BIOMASS AND PRODUCTION OF THE MAJOR ZOOPLANKTON IN LAKE KURIFTU, ETHIOPIA

A Thesis Presented to the School of Graduate studies Addis Ababa University

In partial fulfillment of the requirements for the degree of Master of Science in Biology

By

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July 2009

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Addis Ababa University

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ACKNOWLEDGEMENT

First and fore most I would like to express my heartfelt gratitude to my research advisor, Dr. Seyoum Mengistou, for his unreserved and committed consistent support and guidance of my research study. I also express my gratitude to Nebiyou Mohammed advised by Dr. Demeke Kifle for identification of phytoplankton during the study period.

My special thanks also go to Ageze Abza, Afework Kara, Tigist Wubishet, Taddesse Fetahi and my colleagues and all Fisheries and Aquatic Science students for assisting in the field and the laboratory work.

Finally my thanks also go to Koriftu Children's and Integrated Farm Center for allowing me to use their boat throughout the study period. My warmest thank is also to Ato H/Eyesus Asrat who has been driving the boat and helping me in the field work.

Finally, my great thanks go to my parents and the almighty God Who helped me to withstand all hardships throughout my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Studies on the biomass and production of the dominant zooplankton were done in Lake Kuriftu from August, 2008 to May, 2009. The cyclopoid copepod (Thermocyclops consimilis) constituted 71% in abundance in Lake Kuriftu, but cladocerans and rotifers are also present almost in equal proportions. Brachionus calyciflorus (12%) was the second dominant species next to T. consimilis. T. consimilis was raised in the laboratory to obtain life history information (duration of embryonic and post-embryonic development) at 20 and 25.9^{0}C, and fed mixed algal food enhanced with F/2 culture medium. Laboratory data on the duration of development and biomass, together with population abundance data obtained in the field, were used to estimate the biomass and production of this species in Lake Kuriftu. The mean biomass and production of T. consimilis, attained during the study period, were 23.8 mg dry weight (DW) m^{-3} and 0.78 mg DW m^{-3}day^{-1}, respectively with daily and annual P:B ratio 0.033and 13.10, respectively. The dry mass of B. calyciflorus was determined from its biovolume by approximating the nearest geometric formula. Dry weight and recruitment of new individuals were used to calculate the production of B. calyciflorus. The mean biomass and production of this species were 629.66 µg DW m^{-3} and 180.38 µg DW m^{-3} day^{-1}, respectively with daily and annual P:B ratio 0.29 and 21.31, respectively. Zooplankton production rates were low compared to values reported in the literature for the same or other species of equivalent sized copepods, from both tropical and subtropical regions.

1. INTRODUCTION

Limnological studies of tropical freshwater ecosystems are not intensive when compared to the temperate freshwater ecosystems. The fundamental process of stratification, nutrient regeneration, community interaction and energy transfer in many tropical lakes is not fully understood (Melack 1979; Hecky 1984; Dussart *et al.* 1984; Wiliams 1988). Despite the above fact, more is known about African lakes than others tropical fresh waters (Burgis 1974; Burgis and Walker 1972; Hart and Allanson 1975) and East African lakes have been studied fairly well in comparison with other regions of Africa. Melack and Kilham (1974) noted that East African lakes are regarded as among the world's most productive systems. For example zooplankton production of some African lakes is unusual high, (Nakuru, Kenya (Vareschi and Vareschi 1984)). However the magnitude of secondary production by zooplankton is still little known, and despite the fact that zooplankton are important food items for juveniles and adults of many fish species (Gophen and Landau 1977; Gophen 1980; Mavuti and Litterick 1981; Gophen *et al.* 1988).

Zooplankton play a pivotal role in the aquatic food web, having the potential to affect water transparency, levels of suspended algae (phytoplankton), and the fishery. Many economically important fish depend on a diet of zooplankton during some stage in their life cycle. However, the knowledge of zooplankton biomass and production in tropical African lakes is not intensively studied as its dynamics and phytoplankton biomass and production.

Secondary production can be defined as the increase in biomass, including reproductive products, within the unit of time. According to Downing (1984), secondary production studies are important in elucidating the transfer of energy and material within the ecosystem, permitting the more rational management. Thus the estimate of zooplankton secondary production is one of the goals of studies on ecological dynamics in aquatic ecosystems (Kimmerer & McKinnon, 1987), since zooplankton is on a principal pathway in the energy flow in the ecosystem, viz., which constitutes the link between primary production on one hand, and fish, as secondary consumers, on the other hand.

Just to mention a few quantitative work on production of tropical zooplankton, Burgis (1974) gives a value of 44 mg m^{-2} d^{-1} for the main herbivore *Thermocyclops hyalinus (=crassus*) in Lake Uganda and Lewis (1979) a value of 34.4 μg weight l^{-1} d^{-1} as mean herbivore production for the herbivorous zooplankton. Zooplankton biomass and production in the tropics and sub tropics remains relatively poorly known in spite of great increase in studies on zooplankton dynamics in the tropics and temperate regions. The present understanding of species composition indicates a lower diversity as the equator is reached (Fernando, 1980a, 1980b).

A number of reasons have contributed for poor studies of zooplankton biomass and production in tropics and subtropics aquatic ecosystems than the temperate ones. Unlike temperate, zooplankton populations in tropical regions are continuously recruiting and growing, simpler cohort approach can not be used for estimation of secondary production (Rigler and Downing, 1984). There fore there is a need of culturing of zooplankton at temperature similar to those in natural lakes (Vijverberg, 1989; Seyoum Mengistou and Fernando, 1991; Mavuti, 1994; Amarasinghe *et al.*, 1997a, b), besides the use of field population census data. Therefore lack of a database on the life history of zooplankton species for production calculation in a mixed population is one reason. Another reason is the aquatic science in tropics is dominated by the temperate counter part. The number of publications from temperate studies overshadows the output from tropical once.

In Ethiopia, studies on biomass and production of freshwater zooplankton are extremely scarce, even though Ethiopia has a considerable network of water resources comprising of lakes (many in the Rift-Valley basin), reservoirs, rivers and other small water bodies. The country has about 35 lakes and reservoirs covering a total area of about 7400 km^{-2} (Wood & Talling 1988) and rivers totaling more than 7000 km length (Breuil 1993). The only works on biomass production of zooplankton are Seyoum Mengistou and Fernando, (1991**)** in Lake Awassa and Ayalew Wondie and Seyoum Mengistou, (2006) in Lake Tana**.** Taylor *et al*, (2002) stated that Lake Awassa is the best known lake with respect to its zooplankton abundance, biomass, composition and productivity due to the work of Seyoum Mengistou (eg. Seyoum Mengistou, 1989; Seyoum Mengistou and Fernando, 1991).

In addition to the above global reasons, the infant aquatic sciences contribute for poor studies of biomass and production of zooplankton in Ethiopia. Limnological studies in Ethiopia are not extensively studied and some activities mainly have been focused on biomass and primary production of phytoplankton. However recently activities have been undertaken to evaluate secondary production of zooplankton in different lakes. On the other hand, according to the ministry of agriculture (MOA, 2001), Ethiopia has a fish potential of 28000 tonnes in the lakes and reservoirs, and 23000 tonnes in the rivers. Since much of the production of these higher trophic levels is dependent up on invertebrate production, particularly that of zooplankton, more investigations need to be directed towards the role of zooplankton communities in the biological productivity of freshwater basins of Ethiopia.

There are a number of factors regulating the biomass and production of zooplankton. However, for a long period of time, many studies reported that tropical plankton populations remain relatively constant over time, because of high temperature and light throughout the year allow for primary production to occur all year round in tropical lakes (Talling, 1965a, 1965b; Lewis, 1974; Hecky and Fee, 1981). In addition to this, contrary to temperate zooplankton (Burgis, 1971; Burgis and Walker, 1972), tropical zooplankton can breed continuously (Hart, 1981) so that there would be little seasonal variation in production, biomass and species composition. However, this muted seasonal variation in tropical plankton is not consistent (Twombly 1983), when the population dynamics is examined in detail. In Addition, there is an important body of data which documents seasonal variations in the abundance of zooplankton in large lakes of the African Rift Valley such as Lake Tanganyika (Narita *et al.*, 1986; Kurki *et al.*, 1999) and Lake Malawi (Irvine and Waya, 1999), as well as in smaller, shallow tropical lakes (Mengistou and Fernando, 1991). These temporal variations may depend on changes in the availability of edible phytoplankton and microzooplankton, 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; Hecky and Fee, 1981; Hecky and Kling, 1987).

In general the factors regulating zooplankton dynamics and secondary production in tropical lakes have not been investigated in details (Threlkeld 1979; 1982; Elmore 1980). Zooplankton in large stratisification tropical lakes show seasonal fluctuations that approach those observed in lakes at high latitudes (Hart 1985). At higher latitudes, changes in insulation and temperature are the direct causes of seasonal variations while other factors such as wind, precipitation, and hydrology are more important in influencing the seasonality of zooplankton in the tropical lakes (Twombly 1983a; Serruya and Pollinger 1983; Chutter 1985).

On the other hand zooplankton abundance and secondary production in shallow lakes which lack stable stratisification appears to be influenced by the hydrological regime to a large extent. For examples, in lakes that are fed by seasonal rain, zooplankton was found to be abundant during the rain season (Lake George, Burgis 1971; Lake Albert, Green 1976; Lake Chad, Gras et al. 1967; Lake Chilwa, Kalk 1979). In others, zooplankton were found to be highly abundant during and shortly after, the rainy season, such as Lake Naivasha (Mavuti and Litterick 1981).

Zooplankton community composition in shallow water systems also can be influenced by predation (Donald et al. 2001; Hampton and 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).

In general, factors such a temperature (Edmondson, 1965), salinity (Egborage, 1994), pH (Spirules, 1975) and electrical conductivity (Mavuti, 1965) can affect the zooplankton community with regard to both composition and population density. The size of water bodies (Patalas, 1971), their trophic state and their feeding habits (Gannon and Stemberger, 1978) and the successional stage (Hutchinson, 1967) also greatly influences the species composition of zooplankton. However, the factors recognized as the most important by the majority of authors are temperature, quality and availability of food, competition and predation, even though the magnitude of seasonal variation in zooplankton abundance and production differ widely among tropical lakes (Beadle 1981; Hart 1985) and the standing stocks have not been quantified for many tropical lakes.

Thus understanding of both the plankton dynamics and the magnitude of their secondary production are important because stocking piscivores and harvesting zooplanktivores has been suggested as practical approach towards enhanced fishery production and mitigation of water quality problems (McQueen *et al.* 1986).

The crater lakes of Ethiopia have been the subject of a number of recent limnological studies. However little is known about the ecology of zooplankton in crater lakes (Green, 1986) unlike the rift valley lakes. Green (1986) studied the ecology of zooplankton in these lakes. However the above and most other works did not included Lake Kuriftu, which is one of the crater lakes of the country found in Debrezeit town. Brook Lemma et al. (2001) studied the interaction among Cladocerans and their response to fish predation in Lake Kuriftu using enclosure experiments. Zelalem Dessalegn (2007) also studied the temporal dynamics of biomass and primary production of phytoplankton in relation to some phsico-chemical factors in the same lake and obtained phytoplankton biomass measured as chlorophyll a varied from 18.35 to 45.18 mg Chl a m^{-3} at the near-shore station and from 17.24 to 55.6 mg Chl a m^{-3} at the central station and photosynthetic production varied between 0.686 and 1.05 g O2 m^{-2} h^{-1}. Girum Tamire (2006) studied grazing rates in the same lake and the mean grazing rate at the natural density of zooplankton was 59.3% per day during his study and Ashagre (2008) on his cage culture study on *Oreochromis niloticus* obtained the result that the growth performance of *O. niloticus* was density dependent with mean daily weight gain of 0.69±0.01-1.15±0.02 g day^{-1}. Recently the dynamics and identification of phytoplankton is being studied by another researcher in Lake Kuriftu. There is gap of knowledge about the ecology of this lake with respect to dynamics and production of zooplankton.

Therefore the present work was intended to quantify biomass and secondary production of the major zooplankton species, in Lake Kuriftu, one of Debre-zeit's crater lakes, during the rainy and dry seasons. In addition, the major species of zooplankton were raised under laboratory condition, to obtain life history information such as the duration of embryonic and post-embryonic development and reproductive performance. The study will supply information of a preliminary nature on biomass and production of the major zooplankton species (Rotifera, and Copepda) in Lake Kuriftu.

2. OBJECTIVES

2.1 General objective

- To estimate biomass and production of the major zooplankton species in relation to physico-chemical condition and algal biomass in Lake Kuriftu.

2.2. Specific objectives

- To estimate biomass and production of the major zooplankton species

- To identity which zooplankton species contribute most to secondary production.

- To identify the major factors which are important in determining the biomass and production of zooplankton.

- To provide further baseline data for proper management, fish production and sustainable utilization of Lake Kuriftu.

3. DESCRIPTION OF THE STUDY AREA

The study was conducted on Lake Kuriftu (Fig 1), one of the Debrezeit crater lakes, found at an altitude of 1860 m, some 47 km southeast of Addis Ababa. The lake is located at 8^0 47' N and 39^0 00'E. It is a shallow ($\approx$ 6 m) artificial lake formed by diverting and damming Belbela River for irrigation practices in the area (Seifu Kebede *et al*. 2001). The lake gains water primarily from runoff, with a small contribution from precipitation (Seifu Kebede *et al*., 2001). Groundwater inflow plays a minor role in the water balance of this lake as the static water level in the area is well below the lake and the occurrence of loss of water through seepage is not well known (Seifu Kebede *et al*., 2001).

The region around the lake is characterized by moderate rainfall, about 850 mm *per annum* (Girum Tamire, 2006), high incident solar radiation and low relative humidity. The region has two rainy periods, the minor one extending roughly from March to April and the major one beginning in June and ending in September (Girum Tamire, 2006).

With the establishment of Kale Hiwot Children's and Integrated Development Center in the proximity of the lake, plantation of trees, construction of utilities and establishment of livestock and agricultural farms were made around the southern shore of the lake. The trees found around the lake such as *Accacia abyssinica, Jacaranda mimosifolia* and species of *Eucalyptus* and *Juniperus*. Macrophytes including *Passifloraceae* and *Passiflora subpeltata ortega* predominate in the lake.

According to National Meteorological Service of Ethiopia (NMSE) data, mean monthly minimum air temperature ranged from 3.5 to 13.8^{0}C, while the maximum monthly air temperature varied from 24.0 to 28.4°C. Monthly total rainfall varied from 2.9 mm (November 2006) to 186.7 mm (August 2006) (Gierum Tamire, 2006). Surface water temperature of the lake is reported to be between 20^{0}C and 27.4^{0}C while the bottom temperature was almost constant (19.2^{0}C to 19.3^{0}C) (Girum Tamire, 2006)).

The cyclopoid copepod, *Thermocyclops* spp. dominates the zooplankton community (Table 2) followed by rotifers. The cladocerans are found with lower abundance (Girum Tamire 2006). The fish and phytoplankton species found in the lake are not exhaustively reported, however *Oreochromis niloticus*, *Cyprinius carpio* and *Barbus* species are known to occur in the lake.

According to Girum Tamire (2006) the phytoplankton species composition of the lake is mainly represented by colonial algae and filamentous cyanobacterial forms (Table 3) and Zelalem (2007) identified 25 species of phytoplankton in his study on temporal dynamics of biomass and primary production. Recently the dynamics and identification of phytoplankton is under study by another MSc student (Nibyou).

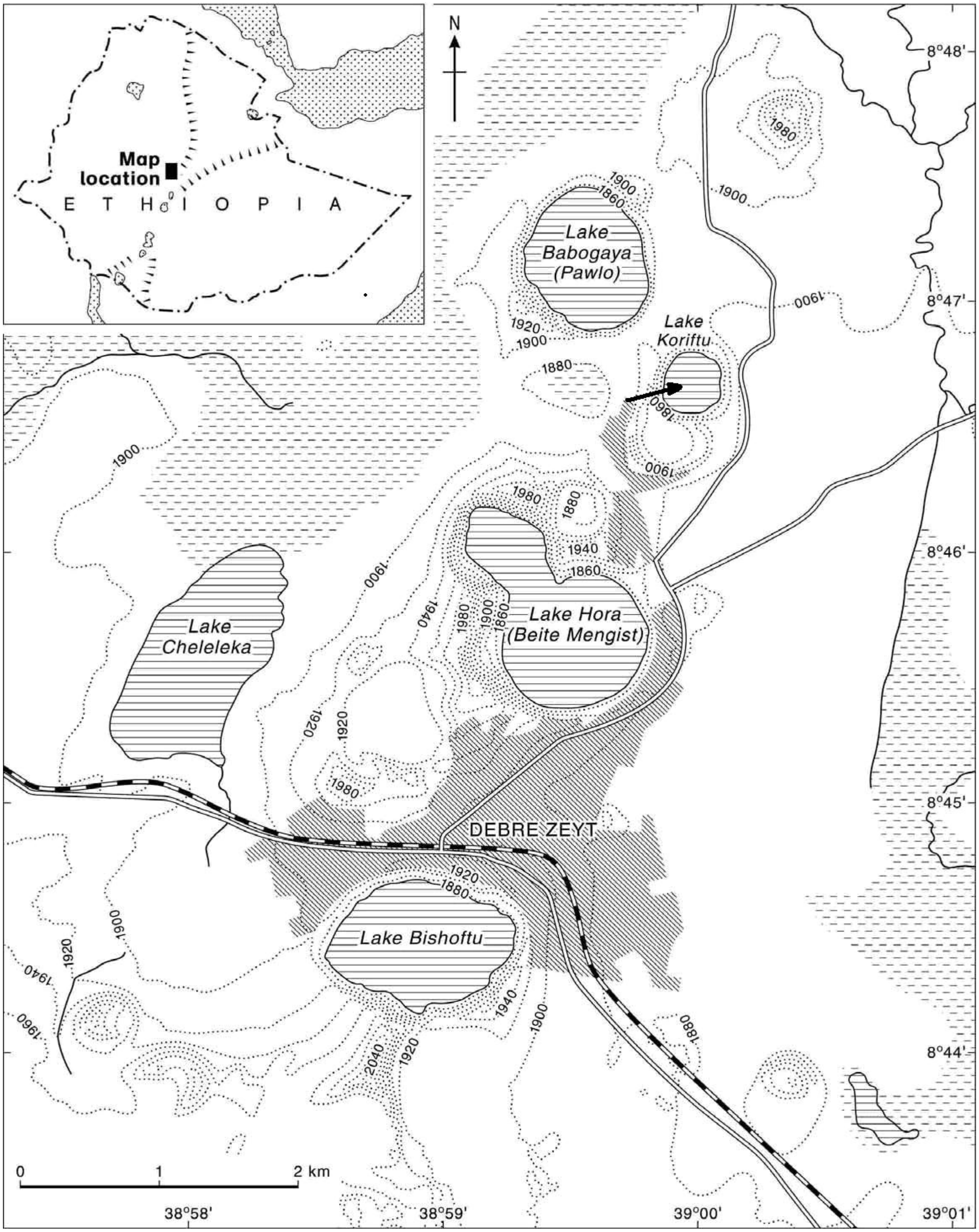


Fig.1 Map of Debrezeit and crater lakes surrounding Lake Kuriftu (After Lamb, 2001)

The chemical composition of the lake (Zinabu Gebremariam *et al.*, 2002) and some physical parameters of Lake Kuriftu (Brook Lemma *et al.*, 2001) are reported in Table1.

