

ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE STUDIES

Seasonal and spatial variations of zooplankton in relation to physico-chemical variables and phytoplankton production in Lake Beseka (Metehara)

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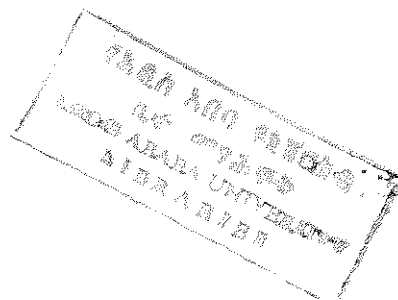
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TABLE OF CONTENTS

	Pages
ACKNOWLEDGEMENT	i
LIST OF TABLES	ii
LIST OF FIGURES	iii
LIST OF APPENDICES	V
ABSTRACT	Vi
1. BACKGROUND AND JUSTIFICATION	1
2. STUDY AREA	10
3. MATERIALS AND METHODS	21
3.1. Physico- chemical analysis	21
3.2 Phytoplankton species composition	22
3.3 Estimation of phytoplankton biomass	23
3.4 <i>In situ</i> measurements of Primary Production	23
3.5 Zooplankton sampling	24
3. 6 statistical analysis	25
4. RESULTS AND DISCUSSION	26
4.1. Physical features of the lake	27
4.2. Chemical features of Lake Beseka	29
4.2.1. Major nutrients	32
4.3. Composition and production of phytoplankton	37
4.3.1. Composition of the major phytoplankton species	37
4.3.2. Phytoplankton biomass	38
4.3.3. Phytoplankton production	40
4.4. Zooplankton species composition and abundance	46
4.4.1. Species composition	46
4.4.2 Spatial and temporal dynamics of major Zooplankton groups	46
Cyclopoid copepods	48
Cladocera	55
Rotifera	58
5. GENERAL DISCUSSION	61
6. CONCLUSIONS	65
REFERENCES	67



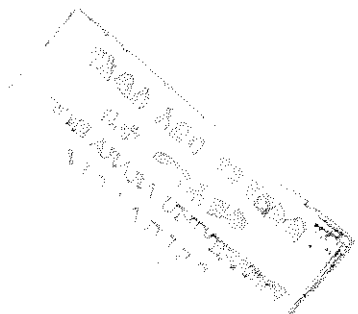
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LIST OF TABLES

pages

Table 1. Some physical and morphometric characteristics of Lake Beseka.....	15
Table 2. Chemical features of Lake Beseka.....	18
Table 3. Analysis of variance for nutrients and phytoplankton biomass between station.....	34
Table 4. Analysis of variance for nutrients between sampling months.....	35
Table 5. List of the most dominant species of phytoplankton in Lake Beseka.....	37
Table 6. Mean values of specific rates of photosynthesis ($\bar{\phi}_{max}$) for some Ethiopian and African lakes.....	41
Table 7. List of zooplankton species identified from Lake Beseka.....	46
Table 8. Analysis of variance cyclopoids between sampling stations and months.....	48
Table 9. Analysis of variance egg stock between sampling stations.....	53
Table 10. Analysis of variance cladoceran between sampling stations and months.....	56
Table 11. Analysis of variance rotifers between sampling stations and months.....	59
Table 12. Analysis of variance total zooplankton between sampling months.....	63

Fig.16 Temporal variations of sex at three stations in Lake Beseka during Oct,04 to Sept,05	53
Fig.17 The cycloid mean egg to adult ratio (a) and egg stock.....	54
Fig.18 The temporal dynamics of cladocera in three sampling site.....	57
Fig.19 The temporal variation of rotifers in the three sampling stations.....	60
Fig.20 Temporal variation of maximum primary production, phytoplankton biomass and mean of total zooplankton during the study period in Lake Beseka.....	64

