenogenetic reproductive pattern and short developmental rates under favorable conditions and they are typical r-strategists (Herzig, 1987).

Copepods are the second contributors of the zooplankton next to rotifers in Lake Babogaya.There was a clear seasonal variation in the abundance of copepods i.e. the density of copepods was high associated with the rainy season but, the maximum peak was coincided with the mixing period of the lake with values up to 297,000 m^{-3}, in December (2006) (ANOVA, $P<0.05$) (Table.4).

Various workers have highlighted the dominance of copepods in tropical freshwaters e.g. Ferguson, (1982); Carmouze *et al.*, (1983); Serruya & Pollingher, (1983); Hecky, (1981); Drenner *et al.*, (1987). Allan (1976) believes that the K-selected life history of copepods (such as low reproductive rates and low susceptibility to predation) gives them a competitive advantage in seasonally stable ecosystems. Their abundance in tropical lakes perhaps reflects their relative importance as grazer or predator in each system (e.g. 1600 m^{-3} in Lake Langano, 318 000 m^{-3} in Lake Chad, 500 000 m^{-3} in Lake Chilwa or 880,000 m^{-3} in Lake George).

Furthermore, the variation in seasonality (mean monthly total) of cladocera was highly significant (ANOVA, $P< 0.001$), but the variation among the sampling sites for the mean total cladocera was not statistically significant ($P=0.12$), (Table 5). The number of cladocerans in Lake Babogaya showed irregular fluctuations patterns in the dry season. Cladoceran reached population seasonal maxima in December 2006 associated with the mixing periods of the lake (Fig.5). In Lake Babogaya there was a negative relationship between Cladocera and rotifer densities. The alternation between Cladocera and rotifers may have been due to their preference for different types of phytoplankton. The cladoceran maximum coincided with the relative increase of chlorophytes whereas the rotifer maximum coincided with a bloom of diatoms and maximum phytoplankton biomass. During the short rainy period and there was a concomitant increase in densities of rotifers and copepods. The latter increased more slowly, probably because of their lower reproductive rates (Edmondson, 1965; Dumont *et al*, 1975). The densities of all three groups of organisms decreased after the big rains (October, 2006).

Generally, the abundance of cladocerans was comparable with other tropical lakes such as, 19,000 to 150,000 ind. / m^3 in Lake Chad (Carmouze *et al*., 1983); 5,000 to 70,000 ind. / m^3 in Lake Navasha (Mavuti and Litterick, 1981), and relatively higher than Ethiopian Lakes, Awassa 18,000 ind./ m^3, Seyoum Mengestou, (1989); Langano and Abiata 20 - 24 x 10^3 ind. / m^3; Kasshun Wodajo and Amha Belay, (1984), $20X10^3$ ind. ind. / m^3 in Lake Beseka Tesfaye Delelegne, (2005).

Moreover, the vertical distribution of the total zooplankton in Lake Babogaya in most sampling periods was observed with a maximum increase in 9 to 15 meter depths (below the euphotic depth) at the near shore and between 15 to 50meter depths in open water stations. Whereas it declines towards the epilimnon region, this decline at the epilimnon region could be due to food limitation. Tessier *et al.,* (2001), also reported that food limitation is much stronger in the surface waters of deep stratified lakes than in shallow lakes of similar productivity.

Furthermore, many taxa of marine and fresh water zooplankton perform diel vertical migrations with amplitudes from a few to 100 meters (Hutchinson, 1967). The normal pattern is an evening ascent and morning descent. Migrating animals spend the day in deep waters, but stay near the surface at night. The amplitude of the movements and the shape of vertical distribution between populations may be different between species and between ontogenetic stages of the same species and may be influenced by factors such as turbidity and food abundance (Bohrer 1980; George 1983). Zooplankton may migrate up and down together in a narrow band or may be sharply stratified in deep waters during the day but spread throughout the entire water column at night.

In Lake Babogaya the shape of diurnal vertical distribution of the major zooplankton groups (Copepods, Cladocera and Rotifers), during December (2006) and March (2007) was in agreement with to the normal pattern. They were more concentrated at 10 and 20 meter depth (below the euphotic depth). The reason may be due to subsurface maxima in algal abundance and predator avoidance. Williamson *et al*. (1996) showed that resources from a metalimnetic peak in chlorophyll supported better zooplankton reproduction than resources from surface waters. They also pointed out that subsurface maxima in algal abundance are common, especially in less productive waters.

Generally, in the present study, zooplankton density had significant variation with change in phytoplankton production and high predation pressure. Therefore, the results indicated that phytoplankton biomass and primary production and the density of predators regulate the total zooplankton dynamics in the Lake Babogaya. However, other combined factors may also play a role. Similar results have been reported for some Kenyan lakes (Haken *et al*., 2003). Zooplankton density fluctuations in these lakes were closely related to the combined effect of annual rainfall pattern, nutrient inputs from catchments and primary production in the lakes.