Table 1. Physico-chemical features of the Lake Kuriftu

Area (Km^2)	0.4
Max. depth (m)	6
Mean depth (m)	2
pH	7.9-8.4
Volume (m^3)	3.0x10^6
Secchi depth (m)	0.15-0.20
Conductivity (mS cm/1)	3.190
Salinity (g/l)	0.260
Cations (meq/l)	3.187
Anions (meq/l)	3.461
Na^{1+} (meq/l)	1.000
Ka^{1+} (meq/l)	0.154
Ca^{2+} (meq/l)	1.250
Mg^{2+}(meq/l)	0.783
Alkalinity (meq/l)	2.890
Cl$^-$ (meq/l)	0.571
SO$_4^{2-}$ (meq/l)	0.000

(After Brook Lemma *et al*., 2001 and Zinabu Gebremariam *et al*., 2002)

Table 2. Zooplankton taxa identified from Lake Kuriftu (After Girum Tamire, 2006)

Copepods	Cladocera	Rotifera
Mesocyclops aequatorialis[a]	*Ceriodaphnia sp.*	*Asplanchna sp.*[a]
Thermocyclops consimilis ++	*Diaphanosoma excisum*	*Brachionus bidentata*
	Moina micrura	*B. calycyflorus*
		B. caudatus
		B. falcatus++
		Filinia sp.[a]
		Karatella sp. [a]

++ Dominant species; [a] Rare occurrence

Table 3 List of phytoplankton identified from Lake Kuriftu (After Girum Tamire, 2006).

Phytoplankton group	Species name
Cyanophyceae (Cyanobacteria)	*Anabaena circinalis*$^{+}$
	Chroococcos sp.
	Cylindrospermopsis africana $^{++}$
	C. Curvispora^{++}
	Microcystis aeuroginesa^{++}
	Psuedoanabaena sp.
Chlorophyceae	*Chlamydomonas reticula*
(Green algae)	*Closterium species*
	Pediastrum simplex
	P. duplex
	Phacotus lenticularis
	Scenedesmus armatus
Bacillariophyceae (Diatoms)	*Navicula cryptocephale*
	Nitzschia vernicularis
	N. rostellate
	Synedra sp.
Dinophyceae (Dinoflagellates)	*Peridinium sp*^{n}.
Cryptophyceae (Cryptophyta)	*Cryptomonas sp.*
Euglenophyceae	*Lepocincilis sp.*
(Euglinophyta)	*Phacus sp*^{n}.

++ most dominant, + dominant, ^{n} rare occurrence

4. MATERIALS AND METHODS

4.1. Sampling protocol

Two sampling stations were selected in Lake Kuriftu; one from an area of high human impact (near-shore station) and another from a relatively less impacted area (mid-lake station). Quantitative water samples were collected at least once a month from the two stations with nets of mesh size 64-µm, 30 cm mouth opening and 1.2 cm cod end which was hauled along the entire water column (from the desired depth up to the surface). The zooplankton was collected from the inshore (ca. 80 m from the shore, depths 2 m) and from the open water (ca. 500 m from the shore, depth 5 m). Three replicates were taken at each site and all samples were preserved in 4% formaldehyde. Sampling was carried out during the day time, generally during 11 am to noon and water samples were also collected for Phytoplankton composition analysis and live zooplankton for laboratory culturing at the same sites. Phytoplankton samples were preserved in Lugol's solution and live samples were contained in larger bottles (2 liters) without preservation.

4.2. Measurement of physico-chemical parameters in the field

The parameters measured *in situ* include the following:

- Secchi depth was estimated with a standard Secchi disc of 20 cm diameter.

- pH was measured *in situ* with a portable digital pH meter.

- Depth profiles of oxygen and temperature were determined with a digital oxygen meter.

-Carbonate-bicarbonate alkalinity was determined by titration with HCI to a pH of 4.5 in the laboratory

4.3. Laboratory procedures

Culture Methods

Theromocyclos consimilis was raised in the laboratory for determination of the development times and weight-length relationships that provide the time and the weight elements required for biomass and production calculation, using the techniques described in Bottrell *et al*. (1976) and Vijverberg (1989). Culture vessels of 60 ml were used and *T. consimilis* was fed with mixed algal culture and natural seston from filtered, concentrated (45 µm mesh sieve) lake water. Algal samples taken from the lake were enhanced with inorganic growth nutrients (Guillard's F/2 media) and maintained in laboratory cultures until fed to zooplankton. Before release to culture media, zooplankton was filtered through 150 µm sieve so that the largest stages (adults) were retained on the sieve and the developmental stages passed into the filtrate. The sieve was gently immersed in filtered lake water to release the large individuals. Then, 15 ovigerous females were pipetted out individually into small test tubes (glass jar) with 45 µm mesh size at the end immersed to another larger flask containing filtered natural lake water, and incubated in a thermostatically controlled water bath at temperature 20 and 25.9^{0}c close to the lake mean temperature (19.40 to 24.78^{0}c) with a 12 hours photoperiod. Culture medium replacement was performed every 2 days and ovigerous female were subsequently observed for hatching and adult females were immediately removed after releasing their eggs. Developmental times of eggs to nauplii were observed twice a day (morning and night) and every two days for nauplii to copepodites and copepodties to adults. The culture was replenished with filtered lake water and mixed algal culture and the animals were given food in excess (not as natural feeding regime), because the objective of this experiment was to ensure unfailing survival of laboratory cohorts until completion of one generation cycle.

Developmental times

The duration times were determined by direct observations of times taken to develop from eggs to nauplii for at least 120 eggs, from nauplii to copepodities for 70 naupli and from copepodities to adult for at least 30 copepodities (own observation).

4.3.1. Identification of Species and Population Density Estimation

Phytoplankton Identification

Major species of phytoplankton preserved with Lugol’s iodine found in samples collected on each sampling date using plankton net of 10µm mesh size were identified. The phytoplankton samples were examined with an inverted microscope and identification to genus or species level using taxonomic literatures available on phytoplankton (Gasse, 1987; Hindak, 1992a, b; Jeeji-Bai *et al*., 1977 and Komarek and Anagnostidis, 2005 and Whitford and Schumacher, 1973). Aliquots of preserved composite samples were used, after sedimentation, for the estimation of the relative abundance of the major algal groups with a Sedgwick-Rafter cell under an inverted microscope (Nikon) following the procedures outlined in Hotzel and Croome (1999).

Zooplankton Identification and Density estimation

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).

For subsampling, preserved sample of zooplankton was poured into a 210 ml beaker and was stirred, and sub samples (Ca, 30 ml) were taken with a bulb pipette and animals were counted in a small petri-dish with equal transects on the bottom, under compound microscope with magnification power 6-50x. Three transects was counted and further extrapolation was used to get individual per meter cube of lake water.

The major zooplankton groups (Rotifera, Cladocera and Copepoda) and immature copepods (nauplii and copepodites) were counted as separate groups and the final estimation of zooplankton abundance (individual m^{-3} of lake water) was computed for each month using the formula of Edmomdson and Winberg (1971).

$$V=\prod r^2 d$$

Where, V is the volume of the water filtered (m^{-3}).

r is the radius of the net (m).

d is the length of the course of the net through the water (m).

The total number of females and males in the adult population and the percentage of females carrying eggs were estimated from the adult counts. The fecundity as eggs per female was also determined each month. The mean size of naupliar, copepodites and adult stages were immediately measured from the field samples or laratory culture.

4.3.2. Biomass and Production Estimation

Biomass of Phytoplankton

Phytoplankton biomass was estimated as chlorophyll a concentration spectrophotometrically from water samples filtered through glass fiber filters (GF/C). Chlorophyll a was extracted from the phytoplankton concentrate with aqueous acetone (90%). The filters were manually ground with a glass rod to enhance extraction of pigments and centrifuged with 13 minutes. The concentration of Chlorophyll a was calculated according to Talling and Driver (1963) using absorbance measurements made at 665 and 750 nm. Chemical analysis for Nitrate, phosphate, silica and total alkalinity were also carried out in each month using laboratory manual.

Biomass and production of rotifers

Production of rotifers in Lake Kuriftu was calculated using **the recruitment method** based on the values for the finite birth rate, organism dry weight and egg developmental times (Edmondson & Winberg, 1971).

$P = P_x * W$

Where

P = Production

P_x = recruitment of new individuals

W = Mean individual body dry weight

$P_x = N_f * B$

Where

N = number of females

B = finite birth rate

$B = E/D_e$

Where

E = proportion of eggs per female

D_e = egg development time

De will be calculated using the formula of Bottrell *et al.* (1976)

$$\mathrm{Ln}\ De = \ln a + b.\ln t + c.\ (\ln t)^2$$

Where a = 2.7547; b = -0.2484; and c = -0.2408 t is lake temperature (^{0}c)

Rotifer dry weight was estimated using an indirect technique of bio-volume calculation from body size measurements and application of approximate geometric formula (Ruttner- kolisko, 1977).

Biomass and production of copepods

The body length (L) of copepod nauplii, copepodites and adults were measured from the top of the cephalothorax to the end of the abdomen with an ocular micrometer. All nauplii stages were measured separately and average of them taken to calculate wet-weight and dry weight and the length of copepodites of five different stages were also averaged and used for calculation. Weight-length regression equation, applied for the same species in Lake Awassa (Seyoum

Mengistou and Fernandio, 1991) was applied to obtain the wet-weigh (WW) and dry-weight (DW) of nauplii, copepodites and adult copepods, even though relationships change according to temperature, food quality and availability, and genotype (Vijverberg, 1989).

$$\mathbf{WW=10.227\ L^{2.249}}$$

$$\mathbf{DW = 2.257\ L^{2.252}}$$

Secondary production (*P*) was calculated by the biomass increment method (Winberg *et al.*, 1971b), which takes into account biomass increment (ΔW), development time (*T*) and number of individuals (*N*) of each instar (subscripts: nauplii = n, copepodites = c and adults–eggs = e), using the following equation:

$$\mathbf{P = (N_e W_e)T_e^{-1} + (N_n \Delta W_n)T_n^{-1} + (N_c \Delta W_c)T_c^{-1}}$$

The adult mean weight was taken as the final value for copepodids, whereas W_e is the mean egg weight, ΔW_n is the weight change from nauplii last to copepodite first and ΔW_c is the weight change from copepodite first to adult. Biomass measurement of different stages of nauplii (I, II, III, IV and V) and copepodities (Copepodite I up to V) were carried out independently and their averages were taken for production calculation. Naupliar and copepodite production estimates are somatic, while adult production is reproductive (eggs).

The production: biomass (P:B) ratio and turnover time $[(P:B)^{-1}]$ were also determined

4.3.3. Data analyses

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. Values were considered significant at 0.05 levels as indicated in Sokal and Rohlf (1981).

5. RESULTS AND DISCUSSION

5.1. PHYSICO-CHEMICAL FEATURES

5.1.1. Physical and some chemical Parameters

The physical and some chemical characteristics of Lake Kuriftu during the study period are given in Table 4. Lake's transparency (vertical visibility) varied between 0.37m in May, 2009 of the minor rainy season at near shore and 0.60 m in December, 2008 of the dry season at the open water station which is similar the result obtained by Zelalem (2007, unpublished thesis) in the same lake. The average secchi depths recorded in the study period were 0.51m and 0.48m at open water and near-shore, respectively. Brook Lemma *et al*. (2001) recorded lower value of Secchi depths (Z_{SD}) in the same lake (0.15-0.20m). The Secchi depth values of Lake Kuriftu are higher than those recorded for Legedadi (0.082-0.11m; Adane, 2006) and Koka (0.28m, Elizabeth Kebede, 1996) reservoirs and Lakes Ziway (0.35m), Abaya (0.43m) (Elizabeth Kebede *et al.*, 1994), and Chamo (0.21-0.375m, Eyasu Shumbulo, 2004), in which attenuation of underwater light is primarily due to silt and clay, which are known to form a stable colloidal suspension in Koka Reservoir and Lake Langano (Wood *et al.*, 1978; Amha Belay and Wood, 1984; Elizabeth Kebede, 1996)

Table 4. Collective chemical and Physical features: pH, Total Alkalinity (TA), Phenolphthalein Alkalinity (PA), **Secchi depths (Z_{SD})** *at near-shore (NS) and open water (OP), temperature and oxygen in lake Kuriftu. ND = not determined.*

				Z_{SD} (m)		Temperature (^{0}c)		Oxygen			
								surface		5m depth	
Months	**pH**	**TA**	**PA**	**OP**	**NS**	**Surface**	**5m depth**	**mg/L**	**%**	**mg/L**	**%**
Aug	8.20	2.40	0.20	ND	ND	22.30	24.20	6.46	75	4.95	64
Sep	8.50	2.80	0.00	0.50	0.49	19.40	24.11	6.46	75	4.95	64
Oct	8.60	2.90	0.00	0.51	0.50	24.50	24.52	5.97	78	4.93	64
Nov	8.56	2.50	0.00	0.54	0.52	24.50	22.40	5.50	72	4.03	60
Dec	8.93	2.20	0.00	0.60	0.51	20.80	20.81	4.56	63	4.02	59
Jan	8.59	1.90	0.00	0.51	0.49	20.30	19.74	4.40	62	3.58	44
Feb	8.64	1.90	0.50	0.56	0.54	22.00	20.73	2.80	52	0.95	12
Mar	8.81	2.40	0.40	0.54	0.48	22.10	21.83	4.50	63	3.58	44

Apr	8.34	2.30	0.40	0.41	0.39	23.80	23.83	5.89	77	3.55	43
May	8.31	2.90	0.00	0.39	0.37	24.78	23.00	5.80	76	4.03	60

ND = non determined

On the other hand, the lakes close to the present study such as Lake Kilole (Z_{SD}=0.37-1.8m) (Brook Lemma, 1994) and Babogaya (Z_{SD}=1.48-4.46m, Yeshiemebet Major, 2006) were more transparent than Lake Kuriftu owing to differences among the lakes in the extent of plant cover found in the catchment areas, human activities including agricultural practices, shelter from wind and water column depth. The temporal variations seen in the transparency of Lake Kuriftu seem to be related to changes in the levels of resuspension of inorganic particles resulting from wind-driven mixing, variation in phytoplankton biomass and external loading of particulate materials through runoff.

The surface water temperatures at the central station of Lake Kuriftu ranged from a minimum of 19.4 in September, 2008 to a maximum of 24.78^{o}c in May. The minimum and maximum lake temperature was coincided with the minimum and maximum atmospheric temperature (see appendix 5). The surface water temperatures of Lake Kuriftu are closer to those of the Ethiopian Rift Valley Lakes including Lakes Ziway (18.5-27.5^{0}c; Girma Tilahun, 1988), Abijata and Langano (18-27^{0}c ; Elizabeth Kebede *et al.,* 1994) and Awassa (23.8-28.4^{0}c) (Demeke Kifle, 1985) and other lakes of the same region as the present study lake, Lakes Kilole (18.5-24^{0}c; Brook Lemma, 1994), Babogaya (20.5-28.4^{0}c; Yeshiemebet Major, 2006) and the Legedadi Reservoir (22.2-23.9^{0}c; Adane Sirage, 2006).

The vertical distribution of temperature and oxygen concentration in Lake Kuriftu shows the occurrence of small differences between successive depths of the water column down to 4 and 5m from the surface. Lake Kuriftu is small and shallow lake and there seems to be no thermal stratification considering its shallow depth and exposure to wind action. The thermal regime of Lake Kuriftu is probably comparable to the shallowest Crater Lake Kilole (Wood *et al*., 1976) and Lake Ziway (Girma Tilahun 1988) which are almost continually stirred to their bottoms. Studies on the thermal characteristics of the Bishoftu crater lakes in Ethiopia were made by Baxter *et al*., (1965) and Wood et al., (1976; 1984). The two deepest Lakes, Bishoftu (87m) and Pawlo (65m), showed the most stable thermal stratification and an anoxic layer. However water column mixing in the Ethiopian Rift valley lakes is frequent (Wood *et al*., 1978) and Baxter *et al*. (1965), in their studies on African lakes, have noted that complete mixing is normally frequent in lakes with maximum depth (Z_{max}) of less than 15-30m and thermal stratification is largely diurnal, a water column condition documented for a large number of Ethiopian Rift Valley lakes (Elizabeth Kebede *et al.,* 1994; Elizabeth Kebede, 1996).

The depth profiles of dissolved oxygen on the surface and in 5m depth determined at the central station of Lake Kuriftu (Table 3) during the study period showed oxygen maximum (5.97 mg/L, 78% O_2) in the upper layer of the water column in October, 2008 and a minimum of 0.95 mg O_2 l^{-1} or 12% O_2 in February, 2009 at 5m depth. Generally dissolved oxygen at 5m depth was lower than at surface which may be related to the progressively lower oxygen contribution of photosynthesis as a consequence of the presumably lower photosynthetic biomass and exponential decline in the level of irradiance and possibly due to the greater demand for oxygen for oxidative decomposition of organic matter by heterotrophs. The oxygen concentration in the surface water of Lake Kuriftu was generally closer to those recorded for the nearby lakes, Lake Kilole (3.4 to 10.6 mg O_2 l^{-1}; Brook Lemma, 1994), and Babogaya (2.75-15.8 mg O_2 l^{-1}; Yeshiemebet Major, 2006).