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LIST OF APPENDICES

Pages

Appendix 1. Secchi depth (Z_{SD}) euphotic depth (Z_{eu}) and turbidity results of the three stations of Lake Beseka.....	75
Appendix 2. Conductivity, K_{25} ($\mu S\ cm^{-1}$) and pH at OP, IO and SH stations and results at OP and SH stations of Lake Beseka.....	76
Appendix 3. Biomass of phytoplankton ($mg\ Chl\ a\ m^{-3}$) at three stations.....	77
Appendix 4. Nutrients concentrations in $\mu g/l$ for nitrate, mg/l for phosphate and silicon in the three sites.	78
Appendix 5 Hourly, daily rate of gross photosynthesis rate per unit area and Biomass at open site.	79
Appendix 6 . Temporal sex ratio variation (Female: Male) at three stations in Lake Beseka during Oct- 04 to Sept- 05.....	80
Appendix 7. Average zooplankton abundance ($No./\ M^3$) for Inshore, Open and shore sites: sample over 10 months in Lake Beseka (Oct ,04 – Sept,05.....	81

ABSTRACT

Seasonal and spatial variations of zooplankton in relation to physico-chemical variables and phytoplankton production in Lake Beseka were studied from October 2004 to September 2005. The measurements were made on monthly basis. The lake shows temporal variations in temperature (24 -31°C), transparency (0.42-0.63 m) and turbidity (27 -88 NTU). Conductivity (6332 - 7438 μScm^{-1}), total alkalinity (31- 41 meq/l) and pH (9.1-9.5) are higher than those of most other Ethiopian rift valley lakes. The present measurements of phytoplankton production (166 -273 mg O₂ m⁻³hr⁻¹) and biomass (7-17 mg chl a m⁻³) suggest that the lake is not productive as other saline lakes. One factor analysis of variance (ANOVA) and Pearson correlation were used to estimate the level of interaction of physico - chemical and biological factors with zooplankton dynamics. All major zooplankton groups showed temporal variations in abundance, with highest densities during wet period (July to September) and minimum densities during dry period (November to April). The cyclopid copepods were the dominant group and made up almost 64% of the total zooplankton abundance. Rotifers and cladocerans also contributed 19% and 13%, respectively, of the major total zooplankton abundance of the lake. The results of the Pearson correlation demonstrated that population dynamics, of the major zooplankton groups in Lake Beseka appear to be mainly governed by biological and environmental factors, their densities fluctuating along with primary production, phytoplankton biomass and nutrients. Among environmental factors, high temperature and rainfall appear to have promoted a higher density of egg production and total zooplankton number, respectively. Turbidity affected the cladoceran population negatively.

Key words: Lake Beseka, zooplankton, temporal dynamics,

1. BACKGROUND AND JUSTIFICATION

Zooplankton are small animals suspended in the water with limited power of locomotion (Wetzel, 2001). They play important role in lakes "trophy net work' as grazers on the phytoplankton and as nutrient recycling agents in lakes. When zooplankton feed on the phytoplankton, they break down the algal and bacterial cell walls and thus through their feeding habits, defecation and respiration, products such as nutrients are made available for essential growth of algae (Mavuti and Litterick, 1991). Zooplankton availability is also important food in determining the relative survival of juvenile fishes (Fernando, 1980).

The seasonal dynamics of plankton species is an important and familiar aspect of the biology of temperate lakes, in which it usually bears some obvious relation to seasonal and temporal weather changes that affect the availability of light and nutrients in the water column. Tropical lakes likewise experience temporal weather changes that reflect physico-chemical changes of various kinds, although these changes differ in amplitude and periodicity from those of temperate lakes (Lewis, 1977).

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

In lakes located in temperate regions, there are several examples of systems in which zooplankton varied seasonally. For instance, crustacean zooplankton in north temperate lakes are usually most abundant during the warmer 'growing seasons' particularly during spring and fall (Gophen, 1976).

Freshwater zooplankton is less diverse in tropical regions than in temperate regions. The uniformly high temperature does not seem to favor diversity of zooplankton (Fernando, 1980). On other hand, due to an extensive growing season, temporal and seasonal variability that result from temperature are not so pronounced as in temperate regions.



Therefore, seasonal and temporal variations in zooplankton assemblages in tropical lakes have been attributed to environmental variables that result from hydrological conditions and meteorological events. Temporal fluctuations of large magnitudes have been observed in many tropical lakes, for instance in Lake George, Uganda (Burgis, 1974), Lake Valencia, Venezuela (Lewis, 1974), Lake Awassa, (Seyoum Mengistou, *et al.*, 1991), Lake Ziway, (Semeneh Belay, 1988; Getachew Beneberu, 2005), and Lake Abjata and Langano, Ethiopia (Kassahun Wodajo and Amha Belay, 1984).