6.Conclusions and recommendations

6.1 Conclusions

- Zooplankton abundance in Lake Babogaya varies significantly among the sampling months and depth. But, there is no significant variation between sampling sites, except for rotifers.
- Rotifers accounted for most of zooplankton abundance in the lake. The maximum abundance of rotifers was during the dry period and declined after the big rain.
- Copepods followed the rotifers in terms of abundance. It was represented only by five genera and dominated by *Mesocyclops aequatorialis similis and Afrocyclops gibsoni ondoensis.*
- The maximum abundance coincides with wet season and mixing periods.
- Cladocerans with three genera recorded were the least abundant of the zooplankton taxa in the lake. *Diaphanosoma exiscum* dominated the cladocera population. The maximum abundance of cladocerans was found during wet and mixing periods, while the lowest abundance was found after the big rain and dry periods.
- Total zooplankton abundance in Lake Babogaya varies significantly with phytoplankton biomass and predation pressure.
- Both bottom up and top-down effect controls zooplankton density.
- Rainfall pattern and seasonal mixing were key factors regulating seasonal variation in zooplankton numbers.

- Their highest densities were recorded in the wet and mixing periods and lower numbers were recorded after a big rain in October.
- Vertical distribution of zooplankton is mostly observed below the euphotic depth.

6.2 Recommendations

1. Further study on the population dynamics and production of zooplankton are useful because the quantification of zooplankton production helps in the understanding of fish production.

2. Future studies should include zooplankton interaction with phytoplankton in relation to measurements of temperature and dissolved oxygen along a vertical profile that extends to the deepest parts of the water column.

3. The tendency to use the lake shore for building resort facilities, fishing and filleting, recreation, watering animals and washing clothes needs proper management by authorized governmental bodies and by the local people.

7. REFERENCES

Agrawal, A. A. (1998). Algal defenses, grazers and their interactions in aquatic trophic cascades. *Acta Oecol*.**19:** 331–337.

Allan, J. D., (1976). Life history patterns in zooplankton. *Am. Nat*. **110:** 165-176.

Baxter, R. M., M. V. Prosser, J. F. Talling and R.B.Wood, (1965). Stratification in tropical African lakes at moderate altitudes (1500 to 2000m). *Limol.Oceanog*.**10:** 510-520.

Baxter, R.M. (2002). Lake morphometry and chemistry. **In**: *Ethiopian Rift Valley lakes,* Tudorancea, C. and Taylor, W.D. (eds.), Backhuys Publishers, Leiden, The Netherlands. 45-60 pp.

Bayly, I. A. E. (1986). Aspects of diel vertical migration and its enigma variations. **In**: *Limnology in Australia.* De Decker, P. and Williams, W. D. (eds). Monogr. Biol., 61, Dr W. Junk, Amsterdam, 349–368 pp.

Beadle, L. C., (1981). The Inland Waters of Tropical Africa: Belsley, D. A., E. Kuh and R. E. (eds). **In**: *An Introduction to Tropical Limnology*. Longman, New York. 475 pp.

Beadle, L. C., (1981). *The inland waters of Tropical Africa*.2nd edn. Longmans, London, 465 pp.

Bollens S.M. and Frost B.W. (1989). A predator-induced diel vertical migration in a planktonic copepod. *Journal of Plankton Research* **11:** 1047–1065.

Bollens, S. M., Frost, B. W. and Cordell, J. R. (1994). Chemical, mechanical and visual cues in the vertical migration behavior of the marine planktonic copepod *Acartia hudsonica*. *J. Plankton Res.* **16:** 555–564.

Brett, M. T. and C. R. Goldman, (1997). Consumer versus resource control in freshwater pelagic food webs. *Science* **275:** 384–386.

Brooks, J. L. and Dodson, S. I., (1965). Predation, body size, and composition of plankton. *Science* **150**: 28-35.

Burgis, M.J., (1971). A preliminary study of the ecology of zooplankton in Lake George, Uganda. *Fresh wat.Biol*.**4:** 535-541.

Burgis, M.J., (1973). Observation on cladocera of Lake George, Uganda .*J. Zool.* **170:** 339-349.

Burgis, M.J., (1974). Revised estimates for the biomass and production of zooplankton in Lake George, Uganda. *Fresh water boil.* **4:** 535-541.

Campbell, J. M. and Haase, B. L., (1981). Availability of suitable phytoplanktonic food for zooplankton in an ice-covered lake. *Hydrobiologia* **79:** 113-119.

Cannicci, G. and Almagia, F. (1947). Notizie sulla'Facies' Planctonica di Alcuni Laghi Della Fossa Galla. Boll. Pesca Piscicult. *Idrobiol*. **23:** 54-74.