The pH of Lake Kuriftu ranged from a minimum of 8.20 in August, 2008 to a maximum of 8.93 in December, 2008. The pH values recorded for this lake in the present study are closer to the result obtained by Zelalem (2007, unpublished thesis) and slightly higher than those reported in an earlier investigation (7.9-8.4; Brook Lemma *et al.,* 2001) in the same lake. On the other hand the pH values of Lake Kuriftu, were generally lower than those recorded in the nearby crater lakes, Lake Bishoftu (9.2; Zinabu Gebre-Mariam, 1994) and Babogaya (8.84-9.09; Yeshiemebet, 2006) and the Rift Valley Lake Chamo (8.53-9.44; Eyasu Shumbulo, 2004).

The total alkalinity (in meq l^{-1}) of Lake Kuriftu showed marked temporal fluctuations, varying from a low value of 1.9meq/l (January and February, 2008) to a high value of 2.9meq/l in October, 2008 and May, 2009. The high total alkalinity values recorded in the present study are similar to that observed in a previous study (2.89; Zinabu Gebre- Mariam 1994) and lower than the result obtained by Zelalem, (2007) 3.1meq/l. The alkalinity of Lake Kuriftu, which is close to that of Koka Reservoir (Elizabeth Kebede, 2006), is very low compared to those of the other lakes in the same area including Lakes Bishoftu (20 meq/l, Wood and Talling, 1988) and Babogaya (6.4-12.1; Yeshiemebet Major, 2006). The use of lake water for irrigation and evaporation may be the reason for fluctuation of alkalify of the current lake. Irrigation affects the water input-output relationship thereby determining the extent of evaporative concentration of ions (Wood and Talling, 1988). Williams (1999) also considers diversion of inflows as one of the main reason for the increases in the salinity of many lakes of the world's largest and permanent lakes during the last several decades.

5.1.2. Chemical Parameters

The temporal variation in the concentration of inorganic nutrients and phytoplankton biomass at the open water and near-shore stations of Lake Kuriftu is shown in Table 5. Concentrations of soluble reactive phosphate (PO_4-P) recorded in this study ranged form a minimum value of 8.64 in September, 2008 to a maximum of 37.00µg/l in May, 2009 at the near-shore station, and from 10.96 in December, 2008 to 36.96µg/l in March, 2009 at the open station. Phosphate concentration reported for other crater lakes of the same region including Lakes Bishoftu (280µg/l; Zinabu Gebre Mariam, 1994) and Arenguade (3200µg /l; Elizabeth Kebede, *et al* 1994) and the rift valley lakes Ziway (mean value of 90 µg/l; Getachew Beneberu, 2004) and Lake Chamo (26.4-91.7 µg /l; Eyasu Shumbulo, 2004). Generally the maximum level of soluble reactive phosphate observed in Lake Kuriftu is much lower than the above mentioned lakes but higher than values recorded for other nearby crater Lakes Babogaya (1-11 µg/l); Yeshiemebet Major, 2006) and Kilole (27; Zinabu Gebre Mariam ,1994).

A phosphate concentration seems low with high phytoplankton biomass and higher at the central station than at the near-shore station. Girma Tilahun, (1988) pointed that low concentrations of phosphate were associated with high phytoplankton biomass in Lake Ziway and Zelalem (2007) on his study suggested that the slightly higher concentrations of phosphate at the central station in Lake Kuriftu were probably associated with the greater exposure of the station to wind blowing over this small lake, whose shore regions are better protected by the elevated surrounding land. It is also possible that there is greater external loading of phosphate through the shoreline which is closer to the central station than the near-shore station.

Table 5. Ambient concentrations of NO_3-N, PO_4-P and SiO_2 in relation to Phytoplankton biomass as Chl a (B) at the open (OP) and Near-Shore (NS) in Lake Kuriftu.

Months	**NO_3-N (µg/L)**		**PO_4-P (µg/L)**		**SiO_2 (mg/L)**		**B (mg Chl a m^{-3})**	
	NS	**OP**	**NS**	**OP**	**NS**	**OP**	**NS**	**OP**
Aug	36.67	35.30	12.93	18.28	7.17	7.59	17.12	17.45
Sep	35.00	36.00	8.64	21.80	7.82	8.02	28.40	29.81
Oct	35.00	34.60	20.15	24.96	8.12	7.00	36.97	36.97
Nov	32.60	35.00	9.91	31.96	7.31	10.04	29.68	38.43
Dec	35.00	38.00	9.28	10.96	9.74	8.93	20.04	29.68
Jan	34.30	34.00	13.57	34.96	8.36	10.47	13.62	17.51

Feb	34.00	35.30	28.22	34.96	9.22	8.74	44.27	49.14
Mar	39.30	38.70	37.35	36.96	7.66	8.13	53.03	48.16
Apr	35.00	33.00	19.44	20.90	5.60	6.98	63.73	46.22
May	44.60	41.30	37.00	35.96	6.03	7.21	27.73	17.51

Nitrate (NO_3-N), concentration varied from 32.60 to 44.60µg/l at the near-shore station and from 33.00 to 41.30µg/l at the open station with the maximum values in May, 2009 during the minor rainy season. The levels of nitrate determined in the present study in Lake Kuriftu are higher than the values recorded for other crater lakes Babogaya (Yeshiemebet Major, 2006) and Bishoftu (25 µg/l; Zinabu Gebre Mariam, 1994) Lakes Awassa (Elizabeth Kebede and Amha Belay, 1994) although they are still considerably lower than those of the rift valley and Ziway (Girma Tilahun, 1988).

The silica (SiO_2) values recorded in the study period are similar with the result obtained by Zelalem (2007). Silica in Lake Kuriftu is low in view of the high concentrations commonly encountered in Ethiopian lakes and high in comparison with Lake Chamo (see Table 6). The values recorded in Lake Kuriftu for the near-shore station ranged from 5.60 to 9.74 mg/l while those for the open station varied from a minimum of 6.98 to a maximum of 10.47 in April, 2009 and January, 2009, respectively. The concentrations of silica were generally higher at the open station than at the near-shore station and the lower concentration of silica in Lake Kuriftu in general may be associated with its removal from solution by diatoms. A relation between decreasing silica concentration and larger diatom growth was also reported for many freshwater bodies of the tropical region including Lake Chamo (Amha Belay and Wood, 1982), Lake Chad (Lemoalle, 1978) and Lake Victoria (Hecky and Bugenyi, 1992; Hecky, 1993).

Table 6. Comparison of PO_4-p, NO_3-N and SiO_4 concentration of Lake Kuriftu to other Ethiopian Lakes

Lakes	PO_4-p (μg/L)	NO_3-N (μg/L)	SiO_4 (mgl^{-1})	Sources
Kilole	27	-	32	Prosser et al and Talling, 1965, Talling, 1964, Zinabu-G/mariam, 1994)
Babogaya	1-11	1-31	10-58	Yeshiemebet, 2006
Ziway	90	28-136.5	45	Wood and Talling, 1988, Getachew, 2004
Koka	-	-	32	Wood and Talling, 1988
Awassa	-	7-20	50-90	Elizabeth Kebede and Amha belay, 1994, Demeke Kifle, 1985
Chamo	26.4-92	-	0-4	Elizabeth Kebede et al., 19994 Zinabu-Gebremariam et al., 2002, Eyassu, 2004
Kuriftu	8.6-37	33.6-44.6	7-10	Present study

5.2. BIOLOGICAL FEATURES

5.2.1. Species composition and abundance of phytoplankton

Table 7 presents a list of the major phytoplankton species identified in samples collected during the study period. A total of 44 species of phytoplankton belonging to 6 classes were identified in the study period. Zelalem Dessalegn (2007) identified a total of 25 species of phytoplankton in the same lake. The species composition and diversity of phytoplankton of Lake Kuriftu are similar to those of Lake Babogaya (32; Yeshiemebet Major, 2006) and Chamo (44) (Elizabeth Kebede and Willen, 1998). Phytoplankton diversity in Lake Kuriftu (44 spp) is low when compared to those of the Ethiopian Rift Valley Lakes Ziway (67), Awassa (70) (Elizabeth Kebede and Willen, 1998). Girma Tilahun (2006) has also reported similarly high species diversity for Lakes Ziway, Awassa and Chamo in which the cyanobacteria were qualitatively and quantitatively important.

Green algae were the richest specie in terms of species diversity whereas blue-green algae were the most abundant phytoplankton during the study period and diatoms were the third major algal groups in terms of species richness and abundance in Lake Kuriftu. The other taxonomic groups-dinoflagellates; cryptomonads and euglenoids were poorly presented. *Cylindrospermopsis curvispora* and *Microcystis aeruginosa* (blue-green algae*)* were usually the most important in terms of abundance and formed the most conspicuous populations.

The persistence and dominance of cyanobacteria in Lake Kuriftu is probably associated with the consistently fairly high levels of nutrients particularly phosphate and the high temperature (19.40 to 24.78^0c). Shapiro (1990) also suggested that high temperature helps the dominance of Cyanobacteria. In general tropical lakes show cyanobacterial dominance during drought and falling water level (Harris and Baxter, 1996) and highest value of cyanobacteria is recorded in December (dry period) in the current lake.

On the other hand different authors pointed the dominance of cyanobacteria in Ethiopian lakes and reservoirs (Adane Sirage, 2006; Ayalew Wondie, 2006; Girma Tilahun, 2006,) and South Africa (Thornton, 1987).

Table 7. List of the major species of phytoplankton identified from Lake Kuriftu during the study period

Phytoplankton group	Species name
Cyanophyceae Cyanobacteria (Blue-green algae)	*Cylindrospermopsis africana* Kom. and Kaling *C. curvispora* M.Watanbe *C.curvispora*

	Lyngbya circumcera *Planktolyngebya tallingii* Kom. and Kaling *Planktolyngebya contorta* (Lemm.)Anagn. And Kom. *Microcystis aeruginosa* Rab. *Anabaena circinalis* Rab. *Anabaena nygaerdinom* *Psuedoanabaena sp.*
Chlorophyceae (Green algae)	*Pediastrum simplex* Meyen *P. duplex* Meyen *P.tetras* *Scenedesmus armatus* Chod. *S.acuminatus* *S.denticulatus* *S. dimorphus* (Turp.)Kutz. *S. quadricauda* (Turp).Breb. *S.bicudata* *Chlamydomonas reticula* *Coelestrum micropsporum* *C.acutum* *Phacotus lenticularis* (Ehr.) Stein *Monoraphidium minutum* *M.contoratum* *Pseodosphaerocystic lacustris* *P.angustus* *Tetraedron minimum* *T.muticum* *Tetrastrum netercanthium*
Bacillariophyceae (Diatoms)	*Thalassiosira sp.* *Cymbella naviculiformis* *C.gracilis* Var Lunata *Navicula cryptocephala* Kutz. *Nitzschia vermicularis* (Kutz.)Grun. *N. rostellate* Synedra ulna
Dinophyceae (Dinoflagellates	*Peridinium sp.*
Cryptophyceae (Cryptomonads)	*Cryptomonas obovata* Skuja *C.marssioni* *C.orata*
Euglenophyceae (Euglenoids)	*Phacus longicauda* (Ehr.) Duj. *P.tortus* *Lepocincilis sp.*

5.2.2. Phytoplankton biomass

Temporal changes in Phytoplankton biomass, measured as chlorophyll a concentration in composite samples collected from both stations, are shown in Fig.2 (See also Table 5). The Phytoplankton biomass of Lake Kuriftu exhibited temporal and spatial variations over the study period. The values recorded ranged from 15.62 in January to 63.73 (mg Chl a m^{-3}) in April at the near- shore station and from 17.45 in August to 49.14 (mg Chl a m^{-3}) in February at the open station. The lowest phytoplankton biomass measured as Chl a was observed in August, 2008 and January, 2009 at both stations. There was an increase of phytoplankton biomass after a heavy rainy season (post-rainy) and the pick value of phytoplankton biomass was recorded in April. The mean Phytoplankton biomass recorded in study period was 33. 27 (mg Chl a m^{-3}).

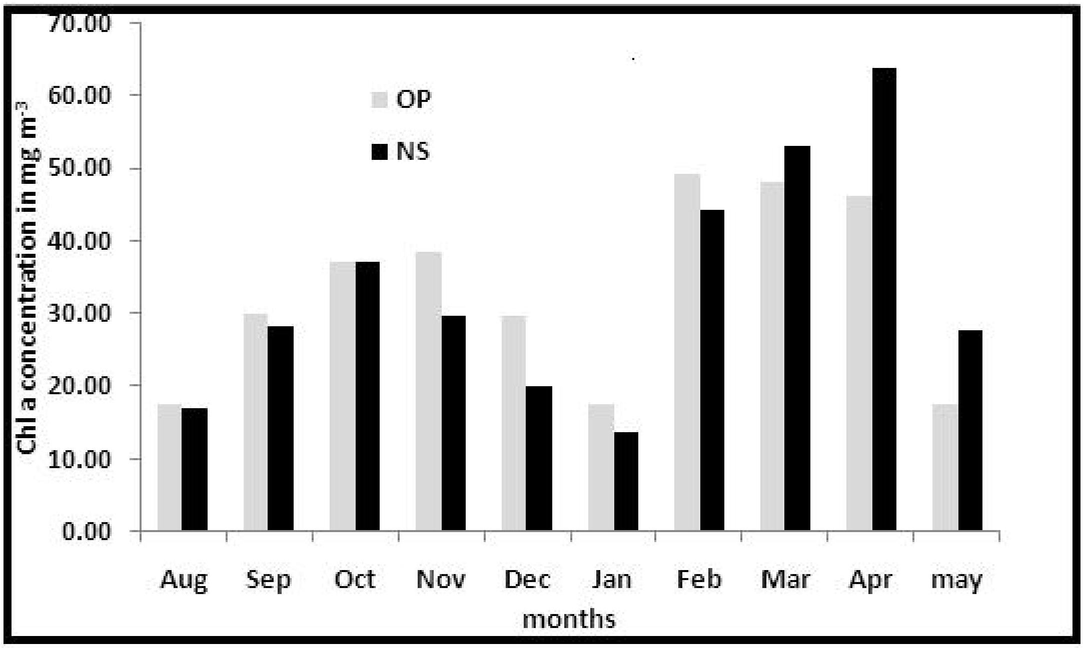


Fig.2. Monthly Chlorophyll a concentration at near shore (NS) and Open water (OP) in Lake Kuriftu in mg Chl a m^{-3}

The low occurrence of phytoplankton biomass in August may be associated with heavy precipitation that resulted in land runoff which brought particulate materials into the lake with consequent reduction in light penetration. The occurrence of low phytoplankton biomass in lakes during periods of heavy rainfall is not unusual and has been reported for Lake Victoria (Lung'Ayia *et al.,* 2000).

Phytoplankton biomass in comparison with the two stations (near shore and open water) is showed in the figure 3. Most of the time the biomass in Lake Kuriftu was almost the same at both stations (mean 33.09 mg Chl a m^{-3}) at the near-shore and (mean 33.46 mg Chl a m^{-3}) at open water station. This seems to be associated with the generally the same concentration of nutrients and transparency (turbidity) at the open station and at the near-shore station. On the other hand different spatial trends were also reported for Lake Ziway in which the near-shore station had lower biomass than the open station (Getachew Beneberu, 2004), and Lake Babogaya (Yeshiemebet Major, 2006). Many authors reported lower phytoplankton biomass in the littoral than in the open water. However Lake Kuriftu is very small and shallow lake (with mean depth 2m and maximum depth 8m (Seifu Kebede, 2001)) with continuous circulation of water both horizontally and vertically.