Several factors are suggested to govern the species temporal fluctuations in zooplankton community in temperate and tropical inland waters. Regarding this, some workers found that both biotic and abiotic factors are responsible for both temporal and seasonal dynamics in tropical regions. Abiotic factors such as wind, precipitation; temperature, turbidity and hydrology have been identified as critical factors in temporal variability of zooplankton in the tropics (Hart, 1990; Seyoum Mengesitou *et al.*, 1991;

Eshete Dejen *et al.*, 2004). Biotic factors like predation by fish and invertebrates (Wayu, 2002), availability of food and inter and intraspecific competition (Hart, 1985) and toxicity effect of algae (Hubble and Harper, 2000) play a major role in temporal and seasonal variation in zooplankton abundance and structural composition in lakes.

Margalef (1978) suggested that turbulence is a major factor in determining temporal and seasonal dynamics of plankton communities in tropical regions especially African lakes. A study on zooplankton temporal dynamics in Lake Le Roux (South Africa) showed that the abundance of zooplankton was directly related to water transparency; the total zooplankton biomass and population density were 1.4 - 3 times higher during the less turbid conditions (Hart, 1986). According to Eshete Dejene *et. al.*, (2004) the density of all zooplankton taxa in Lake Tana, Ethiopia is negatively correlated with turbidity to different degrees; *Daphnia spp.* are most affected and *Diaphanosoma* the least while others are intermediate.

Inorganic turbidity is well known to influence a variety of physico- chemical and biological properties in lake ecosystems. It is indirectly related to the quantity of precipitation and wind force. Rainfall has a direct influence on the turbidity of a water body in that it transports allochthonous organic and inorganic matter to a water body through runoff. Wind has also the greatest effect on the mixing pattern of a lake rather than dust particle loading. Mixing maintains the sediment particles in suspension. Concurrently, it plays an important role in facilitating nutrient uptake by renewing nutrient supply at sites of uptake on cell surface of the organisms in lakes.

Predation of zooplankton by fish and invertebrates is also one of the major factors responsible for seasonal and spatial difference in size and species composition of zooplankton in many tropical lakes. For instance, the paucity of larger crustacean zooplankton and large-sized rotifer species in tropical inland waters is due to predation by fish (Fernando, 1980). In Lake la Orsinera (Venezuela) declines in population of the cladocerans, *Moina*, *Bosmina* and *Diaphanosoma* coincided with high densities of *Chaoborus*, a zooplankton predator (Twombly and Lewis, 1987).

Small zooplankton species apparently benefit from the mostly negative responses of their larger competitors and raptorial predators to the presence of fish (Way, 2002; Vakkilainen *et al.*, 2004). In Lake Awassa, Ethiopia, the absence of *Daphnia* and the presence of small cladoceran *Diaphanosoma* at low densities suggest fish predation as an important determinant of zooplankton community structure (Taylor and Zinabu Gebre-Mariam, 1989). The reason for modest numbers of both ciliates and rotifers in Lake Awassa is probably because they are consumed by the cyclopoid copepods (Seyoum Mengistou *et al.*, 1991).

Therefore, morphologically small-sized zooplankton (*e.g.* *Brachionus angularis*) will dominate tropical lakes. The zooplankton population in Lake George and Valencia are good instances of this kind of composition in the tropics (Lewis, 1974; Talling and Lemoalle, 1998). However, the nature of predator activity and survival strategies of the prey may also contribute to the temporal dynamics and spatial diversity of zooplankton communities in tropical lakes.

Food availability and preference towards prey also have a clear effect on structural composition and distribution of zooplankton populations in lakes (Fernando, 1980). A decrease in, or total elimination of zooplankton species particularly cladocerans has been reported to occur coincidentally with filamentous cyanophyte blooms. For instance, the filter-feeding cladocera in Lake George (Uganda) are limited by lack of small algal particles (Burgis *et al.*, 1973). Limnetic cyclopoid species in any tropical regions are also limited to only two or three species. This is probably due to their limited ability to feed on filamentous algal species. When this happens therefore, the zooplankton communities in the lake are dominated by raptorial feeding copepods. The dominant copepod *Thermocyclops hyalinus* is a raptorial (grasping) feeder in tropical Lakes: such as Lake Valencia, Venezuela (Lewis, 1977) and in Lake George, Uganda (Burgis, 1974), which is related to food availability in these lakes.