Carmouse, J.P., R. Durand and Leveque C. (eds), (1983). *Lake Chad: Ecology and productivity of a shallow tropical ecosystem Monographiae Biologicae*. Dr w. Junk publishers, Vol.53. The Hague, 575 PP.

Carpenter S. R. and Kitchell J. F. (1993). *The Trophic Cascade in Lakes*. Cambridge, Cambridge University Press, Cambridge, UK.

Chapman, L. J. & D. L. Kramer, (1991). Limnological observations of an intermittent tropical dry forest stream. *Hydrobiologia,* **226:**153–166.

Chutter, F.M., (1985). Seasonality/aseasonality: chairman's summary. *Hydrobiologia,* **125**: 191-194.

Davis, C.C. (1996). A Comparison of the zooplankton in two Newfoundland bays with differing influences from major currents. *Int. Review Hydrobiol.***71:** 11-47.

Defaye, D. (1988). Contribution a laconnaissance des crustaceas copepods d’Ethiopiae. *Hydrobiologia,* **164:** 103-147.

Degenbol, P. and S. Mpila, (1982). Limnological observations on the pelagic zone of Lake Malawi from (1978) to (1981). MLW/75/019. *Technical Report No. 1*. FAO. Rome.

DeMott W.R. (1995). The influence of prey hardness on Daphnia’s selectivity for large prey. *Hydrobiologia,* **307:**127–138.

Donald, D. B., R. D. Vine Brooke, R. S. Anderson, J. Syrian's & M. D. Graham, (2001). Recovery of zooplankton assemblages in mountain wetlands from the effects of introduced sport fish. *Canadian Journal of Fisheries and Aquatic Sciences* **58:** 1822–1830.

Drenner, R. W., De Noyelles Jr., F. and Kettele, D., (1982). Selective impact of filter-feeding gizzard shad on zooplankton community structure. *Limnol. Oceanogr.* **27(5**): 965-968.

Dumont, H. J., (1977). Biotic factors in the population dynamics of rotifers. Arch. *Hydrobiol. Beih*. **8:** 98-122.

Dumont, H.J., and Tundisi, J.G. (ed.), (1984). Tropical zooplankton. *Developments in Hydrobiology* **23:** 1-344.

Dumont, H.J. (1994). On the diversity of cladocera in the tropics. *Hydrobiologia*, **272:** 27-38.

Dusart, B.H., Fernando, T. Matsumura- Tundisi and Shiel, R.J. (1984). A review of systematics, distribution and ecology of tropical fresh water zooplankton. *Hydrobiologia*, **113:**77-92.

Dussart, B.H. and Dafaye, D. (1995). *Introduction to the Copepoda*. Bachhuys, Leiden, 277pp.

Durand, J.R. and Leveque, C. (1980). Flore et Faune aquatiques de L’Afrique sahelo-Soudanienne, O.R.S.T.M., Paris.

Edmondson, W. T., (1965). Reproductive rate of planktonic rotifers as related to food and temperature in nature. *Ecol. Monogr*. **35:** 61-111.

Edmondson and Winberg, G.C (1971). *A manual on methods for the assessment of secondary productivity in fresh waters*. Oxford black well Scientific Publications.*1BP hand book17*. 358 Pp.

Edmondson, W. T. (1974). Secondary production. Mitt . *int. Ver. Limnol.* **20:** 229-272.

Egborge, A. B. M., (1981). The composition, seasonal variation and distribution of zooplankton in Lake Asejire. Nigeria. *Rev.zool.Afr*. **95(**1): 136-180.

Egborge, A. B. M., (1994). Salinity and the distribution of rotifers in the Lagos Harbour-Badagry Creek system, Nigeria. *Hydrobiologia*, **272:** 95-104.

Elmegren, R. (1978). Structure and dynamics of Baltic benthos communities, with particular reference to the relationship between macro and mieofunna. *Kieler Meeresforsch sonderh.***4**: 1-22.

Elser, J.J., Hayakawa K. and Urabe J. (2001). Nutrient limitation reduces food quality for zooplankton: Daphnia response to seston phosphorus enrichment. *Ecology,* **82:** 898–903.

Eshete Dejen., Jacoubs, V., Nagelkerk, A.J.Leo. Sibbing, F.A. (2004). Temporal and spatial distribution of micro crustacean zooplankton in relation to turbidity and other environmental factors in a large tropical lake (Lake Tana, Ethiopia). *Hydrobiologia*. **513:** 39-49.

Fernando, C.H., (1980a). The fresh water zooplankton of Sri Lanka, with a discussion of tropical zooplankton composition. Int.Rev.ges. *Hydrobiol*. **65:** 85-125.