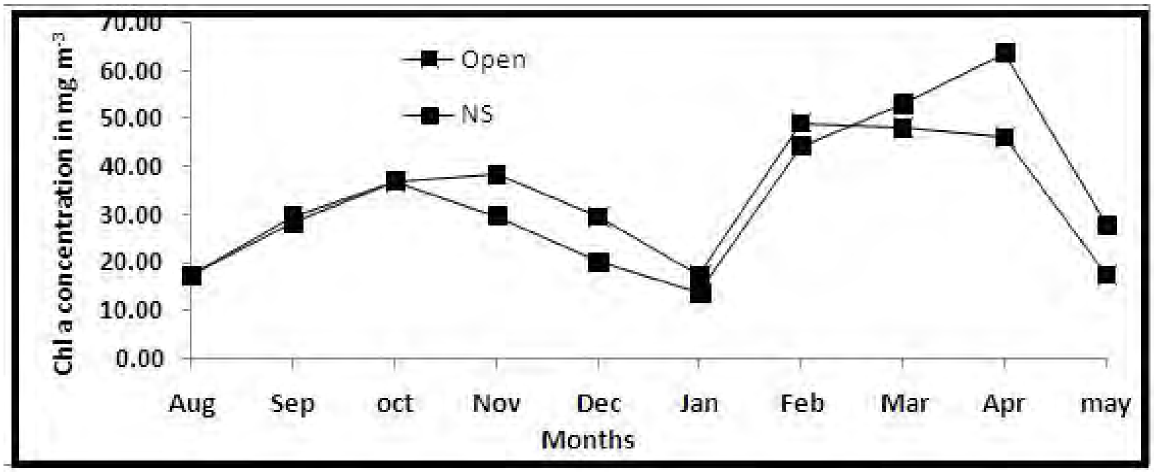
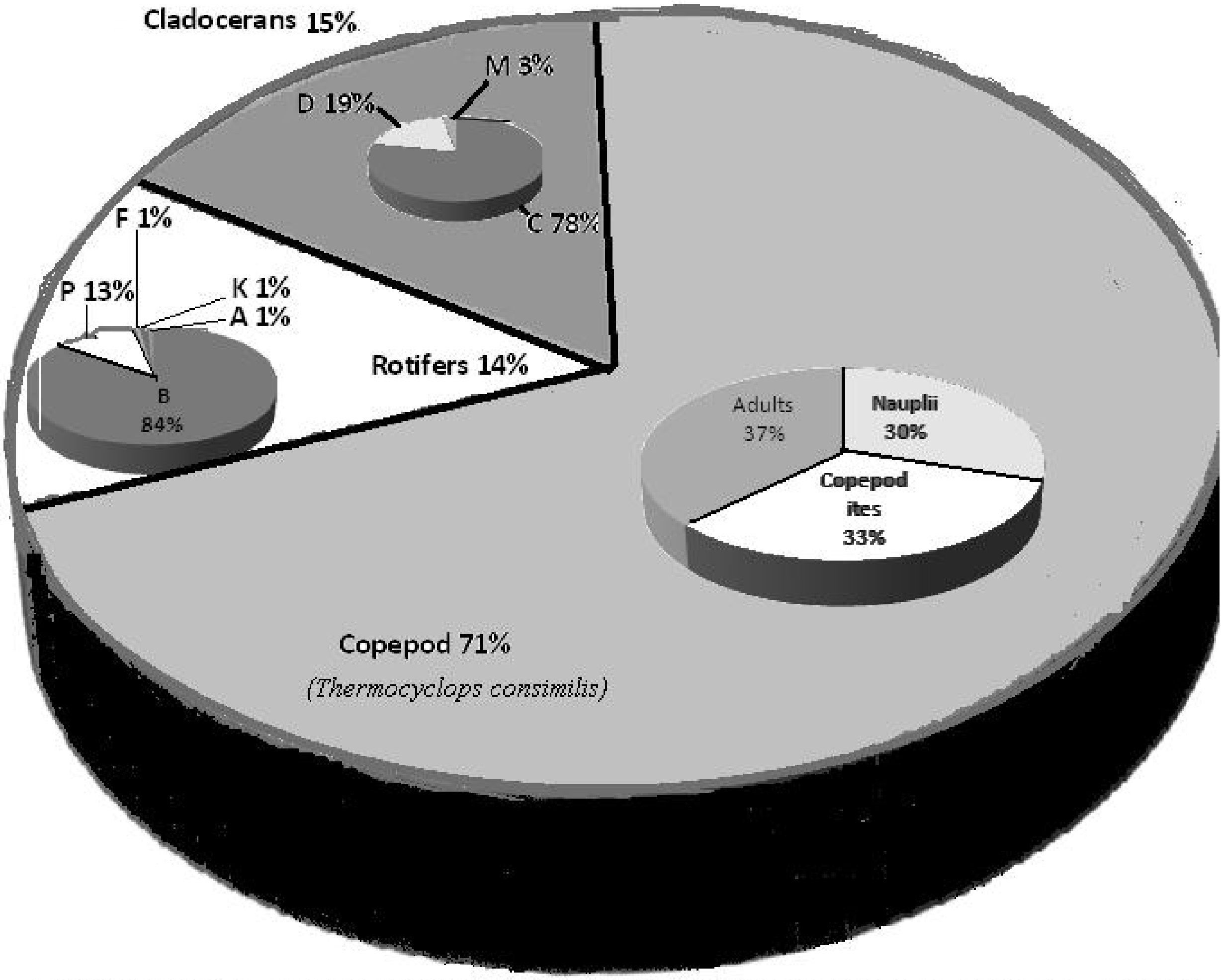


Fig.3. Comparative chlorophyll a concentration at near shore (NS) and open water (OP) in Lake Kuriftu.

5.2.3. Zooplankton identification and numerical density

A total of nine species were identified and their percentage composition in Lake Kuriftu was indicated in Figure 4. In terms of species abundance *Brachionus* spp (*Brachionus calyciforus*) is the second major species (12.0%) next to *Thermocyclops consimilis* (71%) and the third major species is *Ceriodaphnia* (11.8%). The other rotifers, P*olyathra (1.9%)*, *Asplanchni (0.2%)*, *Filinia (0.1%)*, and *Keratella (0.1%)* species and cladocerans, *Diaphanosoma* (2.8%) and *Moina* (0.4%) species were low in numbers.



Ceriodaphnia (C), *Diaphanosoma* (D), *Moina* (M), *Brachionus* spp (B), *Polyathra* spp (P), *Filinia* spp (F), *Asplanchia* spp (A), *Keratella* spp (K),

Figure 4. Percentage abundance of zooplankton in Lake Kuriftu

The zooplankton community in Lake Kuriftu is dominated by the cyclopoid copepods (*Thermocyclops consmilis*) which accounted for about 71% and the other 14 and 15% of the zooplankton community was recorded for rotifers and cladocerans, respectively. No calanoid and Mesocyclops were encountered during this study time.

Figure 5 compares temporal variation in mean monthly numerical density (ind/m^3) of copepods, cladocerans and rotifers and nauplii, copepodites and adults of copepod. The total zooplankton community abundance in Lake Kuriftu shows variability throughout the year with maximum value during the minor season (April 8.6x10^4 and May, 7.7x10^4 per m^3) and minimum value during major rainy season (August, 2.4x10^4) and dry season (February, 4.8x10^4 in per m^3). As observed in Lake Kuriftu and in other eutrophic lakes, zooplankton densities are usually lower during the heavy rainy season, following a decrease of nutrients resulting from the dilution of superficial water (Rodriguez and Tundist, 2002). The opposite occurs in oligotrophic environments (Rodriguez and Tundist, 2002), where an increase in primary production is expected in the rainy season pursuant to the input of nutrients.

Rotifer abundance in Lake Kuriftu is low (max 1.7x10^4) in December as compared with copepods (Wetzel 1983). Underestimation in net (64 µm mesh size) is likely, although with Kimmerer sampler used in another sampling day, higher numbers were not obtained. Minimum value for rotifers was recorded (min 6.9 x10^2) in August. More than 84% of the rotifer community is composed of species of *Brachionus* and low numbers were recorded for *Polyathra (13%)*, *Asplanchni (1%)*, *Filinia (1%)*, and *Keratella (1%)* species. In this case is common in tropical lakes; for example, Fernando (1980) stated that *Brachionus* contributes more than 50% of rotifer species in tropical lakes. Similarly in Lake Awassa, *Brachionus* and *Keratella* made up more than half of the rotifer assemblage (Seyoum Mengistou, 1989).

The seasonal trend in cladoceran community is almost similar to rotifers community which is in contrast to the result obtained by Girum Tamire (2006) that indicated the number of rotifers is much higher than cladocerans. More than 78% of cladoceran community is dominated by *Ceriodaphnia* species while *Diaphanosoma* (19%) and *Moina* (3%) were rare. *Daphnia*, which is reported by Brook Lemma *et al.* (2001), was not found in this study. The reason for low abundance of cladocerans than copepod could be common occurrence of blue green algae, particularly larger cyanbacteria, because they affect filtration capacity by interference and also clog feeding apparatus. De Bernardi and Guissani (1990) pointed that these phytoplankton are less edible, less nutritious, and some times toxic to cladocerans and Ceriodaphnia. *Moina* and *Diaphanosoma* mainly prefer diatoms than other food sources (Gonzalez, 2000). Onther reason for low occurrence of this zooplankton may be food competition among themselves and high water temperature in tropical lakes as compared with temperate ones. High temperature has deleterious effect on reproductive biology of cladocerans and can be reason for low density of these groups of zooplankton (Havens *et al*., 1996).

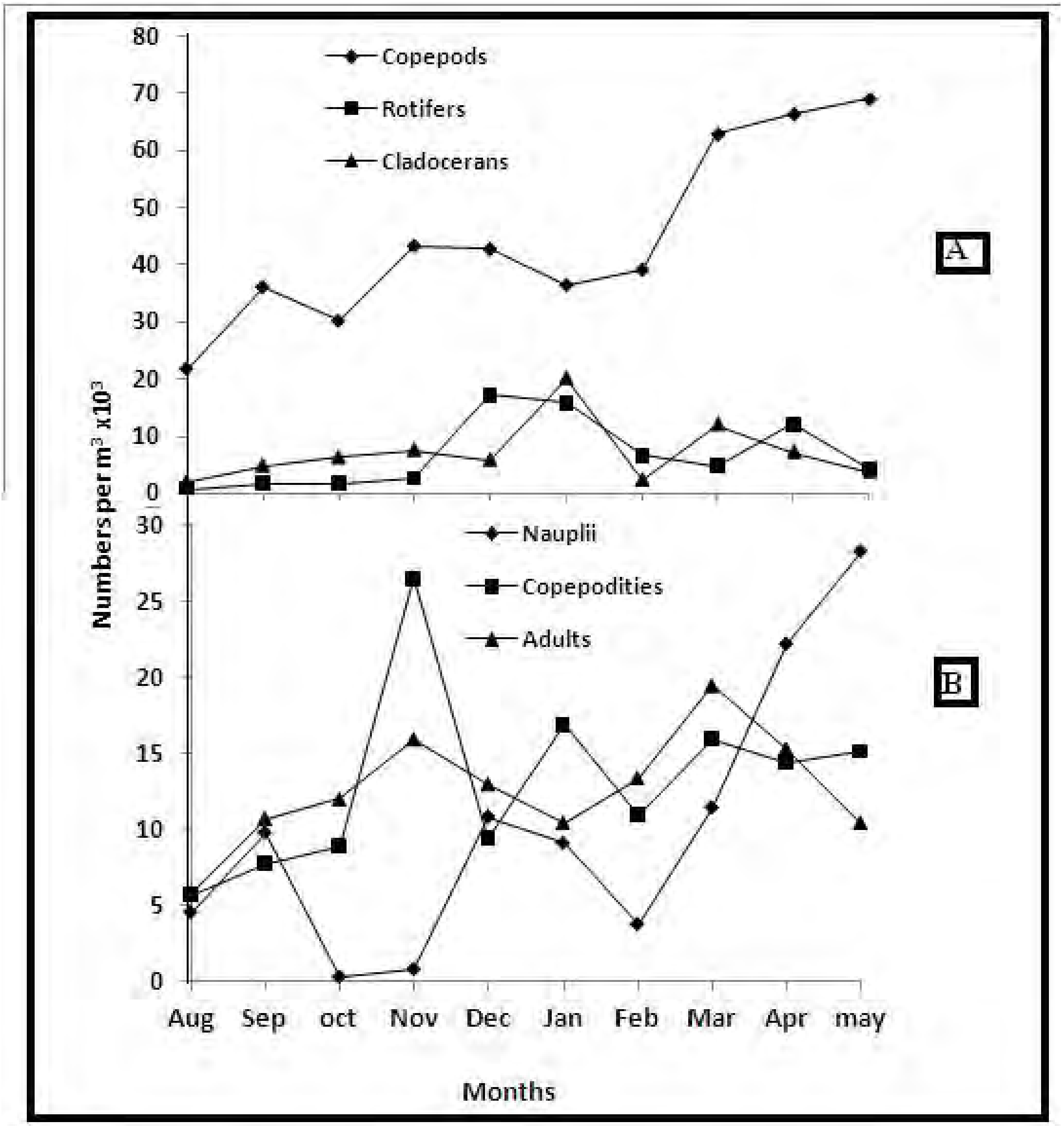


Fig.5. Mean numerical densities of copepods, rotifers and cladocerans (A) and stages of ***T.consimilis*** **(B) in Lake Kuriftu.**

The dominance of cyclopoid copepods is common in most Ethiopian lakes. For example cyclopoids were reported to be dominant in Lake Abijata (Kassahun Wodajo and Amha Belay, 1984) and Lake Awassa (Seyoum Mengistou, 1989). *Thermocyclops* species are reported to occur commonly in many tropical African lakes by Serruya and Pollingher (1983) and that is probably due to their wide range of feeding habits. This species seems more stable throughout the year in the study lake with little seasonal fluctuation. The highest and the lowest density was recorded in May (max 6.9×10^4 in m^{-3}) and in August (min 2.2×10^4 in m^{-3}), respectively.

In general there was an increase of *Thermocyclops* species during minor rainy (April and May) and early dry season (Oct and Nov) and decrease during dry season and major rainy season. This may be correlated with biomass production of phytoplankton and primary production seems to be the main limiting factor for *Thermocyclops* in Lake Kuriftu; because there was an increase biomass of phytoplankton in early dry period and minor rainy season during the study period (see Figure 2). Secondary production may be enhanced by nutrient releases from decomposition during post-rainy (early dry) period. Primary production is also the source of detritus as *Thermocyclops* also depend on detritus food materials (Gophen 1995). Primary production in pre-rainy (minor rainy) season in Lake Kuriftu may be associated with wind-driven mixing and efficient small sized algae compared to the post-rainy months, where it depends on rain-fed production. Thermocyclops was reported as being herbivores and raptorial on *Microcystis* colonies by Moriarity *et al*. (1973) in Lake George. On the other hand they have also been observed to prey on cladocerans and chirononids (De Carvalho, 1984). Gophen (1995) also reported that adult cyclopoids are raptorial feeders and prey on other zooplankton (mostly *Ceriodaphnia*) and detrital particles.

On the other hand the feeding of freshwater cyclopoid copepods on a wide spectrum of food is well known from the classic study of Fryer (Fryer, 1957). According to this author, algae are considered a more important food source for juvenile stages of planktonic cyclopoid copepods, while adults are mainly carnivorous. However Adrian and Frost (1992) pointed that animal body size appears to be an important factor determining the relative importance of both algal and animal prey on its feeding ecology; they have found that *Tropocyclops prasinus mexicanus* is omnivorous, but due to its small size, it exhibits a greater dependence on algal food than other large-bodied cyclopoids. Also, Adrian and Frost evaluated the extension of herbivory is dependent on species body size: small species were much more dependent on algae than the larger species, for which invertebrate prey had a greater importance (Adrian and Frost, 1993). Thermocyclops in the current studied lake is very small in size as compared with even the same species in different lakes (eg. Lake Hora under study) and hence it is believed to be dependent on largely on algal food. Another evidence that this species fed on algal food is that it grows in culture medium with mixed algal food. One interesting thing in current study that all stages (nauplii, copepodites and adult) of *Thermocyclopoid consimilis* were grow successfully with only mixed algal food.

In addition to food resource availability (bottom-up), or primary production of phytoplankton, the regulation of the number of zooplankton in a population is frequently seen as being due to predation (top-down) by fish, but these two types of regulation are related (Leibold, 1989). Juveniles of *Oriechromis niloticus* seem to be important zooplankton predator in Lake Kuriftu.

The mean numerical density (ind/m^3) of each stage of development (nauplii, copepodites and adults) for *Thermocyclops consimilis* species is shown in the fig. 5B. In general, the number of adults were higher in number that of other stages for this species. Among different stages of *T. consimilis*, adults dominated numerically during both the rainy and dry seasons with 37% in the study period with maximum number in March (max 1.9×10^4 in m^{-3}) and minimum value in

August (min. 5.8×10^3 in m^{-3}) whereas copepodites and nauplii represented 33% and 30% respectively throughout the study period. Nauplii were represented in low number during study period with maximum value in May (max. 2.8×10^4 in m^{-3}) which is the highest value for all stages and minimum value in October (min 3.6×10^2 in m^{-3}). Maximum and minimum values of copepodites were recorded in November (max 2.6×10^4 in m^{-3}) and August (min 5.7×10^3 in m^{-3}) respectively.

This result is in contrast to the finding of Ayalew Wondie (2003) in Lake Tana where nauplii had the highest abundance for all three stages of copepods whereas adults' numbers were low. On the other hand Seyoum Mengistou (1989) in his study pointed out that nauplii were very low in Lake Awassa, and cannibalistic predation was suggested as a possible reason for the observation. The high abundance of adult *T.consimilis* in the current study may be associated with long life span of adults than the other stages as observed in laboratory culture.

The density of copepods, rotifers and cladocerans in the two sites (open water and near shore) is represented in Figure 6. Although variable, the abundance of all zooplankton groups was not significantly different between the shore and the open water (see ANOVA Table 8). The highest abundance value for copepods was recorded in the open water (max 6.7×10^4 in m^{-3}) in December in the pen water and for rotifers and Cladocerans in January (max 2.2×10^4 and 2.8×10^4 in m^{-3}) in open water, respectively. The lowest value was recorded in August for all zooplankton, i.e., (min 1.2×10^4 in m^{-3}) in open water, (min 5.0×10^2 in m^{-3}) in open water and (min 1.8×10^3 in m^{-3}) in near shore for copepods, rotifers and cladocerans, respectively.