Size composition of food organisms as well as the preference of zooplankton are also very important factors in temporal and spatial variation of zooplankton communities in tropical lakes. In some African lakes (*e.g.* Lake Awassa, Ethiopia) rotifers are abundant due to bacterial population abundance, because rotifer population maxima have positive correlation with bacterial abundance (Taylor and Zinabu Gebre-Mariam, 1989).

It is well known that some alga species secrete toxic substances into the water around them. Some laboratory experimental works revealed that the toxic and mucous secretion of cyanobacteria enable them to avoid from grazing or created unfavorable environments for efficient grazers such as *Daphnia* (Porter, 1977; Hubble and Harper, 2000). In tropical and temperate regions the minimum abundance of zooplankton

coincides with blooms of blue green algae. Cyanobacteria produce endo and exo – toxins that can be toxic when ingested by their natural herbivorous zooplankton (Sterner, 1989).

The zooplankton fauna of Ethiopia is a mixture of species found throughout tropical African lakes. There are a number of reports from earlier studies (Kassahun Wodajo and Amha Belay, 1984; Semenh Belay, 1988; Hart, 1990; Seyoum Mengesitou and Fernando, 1991; Seyoum Mengesitou *et al.*, 1991; Eshete Dejen *et al.*, 2004), which deal with zooplankton from Lakes Abijata and Langano, Awassa, Ziway, Tana, respectively.

Similar to other tropical regions, the temporal dynamics of zooplankton communities in Ethiopian lakes have been ascribed to a number of climatological, physical and biological factors. Studies from Rift Valley lakes have shown that the temporal dynamics of zooplankton is affected by hydrological and climatic variations (Semenh Belay, 1988; Brook Lemma, 1994)

Water level fluctuation, which is a seasonal or temporal phenomenon, is directly related to the amount of rainfall and is known to have important effects on plants, fishes and plankton. Twombly and Lewis (1987) observed a reduction in the proportion of large zooplankton associated with low water level. These authors concluded that low water level was unfavorable for the lemnetic species. Abundance of zooplankton in Lake Awassa (Seyoum Mengestou and Fernando, 1991) and cyclopids and rotifers in Lake Abijata (Kassahun Wodajo and Amha Belay, 1984), copepods and cladocerans in Lake Ziway (Semenh Belay, 1988; Getachew Beneberu, 2005), and zooplankton in Lake Hora-Kilole (Brook Lemma, 1994) was positively correlated with

the rainy season. In these lakes, the densities declined after the big rains in dry season.

However, during the rainy season, other affects could occur. A heavy silt load in Lake Tana, Ethiopia (Eshete Dejene *et al.*, 2004) and algal blooms in Lake Abijata (Kasshun Wodajo and Amha Belay, 1984) have adverse effect for some zooplankton species during rainy seasons. The three main zooplankton groups (cladocerans, copepods and rotifers) showed lowest densities in the main rainy and post rainy season in Lake Tana (Eshete Dejene *et al.*, 2004).

A recent assessment on the hydrological features of Ethiopian lakes indicated that the water levels of many lakes have changed dramatically over the last three decades. Most of the changes result from natural processes and human activities. Some lakes have shrunk due to excessive abstraction of water (e.g. Lake Abijata) and the others due to increasing input from surface runoff and groundwater source (Tenalem Ayenew, 2004).

Elizabeth Kebede and Willen (1998) state that the lava-dam Lake Beseka, one of the Rift-Valley lakes, has been changing for the last two decades because of human activities and hydrogeological factors. Even though the main cause of water quality changes in Lake Beseka is a combination of subterranean seepage from the basin and spillage from the nearby river Awash, deforestation of the catchment and washing vehicles and clothes at lakeshores contribute towards the changes in species composition of the phytoplankton in the lake.