Fernando, C.H., Seyoum Mengestou and Semeneh Belay, (1990). The chydorid crustaceans, *Alona diaphana* (king) Limnatics in Lake Awassa and Zeway, Ethiopia. Discussion with a Pelagic and Limnatic Zooplankton. *Hydrobiologia*. **75:**15-25.

Fernando, C.H. (2002). *A guide to tropical fresh water zooplankton*: *Identification, Ecology and Impact of fisheries*. Backhuys Publishers, Leiden, The Netherlands. 291Pp.

Gaines, G. and Elbrachter, M. (1987). Heterotrophic nutrition. ***In****: The Biology of Dinoflagellates* (Taylor, F.J.R., and ed.), Botanical Monographs 21, and Blackwell Scientific Publications.225-268 pp.

Galkovskaja,G.A.(1987).Planktonic rotifers and temprature. *Hydrobiologia* **147:**307-317.

Gannon, J. E. and Stemberger, R. S., (1978). Zooplankton (especially crustaceans and rotifers) as indicators of water quality. *Trans Amer. Micros. Soc.*, **97(1):** 16-35.

Gasse, F. (1986). *East African diatoms*: Taxonomy and ecological distribution. Gebruder Burntraeger, Berlin.

Getachew Beneberu, (2005). Study on littoral dynamics in Lake Ziway. M.Sc. Thesis. Addis Ababa University. 65pp.

Ghadouani, A., Pinel-Alloul B. and Prepas, E. E. (2003). Effects of experimentally induced cyanobacterial blooms on crustacean zooplankton communities. *Freshwater Biology* **48:** 363–381.

Ghadouani, A., B. Pinel-Alloul, Y. Zhang and Prepas, E. E. (1998). Relation ships between zooplankton community structure and phytoplankton in two lime-treated eutrophic hard water wetlands. *Freshwater Biology* **39:** 775–790.

Gliwicz, Z. M. (1986). Predation and the evolution of vertical migration in zooplankton. *Nature,* **320:**746-748.

Gliwicz, Z. M. and Pijanowska, J. (1988). Effect of predation and resource depth distribution on vertical migration of zooplankton. *Bulletin of Marine Science,* **43(3**): 695-709.

Gliwicz, Z. M., and Pijanowska, J. (1989). Effect of predation and resource depth distribution on vertical migration of zooplankton. Bull. *Mar. Sci.* **43:** 695–709.

Gliwicz, Z. M. (2002). On the different nature of top down and bottom up effects in pelagic food webs. *Fresw. Biol.* **47**: 2296-2312.

Gras, R., Iltis A. and Leveque-Duwat, S. (1967). La plankton du bas chari et de la partie ouest du Lac T chad. Cah. O.R.S.T.O.M. Ser. *Hydrobiologie* **1:** 25-100.

Greboval, D., Bellemans, M., and Fryd, M., (1994). Fisheries characteristics of the shared lakes of the East African Rift. FAO. Rome. *CIFA Technical Paper No. 24.*

Green, J. (1986). Zooplankton associations in some Ethiopian crater lakes. *Freshwat.Biol.* **16:**495-499.

Graham, L.E. and Wilcox, L.W. (2000). *Algae*. Prentice-Hall, Inc. London.

Haken, J. W., David, H. and Nils, T.W. (2003). A first limnological description of Lake Kichirititch, Kenya; a possible reference site for the freshwater lakes of the Geregory rift valley. *South Africa. J. Science***, 99**: 494-496.

Hampton, S. E. & J. J. Gilbert, (2001). Observations of insect predation on rotifers. *Hydrobiologia* **446/447**: 115–121.

Hart, R.C., (1981). Population dynamics and demography of an estuarine copepod (psedodiaptomus hessei) in Lake Sibaya, a subtropical fresh water coastal lake. J. Limnol. *Soc.S.Afr*. **7:** 13-32.

Hart, R.C., (1985). Seasonality of aquatic invertebrates in low- latitude and southern Hemisphere inland waters. *Hydrobiologia* **125:**151-178.

Havens, K.E. (2002). Zooplankton structure and potential food web interactions in the plankton of a subtropical chain-of-lakes. *Sci. World J.* **2**: 926–942.

Hecky, R.E. and Fee, F.J. (1981). Primary production and rates of algal growth in Lake Tanganyika. *Limnol.Oceanogr*. **26: 532-**547.

Herzig, A., (1987). The analysis of planktonic rotifer populations: a plea for long-term investigations. *Hydrobiologia*, **147:** 163-180**.**

Hillbricht-Ilkowska, A., (1977). Trophic relations and energy low in pelagic plankton. *Polish Ecological Studies* **3:** 3–98.

Hindak, F. (2000). Morphological variation of four planktonic nostocalean Cyanophytes - members of the genus *Aphanizomenon* or *Anabaena*? *Hydrobiologia***,** **438:**107-116.

Hotzel, G. and Croome, R. (1999). *A phytoplankton methods manual for Australian fresh waters.* Land and Water Resource Research Development Corporation, Canberra, 51pp.