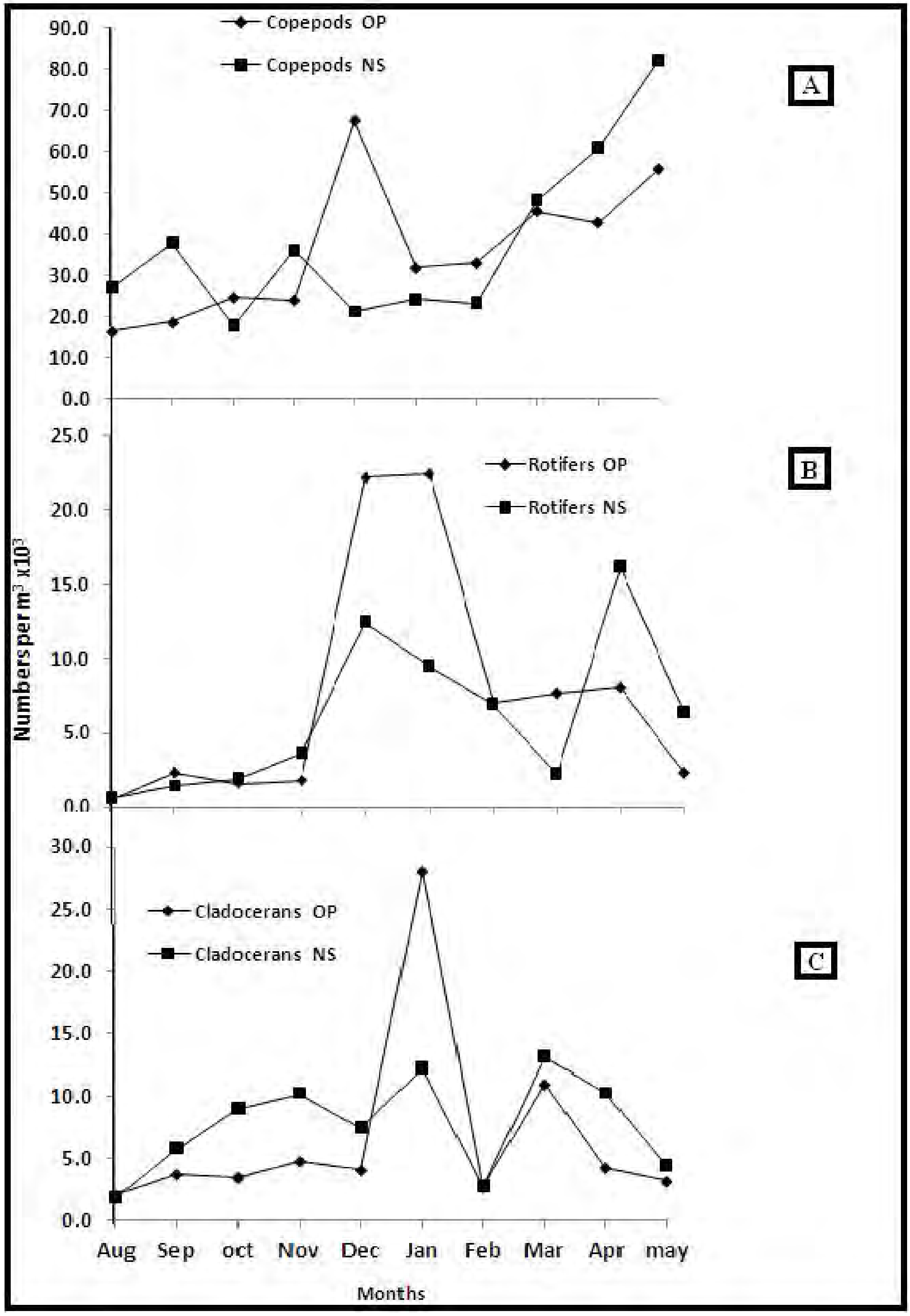


Fig.6. Numerical density of copepods (A), rotifers (B) and cladoceranc (C) in open water (OP) and near shore (NS) in Lake Kuriftu.

Figure 7 shows the numerical density of nauplii (A), copepodites (B) and adults (C) of *T.consimilis* in open water (OP) and near shore (NS). All stages show a slight increase in near shore. Ths is most probably associated with lake temperature, refuge and source of food at nearshore than middle lake. Maximum value (max $3.6 x 10^4$ in m^{-3}) which is the highest value for all stages was recorded in May in nearshore.

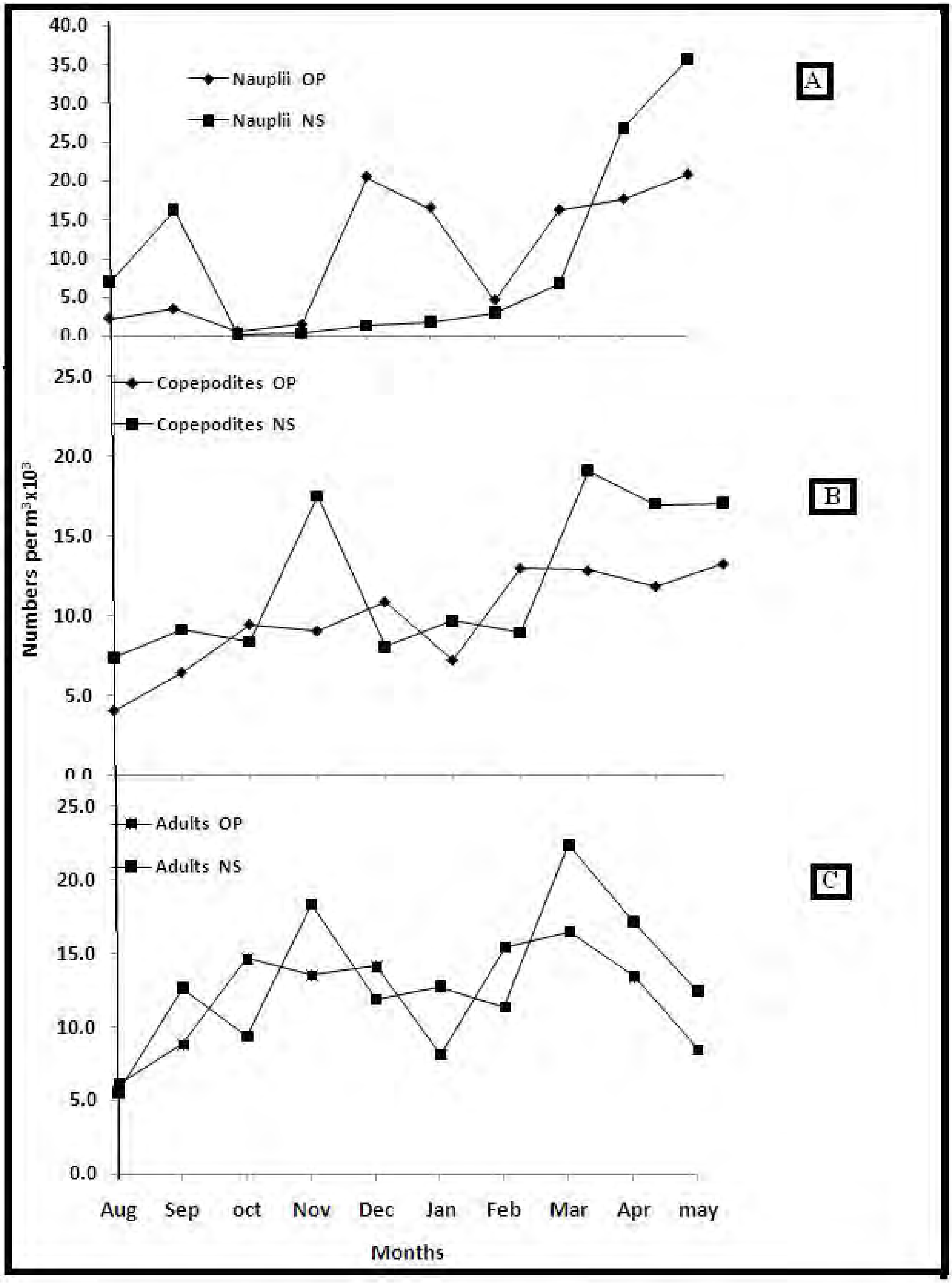


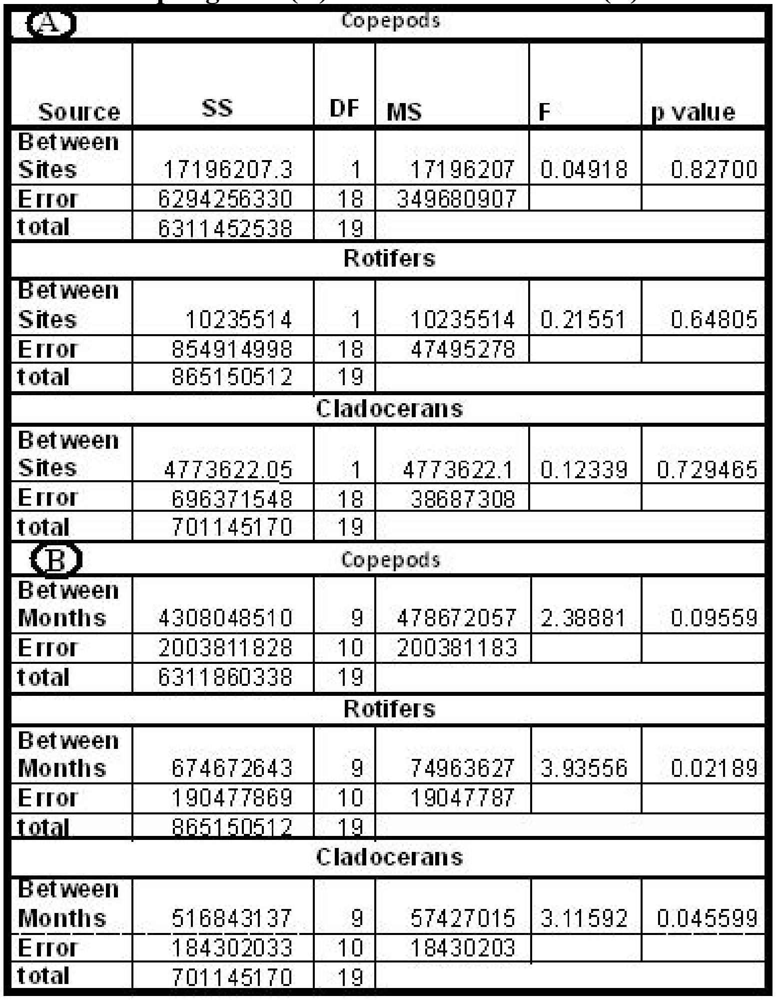
Fig.7. Numerical density of nauplii (A), copepodites (B) and adults (C) of *T.consimilis* in open water (OP) and near shore (NS) in Lake Kuriftu.

Temporal and spatial variation of zooplankton abundance

One-way analysis of variance (ANOVA) showed that zooplankton abundance at the two sites (nearshore and open water) and months (see Table 8) and all zooplankton group abundance at two sites were not significant ($p > 0.05$), and the abundance of rotifers and cladocerans were significantly different ($P < 0.05$) whereas the abundance of copepods were not significantly different between months. However this statical analysis does not tell in which month(s) the differences of rotifers and cladocerans lie; instead the line graphs (Fig.5) clearly show these differences. Copepods showed a peak value in May and low value in August while rotifers and cladocerans showed a peak value in December and Juanuary, respectively. The overall stastical analysis probability is done by counting data from all sites and months with date of counts used as error terms. In this way, the effect of variations between sites was interpreted independent of the months as error factor and variation between months also interpreted by considering the sites as error factors. The result indicated that abundance differences among the ten months were not significant (for copepods only), indicating an overall seasonaly stabllity for the copepod community. The high rotifers and cladocerans abundance and in such period may be associated with increasing in the density of edible phytoplankton such as diatoms and due to their parthenogenetic reproductive pattern and short developmental rates under favorable conditions and typical r-strategy of rotifers (Herzig, 1987) and edible phytoplankton by filter-feeder cladocerans.

However two sites are not enough to determine the zooplankton density fluctuations and hence more than a single site needs to be studied during such periods of peak abundance to characterized mean zooplankton densities. This observation also point to the need to restrict the analysis of zooplankton population dynamics to a few sites rather than using bulk samples across lake transects (Burgis 1974; Hart and Allanson 1975).

Table 8. One-way analysis of variance for Copepods, Rotifers and Cladocerans abundance between sampling sites (A) and between months (B).



Source	SS	DF	MS	F	p value
(A)			Copepods		
Between Sites	17196207.3	1	17196207	0.04918	0.82700
Error	6294256330	18	349680907		
total	6311452538	19			
			Rotifers		
Between Sites	10235514	1	10235514	0.21551	0.64805
Error	854914998	18	47495278		
total	865150512	19			
			Cladocerans		
Between Sites	4773622.05	1	4773622.1	0.12339	0.729465
Error	696371548	18	38687308		
total	701145170	19			
(B)			Copepods		
Between Months	4308048510	9	478672057	2.38881	0.09559
Error	2003811828	10	200381183		
total	6311860338	19			
			Rotifers		
Between Months	674672643	9	74963627	3.93556	0.02189
Error	190477869	10	19047787		
total	865150512	19			
			Cladocerans		
Between Months	516843137	9	57427015	3.11592	0.045599
Error	184302033	10	18430203		
total	701145170	19			

P < 0.05 significant, P > 0.05 insignificant

Figure 8 shows the mean numerical densities of females without eggs, males and females with eggs of *T.consimilis* adult count. The number of males in the adult count was very rare and number of females without eggs was dominant. There was continuous reproduction of copepods as shown by high % of females in the adult population and consistent fecundity throughout the study period. The mean percentage of adult females relative to the total number of adult was 90.2% and the fecundity (as eggs/female) for *T.consimilis* was continuous throughout the study period, with the mean ratio 20.2 eggs per female. The mean percentage of females carrying eggs in the adult count was 7.5 (average 10.3 individuals) eventhogh 0.02% sucros-formaline solution was not used for egg preservation method. The maximum clutch size of individual female (24 eggs per sac) was recorded during the post-rainy season coincides with the period of maximal phytoplankton biomass.

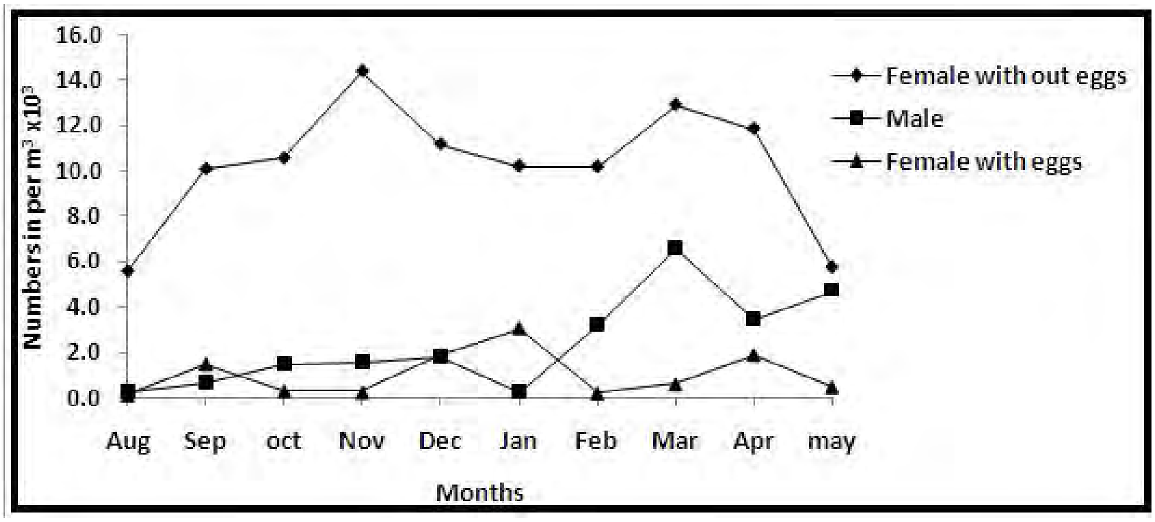


Fig.8. Mean numerical densities of female without eggs, male and female with eggs of *T. consimilis* in the adult count in Lake Kuriftu.

5.2.4. Duration of Development

Table 9 shows the development data of *Thermocyclops consimilis* species under laboratory conditions. According to Herzig (1983), the duration of embryonic development in planktonic freshwater copepods is primarily a function of temperature. The thermal history of the species population influences the relationship between temperature and duration of embryonic development follow the general trend of an inverse relationship between temperature and development time or longevity as reported by other authors (Sarvala, 1979; Herzig, 1983; Hart, 1990). This species showed relatively shorter development time than other species studied by other workers. *T. consimilis* took an average of 16.05

days to complete a generation time at 25.6^{0}c. This species showed a relatively longer development time at 20^{0}c with completing a generation in 21.4 days

Table 9. Developmental time (days) of Different stages of *T. consimilis* in Lake Kuriftu.

stages	20^{0}c	25.6^{0}c
Egg to nauplii (stage IV)	2.1	1.75
Nauplii to copepodites (stage IV)	5.5	4.20
Copepodities to adult	13.2	10.10
Egg to adult	21.4	16.05

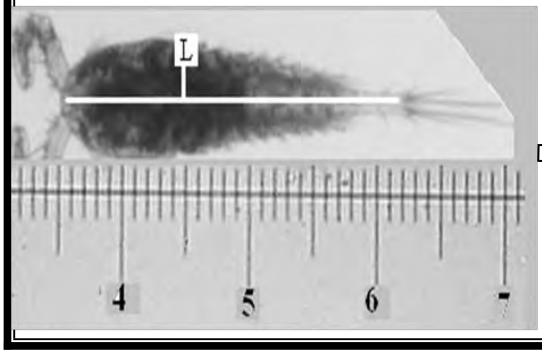
Post-embryonic duration is mainly affected by temperature and quality/quantity of food. There are, however, different responses among copepod species regarding the influence of food concentration on naupliar development. Naupliar durations appeared to be relatively independent of food concentrations, although food supply largely influenced copepodites development times in freshwater copepods (Hart, 1990). However as the experiment in the study was under non-limiting food levels, postembryonic development times were highly dependent on temperature.

5.2.5. Copepod Biomass estimates

Table 10 shows the body lengths and dry weights for the different stages of development of *T.consimilis*. The length (L) of nauplii, copepodites, adult female, adult male and egg (diameter) were measured and the results were used to estimate the wet-weight and dry-weight of the respective stages by weight-length regression equations. The mean dry weight of egg, nauplii, copepodite, adult male and adult female were 0.0046, 0.082, 0.58, 1.18, and 1.29 µg, respectively.

Table 10. length (L) in mm and dry weight (DW) and wet weight (WW) in µg of *Thermocyclops consimilis* in Lake Kuriftu

stages	**N**	**Length (L) in mm**	**WW in µg**	**DW in µg**
Eggs	2	0.064±0.002	0.021	0.0046
Nauplii	25	0.23±0.20	0.038	0.082
Copepodities	25	0.55±0.18	2.67	0.59
Adult male	17	0.75±0.19	5.36	1.18
Adult female	20	0.78±0.11	5.85	1.29
Adult mean			5.60	1.23



$$WW=10.227L^{2.249}$$

$$DW = 2.257\ L^{2.252}$$

Figure 9 shows seasonal variations of biomass (as mg DW m^{-3}) of each stage of development (nauplii, copepodites and adults) of *T. consimilis* in Lake Kuriftu. The sum of mean biomass of all stages is 23.79 mg DW m^{-3}. The biomass of this species was significantly different ($P < 0.05$) between months (see ANOVA Table 11). Higher mean biomass value was recorded in November and March, and minimum value of mean biomass for all stages was recorded in August. Generally, adults of *T. consimilis* had the highest biomass for this species throughout the study period with maximum value in March (max. 23.27 mg DW m^{-3}) and minimum value in August (min. 7.00 mg DW m^{-3}) and a mean biomass of 15.20 mg DW m^{-3}. Nauplii had the lowest biomass with average biomass of 0.83 mg DW m^{-3} (range 0.03 (October) to 2.32 (May) mg DW m^{-3}). Copepodites of this species had an average biomass of 7.76 mg DW m^{-3} with maximum value in November (max. 15.63 mg DW m^{-3}) and minimum value in August (min. 3.36 mg DW m^{-3}). In general the highest biomass of *T. consimilis* coincided with the highest phytoplankton biomass recorded and the lowest biomass of this species was recorded during heavy rainfall (August).