Although these human and naturally induced limnological changes in Lake Beseka are believed to be interesting and important to study, detailed information on hydrology, chemistry, phytoplankton assemblage and on temporal variation and diversity of zooplankton in this lake is largely lacking. The few studies done show that the zooplankton in Lake Beseka is as important as phytoplankton in the diet of *Oreochromis niloticus* (Gashaw Beyene, 2005). They are ingested by all size groups of the fish. Hence, more studies are necessarily to provide baseline information, especially on the ecological interaction of zooplankton with physico-chemical and phytoplankton in the community.

Therefore, the general objective of this research project is to investigate the seasonal and spatial variations of zooplankton in relation to physico-chemical variables and phytoplankton production and to provide recent baseline limnological data for future studies in the lake.

Specific objectives

1. To determine algal composition and production in the lake
2. To determine zooplankton composition, and its fecundity
3. To assess the interaction between nutrients, algae and abundance of the zooplankton community.
4. To compare zooplankton limnological data with previous reported data and note any change that may have occurred and
5. To provide baseline limnological data and to evaluate the existing human impacts on the lake.

2. STUDY AREA

Physical and Climatic features

Lake Beseka ($8^{\circ} 41'-9^{\circ} 10'$ latitude and $39^{\circ} 39'-40^{\circ} 04'E$ longitude) is located in the Eastern Showa Zone of Oromia region in Fentale Woreda near Metehara Town. It is one of the northern Rift Valley lava dam-lakes in Ethiopia.

The Lake has been expanding drastically over the past three decades. In 1978, Sir William Halcrow and partners studied the existing condition of Lake Beseka, based on the hydrology of the lake area and aerial photography. According to their study, the lake used to cover an area of 3 km^2 until 1964. By the year 1972, the area coverage reached 11 km^2 . During Halcrow and Partners study in 1989, it was indicated that the lake area coverage had reached 29.5 km^2 . In 1998, its coverage was about 40 km^2 with a maximum depth of 11 meter. At present, the lake area is estimated to be over 42 km^2 (MoWR, 1999). The level of the lake has risen by about 4m over two decades (1976-1997).

The exact time when the lake expansion started is not known, but most previous studies tend to agree that the main changes in the water balance of the lake comes from groundwater input, which is related to the recent increase in recharging from irrigation fields and the rise in the level of the River Awash after the constriction of the Koka Dam, located some 152 km upstream. Prior to the construction of the Koka Dam, the Awash River used to be dry up between December and March; however, after the construction of the dam, there has been fairly steady flow throughout the year. Hence the regulated flow has become a source of continuous recharging to

ground water, ultimately feeding the lake. According to a recent study, the outflow of hot springs located at the south-western shore of the lake is estimated at 10 l/s (Goerner and Joile 2005).