Hutchinson G.E. (1967). Introduction to Lake Biology and the Vol. 2. Limno plankton, *A Treatise of Limnology*. John Wiley and Sons, New York, p. 1115.

Jamie Bartram and Richard Balance, (1996). Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater. United Nations Environment Programme and World Health Organization (UNEP/WHO).

James, W.F., Tayllor, W.D., and Barko, J.W. (1992). Production and vertical migration of Ceratium hirundinella in relation to phosphorus availability in Eau Galle Reservoir, Wisconsin. *Can.J. Fish. Aquat.Sci*. **49**: 694-599.

Jeeji-Bai, N., Hegewald, E. and Soeder, C. J. (1977).Revision and taxonomic analysis of the genus *Anabaenopsis*. *Arch. Hydrobiologia*. **51**:3-24.

Jeppesen, E., Jensen, J. P., Søndergaard, Ma. (2002a). Response of phytoplankton, zooplakton and fish to reoligotrophication. An 11-year study of 23 Danish lakes. *Aquatic Ecosystem Health & Management* **5:** 3142.

John, D.M., Whitton, B.A., Brook, A.J. (eds.) (2002). The freshwater algal flora of the British Isles: An identification guide to freshwater and terrestrial algae. The British Physiological Society, Cambridge.

Johnson, R. (1987). Seasonal variation in diet of Chironomus plumosus L. and C. antharacinus Zett (Dipthera: Chironomidae) in mesotrophic Lake Erken. *Freshwater Biol.* **17:**525-532.

Kassahun Wodajo, K. and Amha Belay, (1984). Species composition and seasonal abundance of zooplankton in two Ethiopian Rift Valley lakes - Lakes Abiata and Langano. *Hydrobiologia* **113:**129-136.

Kairesalo, T., Tátrai, I. and Luokkanen, E. (1998). Impacts of waterweed (Elodea Canadensis Michx) on plankton fish interactions in the lake littoral. *Verh. Int. Verein. Limnol.* **26:** 18461851.

Kitto, M.R, Bechara G.P. (2004). Business agriculture in Kuwait challenges and solutions, *World Aquaculture* **35(2):** p.56.

Komarek, J. and Crenberg, G. (2001). Some chroococcalean and Oscillatorial- ean cyanoprokaryotes from South African lakes, ponds and pools. *NovaHed- wigia,* **73:** 129 -160.

Komarek, J. and Komarokova, J. (2002). Review of the European *Microcystis-morphospecies* (cyanoprokaryotes) from nature. *Czech phycology, Olomouc*, **2**:1-24.

Lampert, W. (1989). The adaptive significance of dial vertical migration of zooplankton. *Functional Ecology* **3**:21-27.

Lampert, W. (1993). Ultimate cause of diel vertical migration of zooplankton: New evidence for predator avoidance hypostasis. *Arch. Hydrobiol. Ergebn. Limnol*. **39**:79-88.

Lamb, H.F. (2001). Multi-proxy records of Holocene Climate and Vegetation change from Ethiopian Crater Lakes. Institute of Geography and Earth Sciences, University of Wales Aberystwyth, Aberystwyth, http://www.ria.ie/cgi bin/ria/ papers.

Larsson, U;Hobro,RR.7Wulf,F.(1986). Dynamics of phytoplankton spring bloom in a costal area of the northern Baltic proper. contur, Asco lab.Univ.Stockholm **30** :1-32.

Lass, S. and Spaak, P. (2003). Chemically induced anti-predator defences in plankton: a review. *Hydrobiologia*, **491:** 221-239.

Lauridsen, T., E. Jeppesen, M. Sondergaard and Lodge, D. M. (1998). Horizontal migration of zooplankton: predator-mediated use of macrophyte habitat. **In:** *The Structuring Role of Submerged Macrophytes in Wetlands* Jeppesen, E., Ma Søndergaard, M.o. Sondergaard and Kirsten, C. (eds), Springer Verlag Inc, New York: 233–239.

Lehman, J. T., (1984). Grazing, nutrient release, and their impacts on the structure of phytoplankton communities. **In:** *Trophic interactions within aquatic ecosystems* Meyers, D. G. and Strickler J. R. (*ed*s). AAAS selected symposium 85 West view Press Inc, Boulder, Colorado: 49–72.

Levandowsky M. and Kaneta, P.J. (1987). Behaviour in dinoflagellates. **In:** *The Biology of Dinoflagellates.* (Taylor, F.J.R., ed.), pp. 360-391.

Lewis, W, M., (1979). *Zooplankton community analysis*. Springer-Verlag, New york. 163pp.

Lewis, W. M. Jr., (1983). A revised classification of lakes based on mixing. *Can. J. Fish. aquat.Sci*. **40**: 1779-1787.