Table.11. One-way analysis of variance of biomass and production for *T.comsimilis* **in ten months**

Biomass					
source	SS	DF	MS	F	p value
Between Months	408.97	9	45.44	8.42	0.001
Error	53.97	10	5.40		
total	462.94	19			
production					
Between months	1.78	9	0.20	6.11	0.005
Error	0.32	10	0.03		
total	2.10	19			

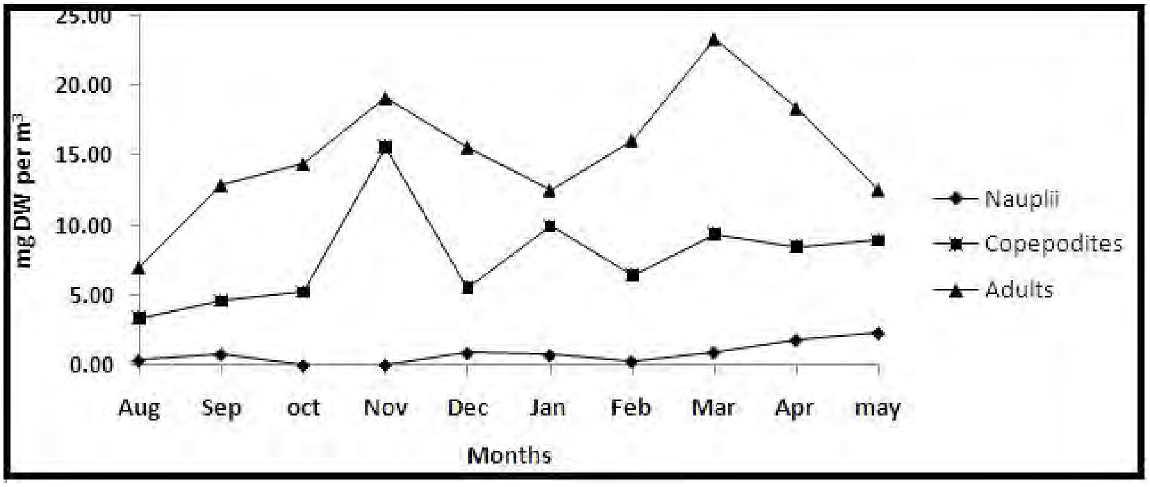


Fig.9. Standing biomass (mg DW m^{-3}) of nauplii, copepodites and adult of of T.consimilis **in Lake Kuriftu.**

The contribution of mean biomass of the different age classes of the copepods in different lakes is reported by different workers and is shown in Table 12.

Table 12. Comparison of biomass of different age classes of copepods in different lakes with age classes of *T. cosimilis* in Lake Kuriftu.

		Biomass in mg DW m^{-3}				
Lakes	**Species**	**Nauplii**	**Copepodites**	Adults	eggs	sources
Lanao	*Thermocyclops hyalinus*	31.8	67.5	25.15	0.9	Lewis, 1979
Awassa	*Mesocyclops aequatorialis*	2	15	70	-	Seyoum Mengistou & Fernandio, 1991
Awassa	*T. consimilis*	2	10	8	-	Seyoum Mengistou & Fernandio, 1991
George	*T. hyalinus*	10	164	74	4	Burgis, 1974
Tana	*T. gelbi*	2.37	10.24	8.3	0.13	Ayalew Wondie & Seyoum Mengistou, 2006
Tana	*T. ethiopiensis*	0.67	3.58	3.09	0.05	Ayalew Wondie & Seyoum Mengistou, 2006
Tana	*M. aequatorialis*	0.66	2.82	2.7	0.06	Ayalew Wondie & Seyoum Mengistou, 2006
Kuriftu	*T. consimilis*	0.83	7.76	15.2	-	Present study

In the present study the mean biomass values of nauplii, copepodites, and adults are 0.83, 7.76 and 15.20, respectively, which is lower than the data obtained from most tropical lake studied. On the other hand the biomass of each age class of *T. consimilis* is higher than the biomass of the respective age class of *Theromcyclops ethiopiensis* and *Mesocyclops aequatorials* in Lake Tana. Adult biomass in Lake Kuriftu was almost 2-fold higher than the biomass of adults of the same species in Lake Awassa, whereas the biomass of nauplii was lower by 2.5-fold of the same species in Lake Awassa. The biomass of copepodites in the present lake was comparable with the biomass of copepodites of the same species in Lake Awassa.

In general lower biomass value in August and September in all developmental stages was probably due to high rainfall and unfavorable feeding conditions in September and perhaps due to poor quality of the phytoplankton as food source and lower mean temperature. Maximum value for adults was recorded in March (max. 23.79 mg DW m^{-3}) and this was associated with high biomass of phytoplankton and high temperature recorded in Lake Kuriftu. Figure 10 shows relative comparison of monthly biomass of nauplii, copepodites and adult of *T.consumilis* (mg per m^3) with monthly biomass of phytoplankton (Chl a mg m^3)

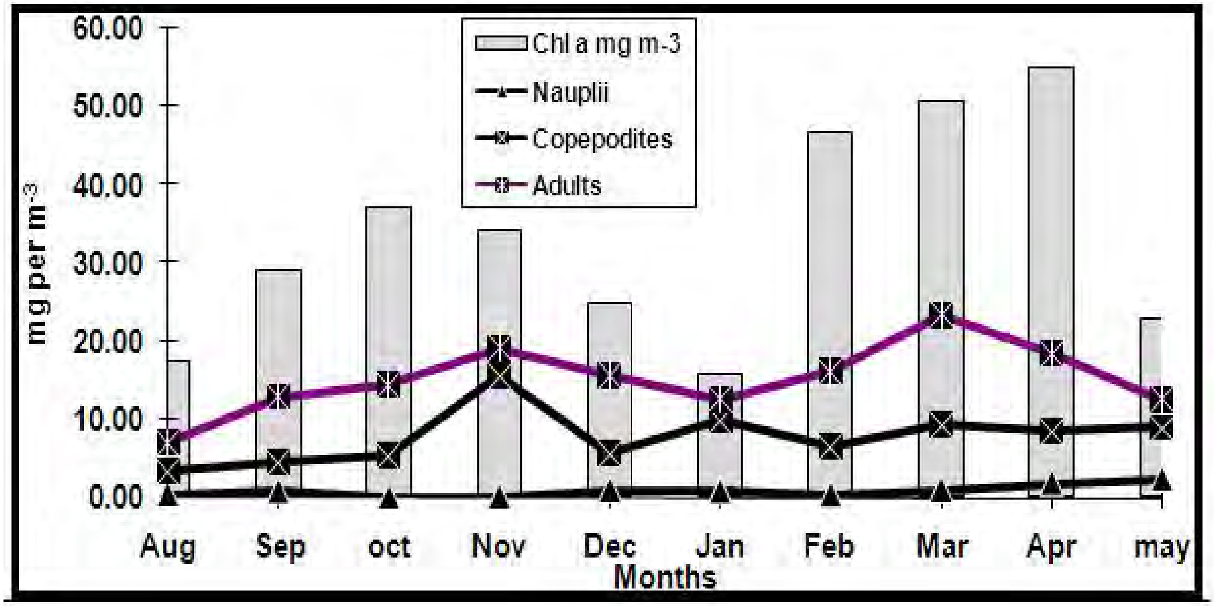


Fig. 10. Comparison between biomass of nauplii, copepodites and adult of *T.consimilis* with biomass of phytoplankton in Lake Kuriftu.

The standing stock data for tropical and subtropical copepod species found in the literature show large variability. This high variability in mean dry mass of tropical copepods in different lakes is reported by different workers and is shown in Table 13. In Lake Naivasha (Kenya), Mavuti (1994) found an annual mean biomass of 120.45 mg DW m^{-3} for *Thermocyclops oblongatus*. Seyoum Mengistou and Fernando (1991) obtained lower mean biomass of 44.85 mg DW for the dominant crustacean in Lake Awassa. Leveque and Saint-Jean (1983) report close value of 56.4 mg DW m^{-3} for *Thermocyclops neglectus* in Lake Chad. Aylew Wondie and Seyoum Mengistou (2006) found the mean annual biomass of 34.43 mg DW m^{-3} in Lake Tana. The mean annual biomass of *T.consimilis* in Lake Kuriftu is 23.79mg DW m^{-3}.

Biomass of *T. consimilis* in Lake Kuriftu was lower than the value recorded in productive equatorial lakes i.e., Lake George and Lake Chad (see Table 13). On the other hand the biomass of this specie was higher than the value recorded in oligotrophic lake of Ethiopia (Lake Tana). Lake Kurifu seems to be mesotrophic. The mean phytoplankton biomass was 33.46 at near shore and 33.09 Chl a m^{-3} at open water with the maximum value 63.73 mg Chl a m^{-3}. Water bodies showing a trophic state index below 44 are oligotrophic, from 44 to 54 they are mesotrophic, and above 54 they are eutrophic. On the other hand the biomass of the same species in Lake Awassa (Seyoum Mengistou, 1989) is about four times higher than the present result. Lake Awassa is in the eutrophic category with a mean daily primary production of 2.6 g C m^{-2} (cf. Seyoum Mengistou and Fernando, 1991). The low biomass of *T. consimilis* in Lake Kurifu than in Lake Awassa may be associated with the trophic status of the lake, quality of food and size of water body. Lake Kuriftu was dominated by cyanobacteria which are less edible, less nutritious, and some times toxic to zooplankton throughout the year; and the size of this species was small compared with the same species of different lake (eg. Lake Hora) and this may be associated with the size of water body. Lake Kuriftu is small and shallow lake (with mean depth 2m and maximum depth 8m (Seifu Kebede, 2001)).

Ggeneraly, standing stock of copepod species in Lake Kuriftu is quite low compared to the figures just reported: biomass of *T. consimilis* (integrated for a water column of 5 m depth) was 14.51 mg DW m^{-3} in rainy season and 26.19 mg DW m^{-3} in the long dry season in Lake Kuriftu under a mean annual temperature of 22.45^{0} c. There was a slight increase of biomass after the heavy rainy season. The standing stock of most crustaceans was higher in the rainy season (Mavuti, 1994).

Table 13. Comparison of production of *Thermocyclops consimilis* species from tropical African lakes. Biomass (mg DW m^{-3}), mean daily production (mg DW m^{-3} day^{-1}); totoal annual production; mean daily and total annual P/B ratio respectively.

Taxa	Lake Mean To (0c)	B	Daily production	Annual production	Daily P/B ratio	Annual P/B	Locality (Lake)	Reference
Mesocyclops aequatorialis	23/24	-	-	-	0.18	14.3	Ethiopia Awassa	Seyoum Mengistou (1989)
Thermocyclops consimilis	23/24	95	6.9	535.2	0.044	14.6	Ethiopia Awassa	Seyoum Mengistou (1989)
Thermcyclops oblongatus	22	120	11	4022	0.09	73.5	Kenya Naivasha	Mavuti (1994)
Thermocyclops hyalinus	25	248	18.6	7154	0.08	28.8	Uganda George	Burgis (1974)
Thermocyclops neglectus	26	56.4	9.6	3580	0.17	63.5	Chad Chad	Leveque and Saint Jean (1983)
Mesocyclops aequatorialis	-	-	3.2-7.0*	-	-	-	Malawi malawi	Irvine and Waya (1999)
M. aequatorialis	21/22	6.18	0.43	157	0.07	25.4	Ethiopia Tana	Ayalew Wondie and Seyoum Mengistou (2006)
Thermocyclops ethiopiensis	21/22	7.33	0.42	156	0.06	21.3	Ethiopa Tana	Ayalew Wondie and Seyoum Mengistou (2006)
Thermodiaptomus galebi	21/22	20.9	1.04	380	0.05	18 .2	Ethiopia Tana	Ayalew Wondie and Seyoum Mengistou (2006)
Thermocyclops consimilis	22.45	23.8	0.78	311.27	0.033	13.10	Ethiopia Kuriftu	present study

5.2.6. Copepod production rates and P/B ratio

Fig. 11A shows daily production rates (mg DW m^{-3} day^{-1}) of nauplii, copepodites and adults (eggs) of *T.consimilis* in Lake Kuriftu. The mean daily production of all stages is 0.78 mg Dw m^{-3} day^{-1} (range from 0.33 to 1.21 mg Dw m^{-3} day^{-1}). The highest daily rate of production is observed in November and in the minor rainy season (May) for this species (max. 1.21 Mg DW m^{-3} day^{-1}) and minimum value was recorded in August (min. 0.33 mg DW m^{-3} day^{-1}).

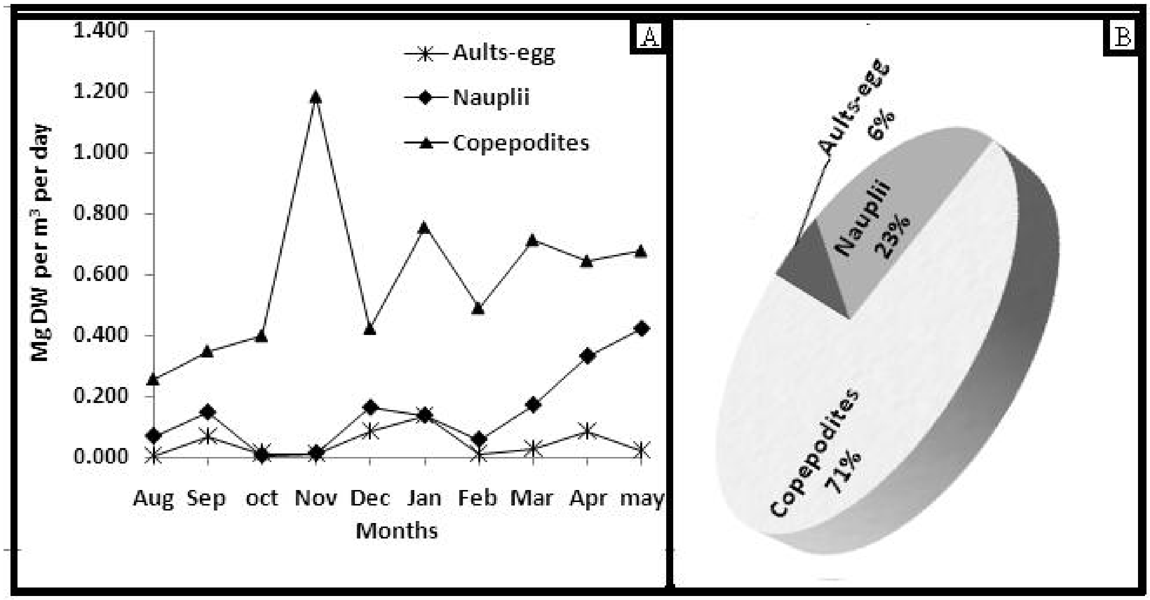


Fig.11. production (mg DW m^{-3}) (A) and percentage contribution (B) of nauplii, copepodites and adults-eggs of *T.consimilis* in Lake Kuriftu.

Studies involving estimations of the dry weight and biomass of zooplankton organisms are rare and comparative approach is difficult due to the use of different methodologies. Some workers use microbalance (error factor is sensitivity) and others including this study use length-weight relationships (by regression equation) to estimate dry weight and biomass. The error factor of the latter method is associated with temperature, food quality and quantity, species genotype, seasons and differences in the physical conditions of habitats, among other factors, can lead to changes in the carbon content of each species (Dumont *et al.*, 1975; Vijverberg, 1989). And even others use data obtained from the literature (eg. Aasquez & Rey, 1992) to estimate the dry weight of zooplankton. Also, comparisons were not always possible due to differences in the composition of species.

However productivity measurements are more realistic than abundance or biomass measurements in describing the contribution of each species in energy flow in the ecosystems. There are several estimates of zooplankton production in African lakes. Leveque and Saint-Jean (1983) estimated the daily production of crustacean zooplankton (cyclopoid copepod) in Lake Chad as 1.3 to 60.6 mg DW m^{-2}. Seyoum Mengistou and Fernando (1991) recorded integrated production of cyclopoid copepod in Lake Awassa as 16.04 mg DW m^{-2} day^{-1}. Burgis (1974) recorded mean production of 44 mg DW m^{-2} day^{-1} for *T.hyalinus* in Lake George. Irvine and Waya (1999) reported production value ranging from 3.2 to 7.0 mg DW m^{-2} day^{-1} for *M. aequatorialis* in oligotrophic Malawi Lake. In Lake Tana, mean daily production of total copepods was 17. 28 mg DW m^{-2} day^{-1} (Ayalew Wondie and Seyoum Mengistou, 2006). The mean production of *T.consimilis* in Lake kuriftu was 0.78 mg DW m^{-3} per day (ranging from 0.34 (September) to 1.21 mg DW $m^{-3}d^{-1}$ (November)). The high value of *T. consimilis* production in November and April and May (1.12 mg DW $m^{-3}d^{-1}$) was correlated with the high phytoplankton biomass in these months. This may be associated with aquality and abundance of food available to this species.