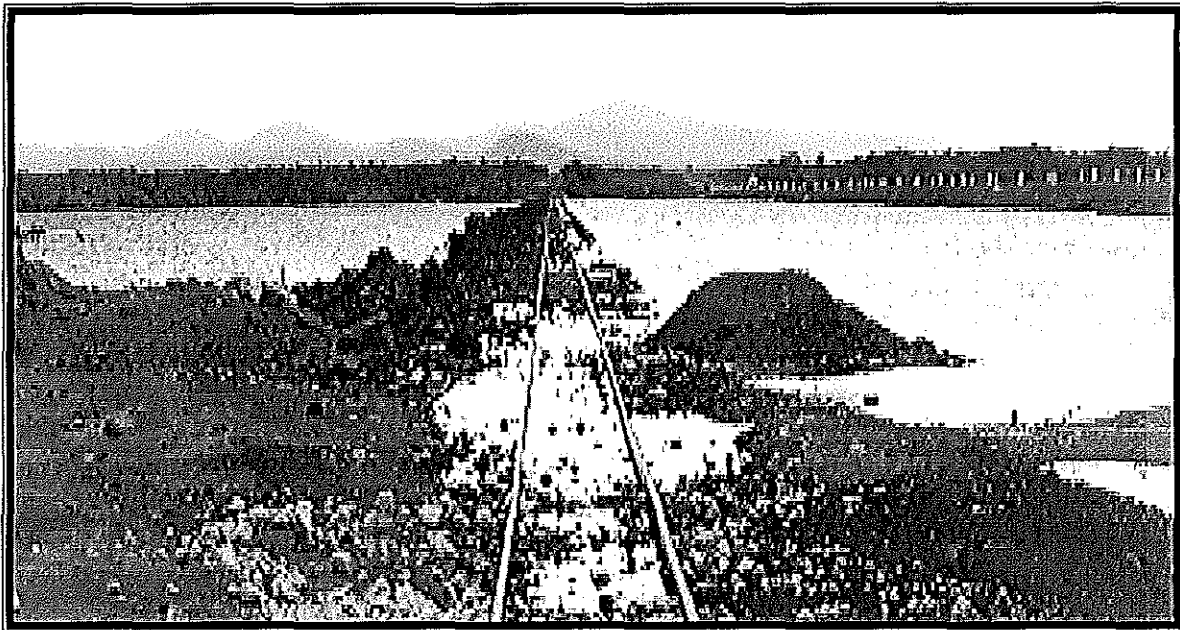


Fig.1. Figure showing the effect of sharp rising water on the highway and railroad.

The sharp rise of the lake level has many effects on the highway and railroad. The lake water threatens the railroad level and the problem has been temporarily overcome by constructing an embankment to elevate the access, but it may still be necessary to change the route. At the beginning of 2004, a water control center was inaugurated by The Ethiopian Ministry of Water Resources (MoWR). A pumping station situated on the northwestern shore is constructed to divert lake water into the river Awash (MoWR, 1999); however, it still had a problem on River Awash during a field check in October 2004. Since the lake water is very alkaline (pH 9.2- 9.4) and saline (electrical conductivity: 6300 - 7500 Scm^{-1}), mixing the lake water with dilute

river water is likely to affect the hydrochemistry of the river and the ecosystem downstream.

The climate of the area is described as semi-arid or 'kolla' and the area receive a mean annual rainfall of about 540 mm. The annual mean maximum air temperature was above 33⁰ C whereas the mean minimum temperature was 18⁰ C (Fig.2), differences between mean maximum and mean minimum air temperature were large during the dry seasons.

The short rain occurs between March and May and the major rain period is between June and October, the Atlantic moisture systems bring heavy monsoonal rainfall to the region. The dry season occurs between November and February, which is only occasionally interrupted by tropical depressions coming from the Indian Ocean (Vallet *et al.*, 2001).