Lewis, W.M. (1987). Tropical limnology.*Ann.Rev.Ecol.Syst*.**18**:159- 184.

Lowndes, A. G., (1930). Freshwater Copepoda from Abyssinia collected by J. Omer Cooper. *Proc. zool. Soc*. **11:** 161-179.

Main, T. M., Dobberfuhl D. R., Elser, J. J. (1997). N: P stoichiometry and ontogeny of crustacean zooplankton: a test of the growth rate hypothesis. *Limnology and Oceanography* **42**: 1474–1478.

Matsumara-Tundisi, T. and Tundisi, J. G., (1976). Plankton studies in a lacustrine environment. I. Preliminary data on zooplankton ecology of Broa Reservoir. *Oecologia*, **25:** 265-270.

Mavuti, K. H. and Litterick, M. R. (1981). Species composition and distribution of zooplankton in a tropical lake. Lake Naivasha, Kenya. *Arch. Hydrobiol*. **93**: 52-58.

Mavuti, K.M., (1990). Ecology and role of zooplankton in the fishery of Lake Naivasha.*Hydrobiologia* **208:**131-140.

Melak, J. M. (1979). Temporal variability of phytoplankton in tropical lakes. *Oecologia*, **44:**1-7.

Monakove, A. (2002). *Feeding of fresh water invertebrates*. Kenobi production Belgium.400pp.

Morgan, N. C., Backiel, G., Bretscko, A., Duncan, A., Hillbricht-Ilkowska, Z., Kajak, J. F., Kitchell, P., Larsson, C., Leveque, A., Nauwerck, F., Schiemer and Thorpe, J. E. (1980). Secondary production. **In**: *The functioning of freshwater ecosystems*. Le Cren, E. D. and Lowe-McConnell, R. H. (eds). I.B.P. No. 22: Cambridge University Press. Cambridge. 247-340 pp.

Moss, B. (1994). Brackish and freshwater shallow wetlands– different systems or variations on the same theme? *Hydrobiologia,* **275/276:** 1–14.

Nandini, S. and Sarma, S. S. (2003**).** Population growth of some genera of cladocerans (Cladocera) in relation to algal food (*Chlorella vulgaris*) levels. *Hydrobiologia* **491:** 211-219.

Nilssen, J. P., (1984). Tropical lakes functional ecology and future developments: the need for process oriented approach. *Hydrobiologia* ***113****:* 231-242.

Nogueira, M. G. and Matsumura-Tundisi, T., (1996). Limnologia de um sistema artificial raso (Represa do Monjolinho São Carlos, SP). Dinâmica das populações planctônicas. *Acta Limnol. Brasil*, **8:** 149-168.

Ohman M.D., Frost B.W. and Cohen E.B. (1983). Reverse diel vertical migration: an escape from invertebrate predators. *Science*, **220:** 1404–1407.

O'Brien W.J. and Vinyard G.L. (1978). Polymorphism and predation: the effect of invertebrate predation on the distribution of two varieties of Daphnia carinata in South India ponds. *Limnology and Oceanography*, **23**: 452–460.

Patalas, K., (1971). Crustacean plankton communities in forty-five lakes in the Experimental Lakes Area, northwestern Ontario. *J. Fish. Res. Bd. Can*. **28:** 231-244.

Paasche, E. (1975). The influences of salinity on the growth of some planktonic diatoms from brackish waters. *J. Bot*. **22:**209-215.

Plath, K. and Boersma M. (2001). Mineral limitation of zooplankton: stoichiometric constraints and optimal foraging. *Ecology*, **82:** 1260–1269.

Pollingher, U. (1987). Freshwater ecosystems. **In:** *The Biology of Dinoflagellates* (Taylor, F.J.R., ed.), Botanical Monographs 21, Blackwell Scientific Publications.

Pollingher, U. (1988). Freshwater armoured dinoflagellates: Growth, reproduction strategies and population dynamics. In: *Growth and reproduction strategies of freshwater phytoplankton* (Sandgren, C.D., ed.), Cambridge University Press, 134-174 pp.

Porter, K. (1977). The plant animal interface in Freshwater ecosystems. *Am. Scientists* **65**:159-170.

Prosser, M.V., Wood, R.B., and Baxter, R.M, (1968). The Bishoftu crater lakes: a bathymetric and chemical study. *Archiv fur hydrobiologic*.**65:** 309-324.

Reynolds, C.S. (1984). The Ecology of Freshwater phytoplankton. Cambridge University Press, Cambridge.

Reynolds, C. S. (1994). The ecological basis for the successful biomanipulation of aquatic communities. *Arch. Hydrobiol.* **130**:1-33.

Ringelberg J., Flik B.G.J., Lindenaar D. & Royackers K. (1991a). Diel vertical migration of Daphnia hyaline (sensu latiori) in Lake Maarsseveen: Part 2. Aspects of population dynamics. *Archiv f€ur Hydrobiologie*, **122:**385–401.