The relative contribution of each developmental stage in the current lake is presented in Figure 11B and Table 14 compares the production of nauplii, copepodities and eggs of *T. consimilis* in Lake Kuriftu with respective age class of copepods in different lakes. Copepodites contribute 71% (ranging from 0.255 to 1.184mg DW m^{-3} d^{-1}) of the total copepod production and nauplii and eggs (adults) contribute 23% (ranging from 0.005 to 0. 421) and 6% (ranging from 0.005 to

0.135), respectively. The contribution of the adult-eggs of the total production was very low in all seasons. However, this species did not show period with zero egg production. Maximum value of egg production was recorded in January (max. 0.135 mg m^{-3} day^{-1}) and in general there was an increase of egg production during post-rainy season (September) and during the minor rainy season (April). Minimum value of egg production was recorded in heavy rainy season (August,) and in the dry season (February). Copepodites had the dominant production values throughout the year with a peak value in November (max. 1.184 mg DW $m^{-3}d^{-1}$) and minimum value in August (min. 0.255 mg DW m^{-3} d^{-1}) while nauplii had the highest recorded value in March (max.0.171 mg DW m^{-3} d^{-1}) and the lowest value in October (min. 0.005 mg DW m^{-3} d^{-1}). In general low daily production was recorded in major rainy season (August) for all stages.

Table 14. Comparison of percentage production of different age class of copepods in different lakes with age classes of *T. consimilis* in Lake Kuriftu.

		% of production			
Lakes	**Species**	**Nauplii**	**Copepodite**	**eggs**	**sources**
Naivasha	*copepod*	48	47	5	Mavuti, 1994
Awassa	*Thermocyclops consimilis*	27	67.7	5.3	Seyoum Mengistou & Fernandio, 1991
George	*T. hyalinus*	8	78	15	Burgis, 1974
Tana	*copepod*	68.5	26.5	5	Ayalew Wondie & Seyoum Mengistou, 2006
Kuriftu	*T. consimilis*	23	71	6	Present study

In all studies (Table 14) including the present study, the relative contribution of egg production was low and copepodites had high production rates. On the other hand Ayalew Wondie and seyoum Mengistou (2006) reported that nauplii had high production rate than other age classes and Vareschi and Jacobs (1984) reported an exceptionally high value (>50%) of egg production for the calanoid copepod *Paradiaptomous africanus*, in Lake Nakuru (Kenya).

Annual mean production calculated as geometric mean is really a log-transformation of data to enable meaningful statistical evaluations than daily mean production. Thus the annual mean production rate for all stages in Lake Kuriftu was 311.27 mg DW m^{-3} yr^{-1} (ranging 118.12 to 434.92 mg DW m^{-3} yr^{-1}). *Thermocyclops consimilis* in Lake kuriftu had high annual production than T. *ethiopiensis* and *Mesocyclops aequatorialis* in Lake Tana (see table 13) whereas annual production of the same species in Lake Awassa had 1.7-fold production than in Lake Kuriftu.

The P/B ratio is the biomass turnover rate on daily or annual basis. The mean daily P/B ratio for *T.consimilis* in Lake Kuriftu is 0.033. Eggs had the highest P/B ratio. The lowest daily P/B ratio was recorded for copepodites. The P/B ratio was seasonally stable for this species. The turnover time (days) of biomass for nauplii was 5.5 and 13.2 and 2.2 for copepodites and eggs respectively. This is in close agreement with the generation times obtained from culture experiments for this copepod. The annual P:B ratio for this species during the study period was 13.10. Both the daily and annual P/B ratio of this specie was comparable to the daily and annual P/B ratio of the same species and *Mesocyclops aequatorialis* in Lake Awassa (see Table 13). On the other hand Ayalew wondie and seyoum Mengistou (2006) obtained higher P/B ratio for *M. aequatorialis* and *Thermocyclops ethiopiensis* in Lake Tana. Lower daily and annual P/B ratio and lower turnover times were observed for the Lake Kuriftu copepod, which suggested that this species shows relatively high turnover rates in the food chain. The high turnover rates of this species in Lake Kuriftu may be associated with its size as small organisms have high low turnover time or high turnover rates in their production.

5.2.7. Rotifer biomass and production

Table 15 shows the geometric formula used for calculation of the body volume, dimensions measured (in µm), calculated biovolume (in µm^3), conversion factor for transforming wet weight to dry weight, and dry weight biomass (in µg DW m^{-3} ind^{-1}) for *Brachionus calyciflorus.* The geometric formula used for *B. calyciflorus* to calculate its volume is cylinder ignoring appendices (setae). The body dimension in µm and the calculated biovolume (in µm^3) and the calculated volume was converted to wet and then dry wet (in µg DW). The conversion factor from wet weight to dry weight is 26% according to Pauli (1989). The mean body length was 155 µm and mean body width was 60 µm, providing a biovolume 438030 µm^3. Applying the wet weight-dry weight conversion factor 26% gave a dry weight of 0.11µg ind^{-1}. Rodriguez and Tundist (2002) obtained the dry mass of *Filinia pejlerii* and *Keratella Americana* 0.02 µg DW ind^{-1}. Tundisi, et al. (2006) calculated the dry mass of the same species of the present study 0.23 µg DW ind^{-1} and for *Brachionus mirus tpicus* and *B. havanaensis havanaensis* 0.01 and 0.02 µg DW ind^{-1}, respectively.

Table 15. Geometric formula used for calculation of the body volume, dimensions measured (in μm), calculated biovolume (in μm^3), conversion factor for transforming wet weight to dry weight, and dry weight biomass (in μg DW m^{-3} ind^{-1}) for *B. calyciflorus* in Lake Kuriftu.

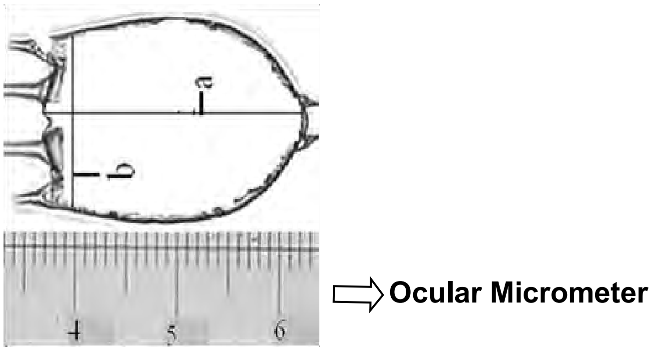
Species	Geometric formula used	Measurements for formula	Dimensions	Biovolume	Factor	Biomass
Brachionus calyciflorus	Cylinder $=\prod r^2h$	a = h b = 2r	a = 155 b = 60	438030	26%	0.11
Body a = length b = width						

Table 16 shows the temperature, number of females and number of eggs m^{-3} for *B. calyciflorus*. The egg developmental time (De) final birth rate (B), recruitment of new individuals (P_N), necessary parameters to obtain the production are also presented in table 16. The data showed that the temperature ranges from 19.40^0c and 24.78^0c, and egg development time varied between 0.84 and 0.55 days with mean value of 0.66 days, which is equivalent to 15 hours and 8 minutes.

Table 16. Lake temperature, number of females and number of eggs (m^{-3}), egg developmental time (De), biomass (µg DW m^{-3}), finite birth rate (B), recruitment of new individuals (P_N) in m^{-3} and production (µg DW m^{-3} d^{-1}) for *Branchinus calyciflorus* in Lake Kuriftu.

Months	To.(^{0}c)	(N_f) in m^{-3}	Eggs in m^{-3}	Biomass	De	B	P_N	P
Aug	22.30	335.40	123.85	36.89	0.66	0.56	187.46	20.62
Sep	19.40	1271.55	0.00	139.87	0.84	0.00	0.00	0.00
Oct	24.50	1012.55	842.18	111.38	0.56	1.49	1512.29	166.35
Nov	24.50	1644.70	0.00	180.92	0.56	0.00	0.00	0.00
Dec	20.80	13937.85	4384.29	1533.16	0.75	0.42	5864.17	645.06
Jan	20.30	12918.45	2724.70	1421.03	0.78	0.27	3492.28	384.15
Feb	22.00	6543.90	148.62	719.83	0.68	0.03	219.56	24.15
Mar	22.10	4339.35	1585.28	477.33	0.67	0.54	2361.06	259.72
Apr	23.80	11522.65	767.87	1267.49	0.59	0.11	1307.52	143.83
May	24.78	3715.50	792.64	408.71	0.55	0.39	1453.45	159.88
Mean	22.45	5724.19	1136.94	629.66	0.66	0.38	1639.78	180.38

Egg developmental time

Egg developmental time (De) of *B.calyciflorus* was highly correlated with lake temperature (see Table 16 and fig. 12). At lower temperature (19.40^{0}c) the egg development time takes 0.84 days (maximum) while at higher temperature (24.78^{0}c) in May, it takes 0.55 days (minimum). The mean egg developmental time during the study period was 0.66 days. Egg developmental time is directly related with temperature. Okano (1994) obtained egg developmental time for the species *Branchionus falcatus, Filinia longiseta* and *Keratella cochlearis* at 0.83 days, where mean water temperature was 20.4^0c. The egg development time for *F. pejleri* and *Keratella Americana* was 19 hours with mean lake temperature 20.9^0c (Rodriguez and Tundist, 2002).

Biomass estimates

The biomass calculated for this species and its monthly fluctuation is presented in Figure 12C. Monthly biomass of *B. calyciflorus* was significantly variable ($P < 0.05$) (Table 17). The average value of dry biomass of this species obtained in the study period is 629.66 µg DW m^{-3} with a maximum value of 1533.16µg DW m^{-3} in December and minimum value 36.89 µg DW m^{-3} in August. *B. calyciflorus* has lower zooplankton biomass compared to the biomass of copepods. On the other hand the biomass of the current studty was comparable with the biomass of the same species (898.75 66 µg DW m^{-3}) and higher than *Brachionus mirus tpicus* (57.55 µg DW m^{-3}) and *B. havanaensis havanaensis* (65.55 µg DW m^{-3}) in lake São Paulo, Brazil (Tundisi *et al.,* 2006). The dry mass for *F. pejleri* and *Keratella Americana* was 0.11 and 0.27 mg DW m^{-3}, respectively (Rodriguez and Tundist, 2002). Analysis of biomass gives estimates of the energy stored as organic matter by the population, and, if done for each trophic level, can assist the estimation of energy fluxes within community and the productive potential of the system. However, the biomass of organism present at any particular time does not necessary reflect the rate of production of new matter or the rate of energy processing. *B. calyciflorus* in present study contributes insignificant biomass in Lake Kuriftu than *T. consimilis*. This was because of their small size and lesser abundance than the copepods.

Table 17. One-way analysis of variance for biomass and production of *B.calyciflorus* in ten months.

Biomass					
Source	**SS**	**DF**	**MS**	**F**	**p value**
Between Months	6039414.12	9	671046.01	764.75	0.000
Error	8774.69	10	877.47		
total	6048188.81	19			
production					
Between months	762097.18	9	84677.46	3400.97	0.000
Error	248.98	10	24.90		
total	762348.16	19			

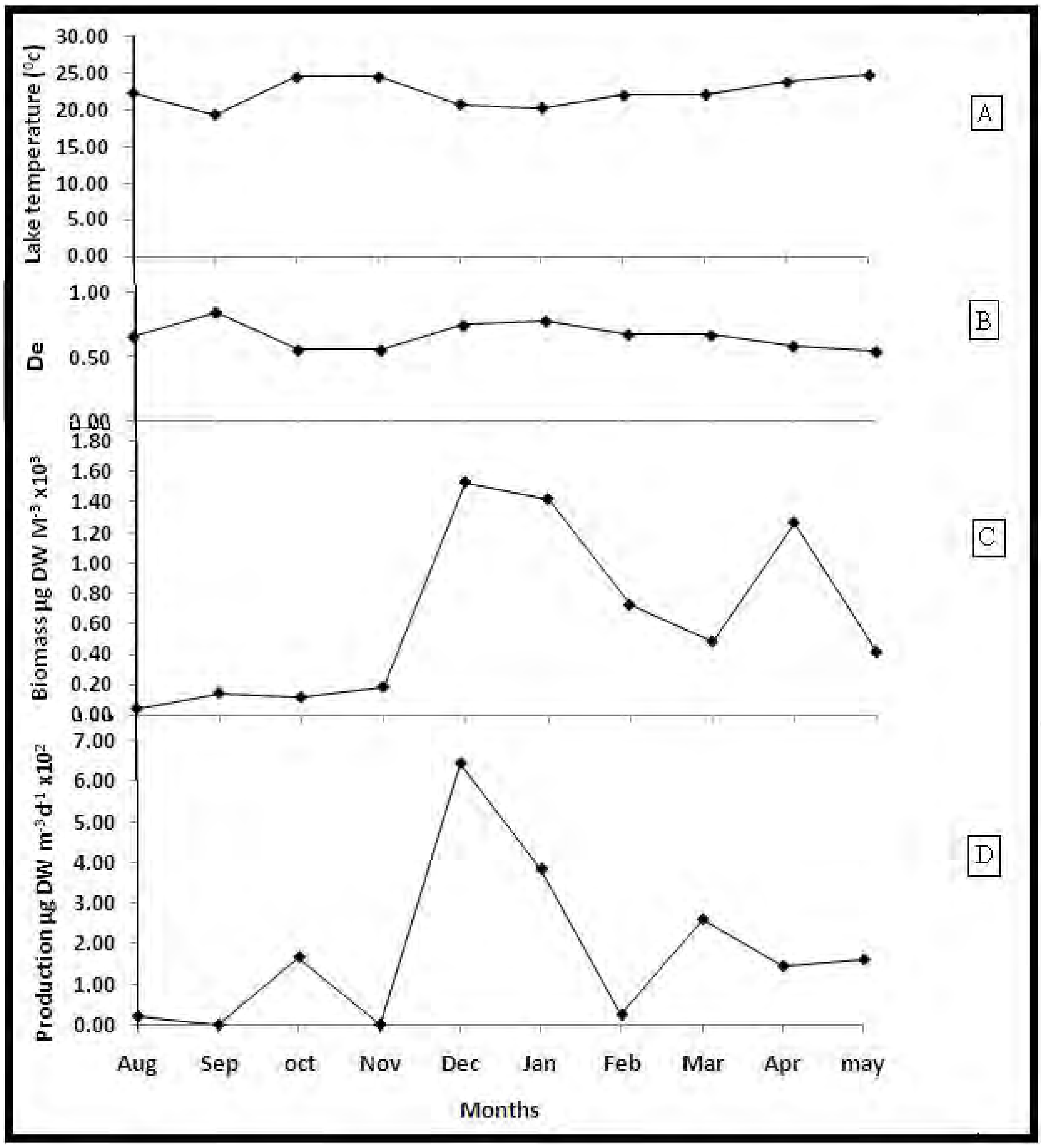


Figure 12. Monthly fluctuation of lake temperature (A), egg development time, De (B), biomass (C) and production (D) of *B. calyciflorus* in Lake Kuriftu.

Production estimates and P/B ratio

The production calculated for *B. calyciflorus* and its monthly variation is presented in the Figure 12D. The average value of production of *B. calyciflorus* obtained in the study period was 180.38 µg DW $m^{-3}day^{-1}$ with a maximum value of 645.06 µg DW m^{-3} day^{-1} in December and minimum value 0.00µg DW m^{-3} day^{-1} in September and November. Daily production of the current species was lower than daily production of *F. pejleri* (48.37mg DW m^{-3} day^{-1}) and *Keratella Americana* (91.09 mg DW m^{-3} day^{-1}) (Rodriguez and Tundist, 2002). The mean annual production of this species is 49.25 mg DW m^{-3} yr^{-1} with maximum value in December (max. 232.22 mg DW m^{-3} yr^{-1}). In general, production of this species is high during the dry season than rainy and minor rainy season. Althougvh rotifers (in this case *B. calyciflorus*) contribute less biomass because of their small size when compared to copepods; they may have significant production in this lake, because of their high biomass turnover rate. The mean daily and annual ratio of Production: Biomass of this species is 0.29 (ranging from 0.00 to 1.49) and 21.31, respectively. The mean daily and annual P/B ratio of *T.consimilis* in the same study is 0.033 and 13.10, respectively which is lower than *B. calyciflorus.* This indicates that rotifers, in this case *B. calyciflorus,* has high biomass turnover rate than copepods. However these two species had different production maxima. Rotiffers had the highes production values in dry season (December and juanuary) whereas *T. consimilis* had the highest production during post-rainy and pre-rainy seasons. Therefore these two species can provide food to consumers at different times.

General discussion

The phytoplankton community in Lake Kuriftu was constituted for most of the study period largely by cyanobacteria and green algae whose dominance was favored by the hydrological conditions (water input-output through runoff from precipitation and evaporation) which are contributory factors for the marked temporal fluctuations in the abundance, biomass and photosynthetic activity of phytoplankton. The contribution of hydrographic conditions of the lake (physical stratification/mixing), is low in Lake Kurftu which are regarded as factors of over-riding importance in determining the seasonal dominance of algal groups in other tropical lakes. Lake Kuriftu is a shallow lake and its algal biomass and primary production are associated with its fairly high concentrations of nitrate and phosphate, which must have resulted from their high external and internal input into the trophogenic zone.

The zooplankton community composition in Lake Kuriftu is dominated by Thermocyclops copepods, even though the total species diversity of zooplankton is low as compared to other tropical lakes. A number of literatures discussed the dominance of copepods over other zooplankton groups (rotifers and cladocerans) in tropical Lakes. Zooplankton communities in tropical lakes are usually dominated by copepods (Burgis 1973; Serruya and Pollingher, 1983; Payne, 1987) and the species diversity of zooplankton community are as a whole low (Richerson et al., 1977; Fernando, 1980a; Lewis, 1979).

Tropical climate with muted seasonality is one factor that favors the dominance of copepods over cladocerans (Allan, 1976). The k-selected nature of their life history, moderate rate of increase, less susceptibility to predation gave them a competitive advantage in seasonally stable tropical lakes. Many studies appear to support the decreased susceptibility of copepods to fish predation (Twomply and Lewis, 1987). One consequence of this is that the copepods dominate the crustacean biomass in lakes with severe vertebrate planktovory (eg. Wells, 1970).

The feeding plasticity of copepods is other aspect which involves much wider habits than herbivory. For example, *Mesocyclops* feed on food of animals and plants origin (Jamieson, 1980), and even on detritus and dead crusteceans (Papinska, 1985). *Thermocyclops* although predominately herbivores, has also been observed to prey on cladocerans and chironomids (DeCarvalho, 1984). In addition these copepods have been reported to subsist on bacterial suspension (Finlay *et al*., 1987; Payne, 1987). Thus one additional reason why these two Cyclopopids are common in tropical lakes may be because of their wide range of feeding habits.