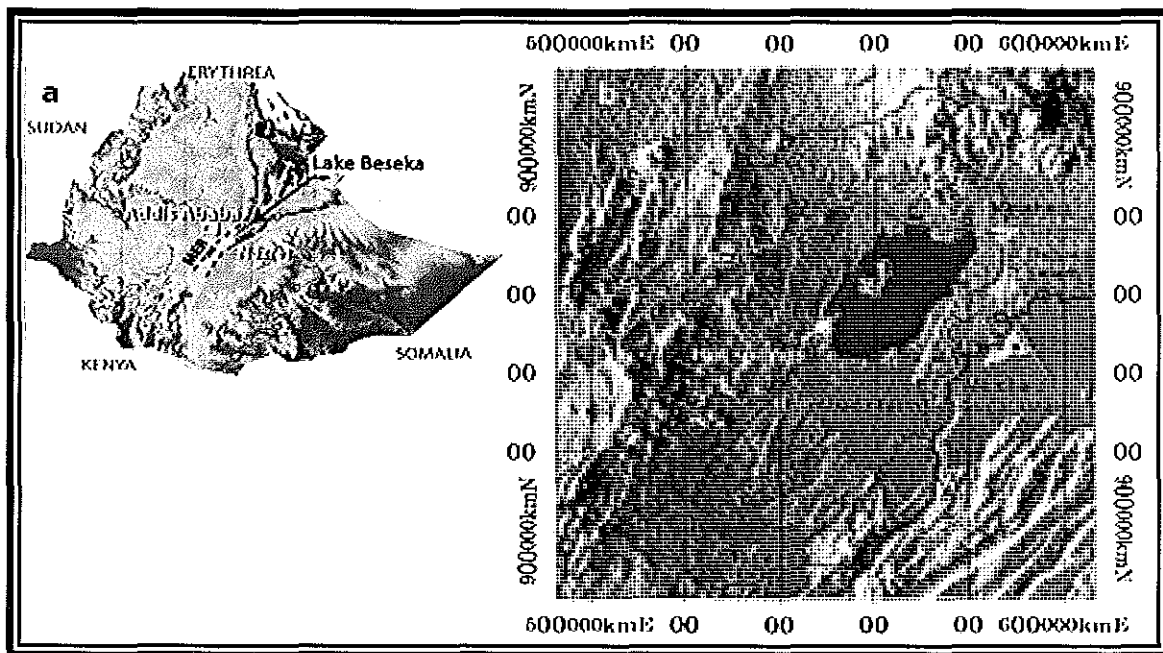


Fig. 4. Map of Lake Beseka. The drainage area covers a surface of nearly 400 km² (After Goerner and Jolie, 2005).

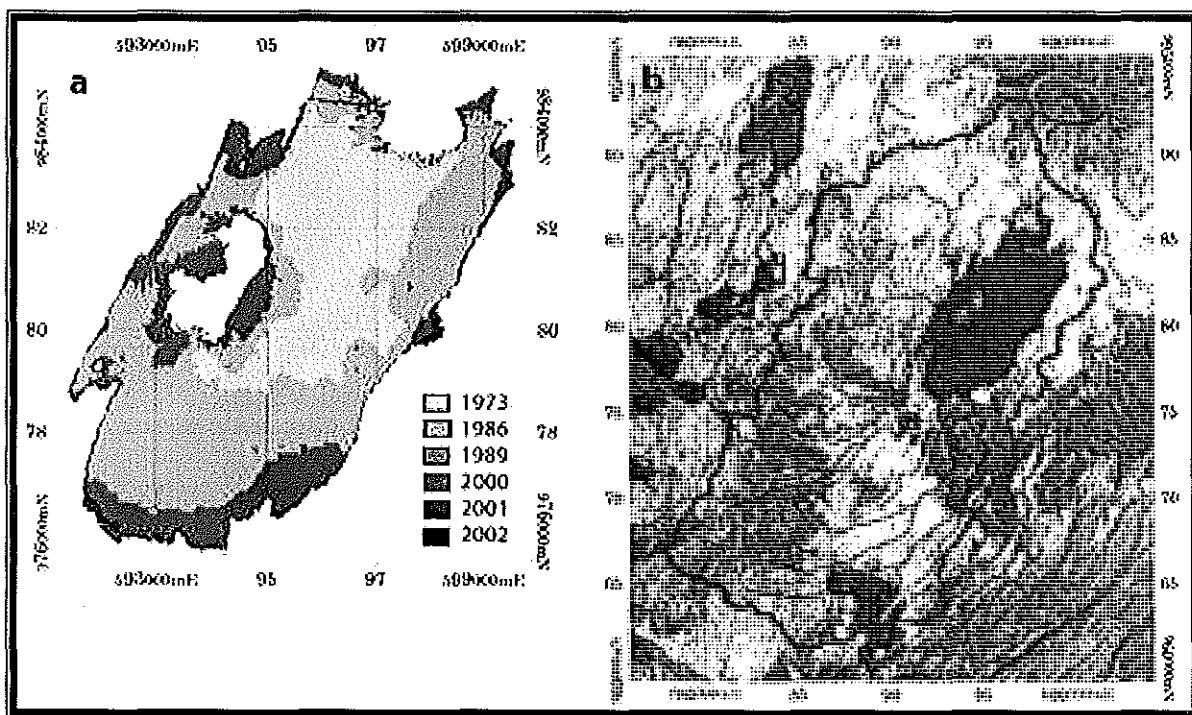


Fig. 5. A map showing temporal trends in expansion of Lake Beseka. (After Goerner and Jolie, 2005)