Ringelberg, J. (ed.), (1993). Diel vertical migration of zooplankton. *Arch. Hydrobiol. Beih. Ergebn. Limnol* Stuttgart, 222p.

Ringelberg, J. (1995). Changes in light intensity and diel vertical migration: a comparison of marine and freshwater environments. *J. Mar. Biol. Assoc. UK*, **75:** 15–25.

Rippey, B. and Wood, R.B. (1985). Trend in major ion composition of five Bishoftu Crater Lakes. *SINET: Ethiop.J.Sci.**8***: 9-29.

Rocha, O., Matsumura-Tundisi, T., Espindola, E. L. G., Roche, K. F.and Rietzler, A. C., (1999). Ecological theory applied to reservoir zooplankton. **In**: *Theoretical reservoir ecology and its applications* pp. 457-476. Tundisi, J. G. and Straškraba M. (eds.) International Institute of Ecology/Backhuys Publishers, São Carlos, 592pp.

Rodriguez, M. A., Magnan P. and Lacasse, S. (1993). Fish species composition and wetland abiotic variables in relation to abundance and size of structure cladoceran zooplankton. *Canadian Journal of Fisheries and Aquatic sciences* **50:** 638–647.

Rot, E. and Lenzenwger, R. (1994). Some rare and interesting plankton algae from Sri Lankan reservoirs. *Biologia*. **49 (4):** 479-500.

Saunders, J. F. and Lewis, W.M. (1988). Zooplankton abundance and transport in a tropical white water river. *Hydrobiologia* **162:** 147-155.

Semeneh Belay, (1988). Zooplankton composition and seasonal dynamics in Lake Zeway, Ethiopia. M.Sc.Thesis.Addis Ababa University, 121pp.

Serruya, C. & Pollingher, U. (1983). *Lakes of the warm belt*. Cambridge University Press. Cambridge, 569 pp.

Seyoum Mengestou (1989). Species composition, dynamics and production of the dominant crustacean zooplankton in Lake Awassa, Ethiopia. Ph.D Thesis. University of Waterloo, Ontario, Canada.228pp.

Seyoum Mengestou and Fernando, C.H. (1991). Seasonality and abundance of some dominant crustacean zooplankton in Lake Awasa: a tropical rift valley lake in Ethiopia. *Hydrobiologia*. **206**: 137-152.

Seyoum Mengestou and Green, J. (1991).Specific diversity of community structure of Rotifera in a salinity series of Ethiopian inland waters. *Hydrobiology*, **209**: 95-106.

Seyoum Mengestou., Green J. and Fernando, C.H. (1991). Species composition, distribution and seasonal dynamics of Rotifera in Rift valley lake in Ethiopia (Lake Awasa). *Hydrobiologia*, **209**:203-214.

Smith, D. W. and Cooper, S. D., (1982). Competition among Cladocera. *Ecology*, **63(4):** 1004-1015.

Sokal, R.R., and Rohlf, F.J (1981). *Biometry*. San Francisco Freeman 859pp.

Spirules, W. G., (1975). Zooplankton in acid-stressed lakes. *J. Fish. Res. Bd. Can*., **32(3):** 390-393.

Suzanne, L.G. and Jeffery, R.C. (1997). Zooplankton composition abundance in Budd inlet Washington. *J. Oceanography* **8:** 123-345.

Stich H.B. (1989). Seasonal changes of diel vertical migration of crustacean plankton in Lake Constance. *Archiv f€ur* Monographische Beitra¨ge**,** *Hydrobiologie*, **3:** 355–405.

Sterner, R. W. (1997). Modeling interactions of food quality and quantity. *Freshw. Biol.* **38:** 473–482.

Tailling, J.F.and Driver, D. (1963). Some problems in the estimation of chlorophyll *a* in phytoplankton.*Pro.Conf primary productivity measurement mar & freshwat.*U.S.Atomic Energy Commission. TID **7633**:142-147.

Talling, J.F. (1986). The seasonality of phytoplankton in African lakes. *Hydrobiologia*. **138**:139 -160.

Talling, J.F. (1987). The phytoplankton of Lake Victoria (East Africa). *Arch. Hydrobi Beih*. **25**: 229-256

Talling, J.F. and Lemoalle, J. (1998). *Ecological dynamics of tropical inland waters*. Cambridge University Press, Cambridge.

Tamiru Gebre, (2006). Study of zooplankton community grazing rates on the natural phytoplankton assemblages in Lake Hora, Ethiopia.MSc.Thesis. Addis Ababa University.

Taylor, W.D., and Zinabu G. M. (1989). Size structure and productivity of the plankton community of an Ethiopian rift valley lake. *Freshwater Biol.* **21**: 353-363.