Secondary production in Lake Kuriftu is very low as compared with other tropical lakes. It is assumed that the high primary production of tropical freshwater is complemented by high secondary production, but available data from different literatures do not support this assumption. For example Hecky (1984) compiled data from some African lakes which shows that only a tiny fraction of the carbon in phytoplankton ends in fish (eg. George = 0.25%; Chad = 0.03%, Malawi = 0.16%; Awassa = 0.49-0.67). This suggested that tropical zooplankton production is low in relation to primary production (Hecky 1984; Kalf and Watson, 1986). One explanation for this is that the respiratory loss of primary producers is comparatively high in tropical lakes. Carmouze et al. (1983) calculated that about 90% of the gross production in Lake Chad was lost in respiration while in Lake George only 28% of the gross was available as a net production (Burgis and Dunn, 1978). Phytoplankton production is also a very tiny fraction of incident radiation in tropical lakes, most probably because of their efficiency in utilization of light energy and self standing. For example, Lewis and Weibezahn (1976) found that phytoplankton production was within the range of 0.16-0.54% of the solar radiation in some lowland Venezualan lakes, and similar rates were observed for phytoplankton in Lake Chad (0.25%; Carmouze *et al.* 1983) and Lake George (0.79%; Burgis and Dunn, 1978). Therefore further investigation of the transfer of fraction of carbon from phytoplankton to fish and the respiratory loss of primary producers should be carried out in order to ascertain the above facts in Lake Kuriftu.

It is also evident that the food quality of Lake Kuriftu is dominated by Cyanobacteria, particularly of *Microcystis aeruginosa* and *Cylindrospermopsis curvispora* throughout the year with some peaks in December, 2008 and January, 2009. There are also evidences that tropical phytoplankton biomass is dominated by colonial and filaments cyanobacteria, some of which are not only inedible and less nutritious, but also toxic to zooplankton (eg. Lampert, 1981; Fulton and Pearl, 1987). Therefore another reason why the production of *T.consimilis* in Lake Kuriftu was low is probably the quality of food.

While all of these factors might help to explain the lower secondary production than at expected in tropical lakes, the possibility that production is low because of domination by carnivorous zooplankton should also be considered. The energy transfer efficiency of carnivores zooplankton is much lower (mean 1.4%) (Brylinsky, 1980). However the zooplankton community in Lake Kuriftu is dominated by *Thermocyclops* which is probably herbivores. Moriarty *et al.* (1973) and Burgis (1971) recorded *T.hyalinus* from Lake George as being herbivorous and raptorial on *Microcystis* colonies, while De Carvalho (1984) reported that it can also be predatory on cladocerans. On the other hand Gras and Saint-Jean (1983) found animal remains in 67% of the gut contents of the adult *Thermocyclops* in Lake Chad. The production of *T. consimilis* in Lake Kuriftu is even smaller than the production of carnivorous *Mesocyclops* copepods.

To conclude the idea, *Thermocyclops* in Lake Kuriftu is probably mainly herbivores because of three reasons in addition to the above facts. First I never encountered engorged animals in the fixed samples, second it was successfully cultured in algal mixtures and third the body size of this species was small as compared to other copepods as small species were much more dependent on algae than the larger species, for which invertebrate prey had a greater importance (Adrian and Frost, 1993).

In addition to the quality of food, lake temperature and abundance of food are also another aspect regulating production of crustaceans in aquatic environment. The influence of temperature and abundance of food on the growth and development of rates of plankton also influence secondary production. Landry (1978) pointed that temperature and food abundance are the most critical factors affecting the development rates of copepods. In Lake Kuriftu the mean annual lake temperature was 24.45^0c which is lower than pervious studies. While the abundance of food influences the post embryonic development of copepods (Lampert, 1985) and reproductive parameter in copepods, such as increase clutches size in female (Checkley, 1980; Burns, 1980), temperature primarily affects egg development time of copepods. The maximum clutches size in female *T. consimilis* (24 per female) in Lake Kuriftu was observed during the post-rainy season which coincided with high phytoplankton biomass (food abundance). Temperature also affects post embryonic development of copepods, but the relation between temperature and post-embryonic durations, reported to be inverse in most cases (Harris and Paffenhofer, 1976; Gophen, 1976).

On the other hand Jacobs and Bouwis (1979) and Burgis (1978) found that development times of copepods increase to a minimum with increased temperature up to 30^0c and then decreased with further rise in temperature. Burgis (1973) similarly observed that egg development times of *Thermocyclops* increased abruptly above 30^0c in Laboratory cultures. In Lake Kuriftu the egg development time of *T. consimilis* was 2.1 days at 20^0c and 1.75 days at 25.6^0c in laboratory culture. The total development days (egg to adult) for this species were 20.4 days and 16.05 days at 20^0c and 25.6^0c, respectively. This indicates that there is an increase of egg and post embryonic development with an increase of temperature. Therefore another reason for low production of this species in Lake Kuriftu is probably the decrease of lake temperature during the study period in the whole and particularly during the dry and heavy rainy seasons.

6. CONCLUSION AND RECOMMONDATIONS

Conclusion

Lake Kurifu is a small and shallow lake and its shallowness, plus the solar and wind regimes of its particular position, combine with the fairly low fluctuation in chemical composition to form the template for a relatively unchanging phytoplankton composition which is fairly high in biomass. This provides a constant supply of food only for those herbivores zooplankton able to utilize it, and because of this the number of species dominating the zooplankton community in Lake Kuriftu appears to favor a few species and there is muted seasonal succession. Although there are fairly low fluctuations in physical environmental conditions, such as pH, temperature and oxygen, and chemical parameters, such as phosphate, nitrate and silicate in the lake, the same specie, *Thermocyclops consimilis*, which is herbivores, was dominant throughout the year. This species was able to withstand these changes were little variation throughout the year. The remaining zooplankton community, such as rotifers and cladocerans are therefore determined by the relatively limited types of food available to them in the lake with some peak value during the dry season which is associated with edible food during that period. Because of its abundance throughout the year the major secondary production of Lake Kuriftu is associated with the species *T.consimilis* and the major factors determining the biomass and production of this species are lake temperature and biomass of phytoplankton. The total production of this species is low as compared to other lakes.

In general, Lake Kuriftu has a mean annual total copepod biomass and production which is much lower than the eutrophic Lake Awassa but higher than the meso-oligotrophic Lake Tana. The P/B ratio of *T. consimilis* was almost equal to the same species in Lake Awassa but lower than in Lake Tana. On the other hand the biomass contribution of rotifers in Lake Kuriftu was not significant being small size compared to T. *consimilis*. However rotifers contribute significantly to productivity (energy cycling) because of their high turnover times. The role of rotifers in energy flow is of a geate important in Lake Kuriftu during the dry season (high abundance) due to their high reproductive potential associated with their relatively short life cycles and their opportunistic behaviors. The reason for low zooplankton production in Lake Kuriftu despite relatively high phytoplankton biomass may be quality of food and decreased lake temperature during the study period and in the food web structure by itself; the zooplankton community in Lake Kuriftu does not include large Mesocyclops copepod and Calanoid, which represents a major contribution to mesozooplankton biomass. Other factors involved may be the low trophic efficiency, notably a trophic cascade that would explain why in Lake Kuriftu relatively high phytoplankton biomass does not result in high zooplankton biomass. Therefore, further studies have to be done on quantitative assessment of zooplankton production in relation to primary production rates and fish predation rates, which could verify this hypothesis. This study provides the evidence that Lake Kuriftu copepod biomass and production clearly depends on the post-rainy nutrients resulted from decomposition and the pre-rainy wind driven increase of phytoplankton biomass whereas rotifer production depends on the dry season associated with increasing in the density of edible phytoplankton like diatoms.

Recommendation

It is clear that the zooplankton community in Lake Kuriftu is shifted from cladocerans (previous studies) to cyclopoid copepods (present study). Therefore further long-term study has to be done to investigate the seasonal pattern or annual cycle that favors copepods (*Thermocyclops*) and leads to the decrease of cladoceran community in Lake Kuriftu.

This study was focused on biomass and production of the dominant species, however further study has to be done on the transfer of fraction of carbon from phytoplankton to fish and the respiratory loss of primary producers to evaluate the secondary production and the construction of models on energy and carbon flux through the zooplankton and thus to evaluate the carrying capacity for zooplanktivore fish and the productive power of the lake and its efficiency as a fishing ground.

Eutrophication has proved to be one of the most widespread and serious anthropogenic disturbances to aquatic ecosystems and Lake Kuriftu is exposed to this condition; because there is high probability of loading of nutrients, especially introduction of phosphorous containing detergents and increasing wastewaters use (from nearby hotel), fertilisers (from Kale Hiwot farm), and erosion in the watershed. Therefore there is a need to prevent loading of these nutrients to the lake before creating serious problems in this aquatic ecosystem.

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Appendicies

Appendix 1. Determination of chlorophyll a from Talling and Driver (1963)

$$\text{Chl a } \mu\text{g/L} = \frac{13.9 \times (E665 - E750) \times Ve}{Vsf \times PL}$$

Where

E_{665} = extinction at 665 nm

E_{750} = extinction at 750 nm

V_e = Volume of extract

V_{sf} = Volume of sample flittered (in liters)

PL = path length of the cuvette (1cm)

Appendix 2. Estimation of numerical zooplankton community as per m^3 of lake water

$$\textbf{Total count at open water} = \frac{\textbf{5 X 7 X count}}{\textbf{0.353m}^3}$$

Where

5 = grideline constant

7 = sampling constant

Count = count per three grideline of petridish

0.353m3 = $v = \prod r^2 d$, d = 5m, r = 0.15m

$$\textbf{Total count at near shore} = \frac{\textbf{5 X 7 X count}}{\textbf{0.141m}^3}$$

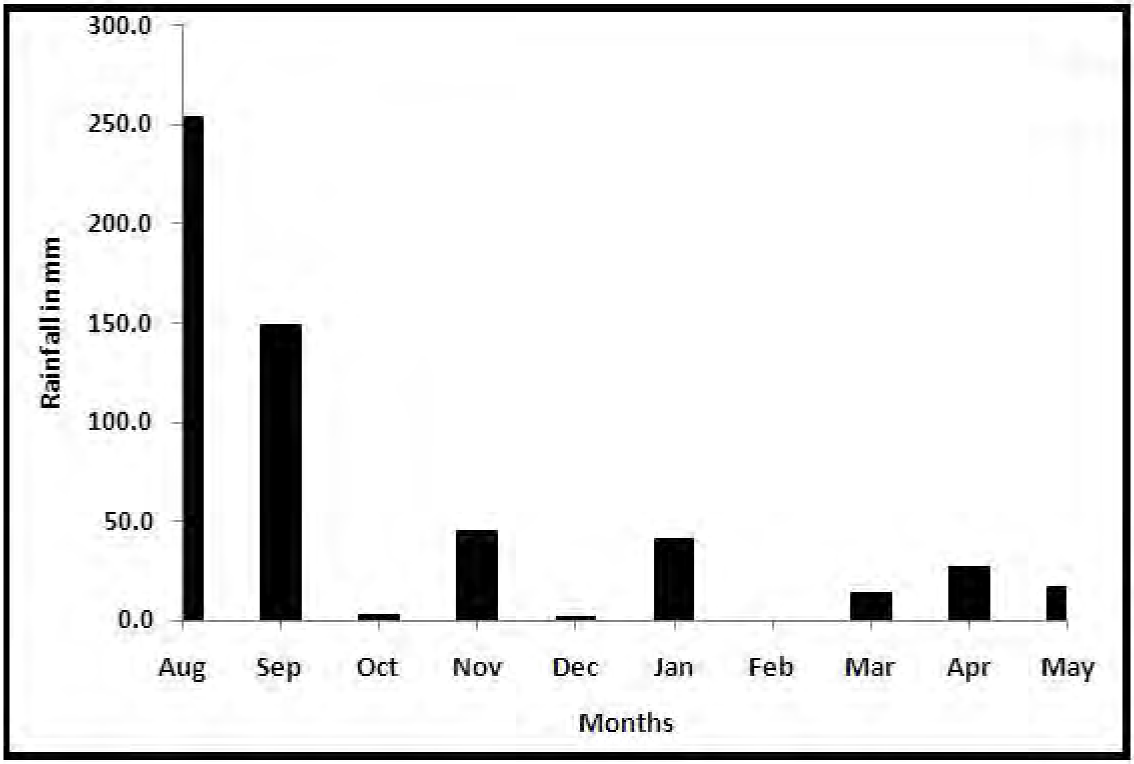
Where, 0.141 = $v = \prod r^2 d$, d = 2m

Appendix 3. Numerical density of zooplankton as per m^3 in Lake Kuriftu.

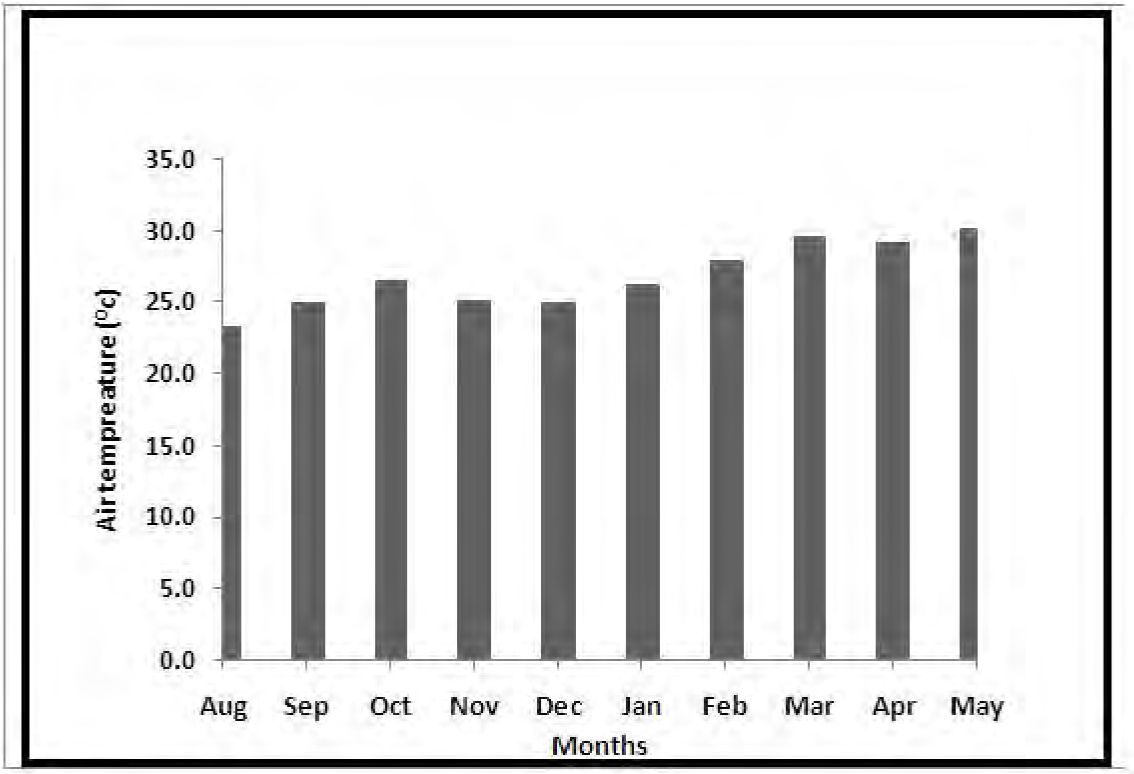
Numerical density of Copepods, nauplii (N), copepodites (C), adults (A), Rotifers, *Brachionus* spp (B), *Polyathra* spp (P), *Filinia* spp (F), *Asplanchia* spp (As), *Keratella* spp (K), and Cladocerans, *Ceriodaphnia* (Cr), *Diaphanosoma* (D), and *Moina* (M) per m^3 of lake water at near shore NS) and open water (OP)

		Copepods			Rotifers					Cladocerans		
		N	C	A	B	P	F	As	K	Cr	D	M
Aug	**OP**	2275	4040	6143	396	99	0	0	0	1340	694	0
	NS	6936	**7352**	5529	275	372	0	0	247	1070	743	0
Sep	**OP**	3483	6404	8825	1296	199	100	597	100	1791	1193	747
	NS	16181	9126	12656	1247	199	0	0	0	5334	443	0
Oct	**OP**	597	9431	14656	998	597	0	0	0	2686	247	547
	NS	125	8363	9380	1027	862	50	0	0	6770	1262	996
Nov	**OP**	1493	9013	13515	1296	398	100	0	0	3781	994	0
	NS	249	17481	18367	1993	996	387	252	0	7517	2438	251
Dec	**OP**	20504	10842	14132	21402	597	0	199	0	3781	198	100
	NS	1244	8031	11884	6474	5974	0	0	0	6024	1443	0
Jan	**OP**	16522	7183	8146	17620	4420	100	199	100	17762	10151	100
	NS	1743	9693	12769	8217	747	0	498	0	9758	2189	241
Feb	**OP**	4657	12937	15450	6148	99	0	0	99	989	493	397
	NS	2972	8947	11364	6940	0	0	0	0	2277	195	248
Mar	**OP**	16250	12803	16525	6940	396	99	0	198	9906	790	248
	NS	6688	19068	22422	1739	495	0	0	0	12938	195	0
Apr	**OP**	17636	11812	13453	7436	198	198	0	198	3765	493	0
	NS	26752	16983	17200	15610	495	0	0	99	9213	939	0
May	**OP**	20807	13221	8477	1486	694	0	0	99	2873	297	0
	NS	35669	17037	12439	5945	495	0	0	0	2783	1239	372

Appendix 4. Maximum monthly rainfall at Lake Kuriftu area (Source: NMSE) during the study period.



Appendix 5. Maximum monthly temperature at Lake Kuriftu area (Source: NMSE) during the study period



DECLARATION

I, the undersigned, hereby declare that this thesis is my original work, has not been presented for a degree in any other University and all source of materials used for the study have been well acknowledged.

Name: Eshete Assefa

Signature: _____________

Place: Addis Ababa University

Date of Submission___________

This work has been presented with my approval as supervisor.

Name: Seyoum Mengistou (PhD)

Signature: _______________

Date: _______________