Tesfaye Delelegne, (2006).Seasonal and spatial variations of zooplankton in relation to physico- chemical variables and phytoplankton production in Lake Beseka (Metehara), Ethiopia. MSc.Thesis. Addis Ababa University.

Tesfaye Wudneh, (1998). Biology and Management of Fish Stocks in Bahir Dar Gulf, Lake Tana, Ethiopia.PhDThesis, Wageningen Agricultural University.143PP.

Tessier, A. J., E. V. Bizina, and Geedey, C. K. (2001). Grazer resource interactions in the plankton: Are all daphniids alike? *Limnol. Oceanogr*.**46:** 1585–1595.

Threlkeld, S. T., (1986). Resource-mediated demographic variation during the midsummer succession of a cladoceran community. *Freshwat. Biol*.**16:** 673-683.

Tollrian, R. and Dodson, S. I. (1999). Inducible defenses in cladocera: Constraints, costs, and multi predator environments. **In:** *Ecology and evolution of inducible defenses*, pp. 177-202. Harvell C.D. and Tollrian. R. (eds). Princeton, New Jersey: Princeton, University Press.

Tudorancea, C. and Taylor, W.D. (2002). *Ethiopian rift valley lakes*. 296pp.

Twombly, S.,(1983). Seasonal and short-term fluctuations in zooplankton abundance in tropical Lake Malawi. *Limnol. Oceanogr*. **28**: 214-1224.

Vanderploeg, H, A. (1990). Feeding mechanisms and particle selection in suspension feeding zooplankton. **In:** *The biology of particles in aquatic systems*.(Wotten R.S. (ed)), CRC press Inc., Boca Raton, USA.

Van de Velde, I. (1984). Revision of African species of the genus Mesocyclops Sars, 1914(Copepoda: Cyclopoida). *Hydrologia*, **109**: 3-66.

Vogit, M. and Koste, W. (1978). *Rotatoria*. Gebruder Borntraeger, Berlin, Stuttgart.

Wetzel, R. G., (1975). *Limnology*. W. B. Saunders Co., Philadelphia. 743 pp.

Wetzel, R.G. and Likens, G.E. (2000). *Limnological analyses*. Third edition. Springes Verlag, New York, Inc. N.Y.

Welcomme, R. L., (1979). *Fisheries Ecology of Floodplain Rivers*. Longman, New York. 317 pp.

Whitford, L.A. and Schumacher, G.J. (1973). *A manual of freshwater algae*. Sparks Press Raleigh, N.C.

Williamson, C. E., Sanders, R. W. Moeller, R. E. and Stutzman P. L. (1996). Utilization of subsurface food resources for zooplankton reproduction: Implications for diel vertical migration theory. *Limnol. Oceanogr*. **41:** 224–233.

Wood, R.B., Prosser, M.V. and Baxter, R.M. (1976). The seasonal pattern of thermal Characteristics of four Bishoftu crater lakes in Ethiopia.*Freshwat. Biol*.**6**: 519-530.

Wood, R.B., Prosser, M.V. and Baxter, R.M. (1978). Optical characterstics of the Ethiopian rift valley lakes, Ethiopia. *SINET Ethiop. J.Sc*. **1:** 73-85.

Wood, R.B., Baxter, R.M and Prosser M.V. (1984). Seasonal and comparative aspects of chemical stratification in some tropical crater lakes, Ethiopia. *Freshwat. Biol.* **14:** 551-573.

Wood, R.B. and Talling, J.F (1988). Chemical and algal relationships in a salinity series of Ethiopian inland waters. *Hydrobiologia,* **15**: 29-67.

Yeshimebet Major, (2006). Temporal changes in the community structure and photosynthetic of phytoplankton in Lake Babogaya, Ethiopia. Unpublished MSc.Thesis. Addis Ababa University.

Zaret, T. M. and Suffern, J. S. (1976). Vertical migration in zooplankton as a predator avoidance mechanism. *Limnol. Oceanogr,* **21:** 804–813.

Zaret, T. M., (1980). *Predation and freshwater communities*. Yale University Press, New Haven, 187pp.

Zinabu Gebre-Mariam and Taylor, W.D. (1997). Bacteria-chlorophyll relationships in Ethiopian lakes of varying salinity: are soda lakes different? *J. Plankt. Res*.**19**: 647-654.

Zinabu Gebre-Mariam, (1994). Long-term changes in indices of chemical and productive status of a group of tropical Ethiopian lakes with differing exposure to human influences. *Arch. Hydrobiol.* **132**:115-125.

Zinabu Gebre-Mariam, Elizabeth Kebede, and Zerihun Desta, (2002). Long-term changes in chemical features of waters of seven Ethiopian Rift Valley lakes. *Hydrobiologia*, **477:** 81-91.

APPENDICES