Chemical features

The chemistry of Lake Beseka has been described by Wood and Talling (1988); Elizabeth Kebede and Willen (1998); Goerner and Jolie (2005), Tenalem Ayenew (2004) and Bedlu Abera (2005) (Table 2). The Lake is sub- saline with a salinity of $\leq 3\text{g/l}$ and with sodium (Na^+) and carbonate-bicarbonate ($\text{CO}_3^{2-} + \text{HCO}_3^-$) dominating the major ionic composition. According to previous studies, total ionic concentration of the lake has decreased by about a factor of 10 over the last 30 years. Conductivity decreased from $72500\mu\text{Scm}^{-1}$ to $7441\mu\text{S cm}^{-1}$ and salinity decreased from 56.3gl^{-1} to 5.3gl^{-1} during 1961 to 1996 (Elizabeth Kebede and Willen 1998). The hot springs in the southwestern part clearly influence pH and conductivity of Beseka. Differences up to $5600\mu\text{S/cm}$ have been measured. Near the hot springs conductivity values reached their minimum of $1900\mu\text{S/cm}$ compared to $7400\mu\text{S/cm}$ in the center of the lake (Goerner and Jolie, 2005).

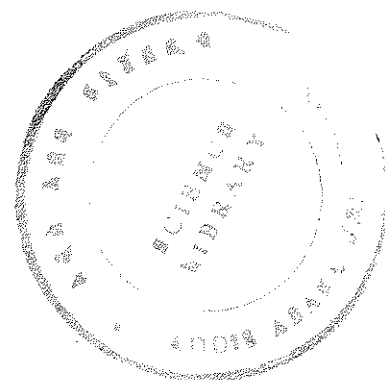


Table.2. Chemical features of Lake Beseka. (Data are from present study, unless otherwise indicated).

Parameters (Units)	values
K (meq /l)	0.56†
Na (meq /l)	78.56†
Ca (meq /l)	0.11†
Mg (meq /l)	0.04†
Cl (meq /l)	12.6†
F (mg/l)	40.0 ^ψ
Conductivity ($\mu\text{S cm}^{-1}$)	7441 [@]
Total alkalinity (meq/l)	46.5 [@]
Salinity (g/l)	3.1 [@]
SO ₄ (meq/l)	12.1 ^ψ
SiO ₂ (mg/l)	27.6 ^ψ
NO ₃ -N ($\mu\text{g/l}$)	683 ^ψ
PO ₄ -P (mg/l)	2.3 ^ψ
Chl-a (mg chl a m ⁻³)	27 [@]
pH	9.4 ^ψ

[@]Elizabeth Kebede and Willen (1998)

[†] Bedlu Abera (2005)

^ψ present study

Lake Biology

Because of the continuing change of the lake's chemistry, the species composition of some phytoplankton has also changed in time. Of these phytoplankton community *Spirulina platensis*, *Oscillatoria* and *Anabaenopsis* (the characteristic blue-green algal species found in African soda lakes) were reportedly dominant in 1961 (Wood and Talling, 1988), But based on field report in 1991 *Spirulina platensis* was rarely found and the others had changed moderately. According to recent studies the phytoplankton community of Lake Beseka is dominated by three groups, namely, diatoms, blue – green and green algae. From among diatoms, *Thalassiosira rudolfi*, *Melosira* (Aulacoseria), *Surirella* and *Navicula*, and from blue green *Merismopedia glacis* were found to be the dominant ones. Green algae were also represented by three genera *Scenedesmus*, *Tetrastrum* and *Tetraedron*. Generally, diatoms and blue green algae as a group contributed the bulk of the diet and are the most important food for *O. niloticus* in the lake (Gashaw Beyene, 2005)

The zooplankton community of Lake Beseka is composed mainly of the Cyclopod Copepods: *Mesocyclops* and *Thermocyclops spp.* and Cladocerans such as, *Moina*, *Diaphanosoma* and *Daphnia* species (Gashaw Beyene, 2005). Rotifers are represented by *Brachionus plicatilis* and *B. dimidiatus* (Seyoum Mengestou *et al.*, 1991). Some additional zooplankton species were also identified in the present study using the descriptions from Defaye (1988) and Dussart and Fernando (1988) and are listed in Table 5.

The fish species of Lake Beseka is represented by *O. niloticus* and *Clarias gariepinus* (LFDP, 1998). Fishing activity is done by using traditional method. Gill net is used to catch tilapia; whereas, hook and line is used to catch *C. gariepinus* by the local fishermen. Fishermen appear to get good income from the fishing activities from local markets.

3. MATERIALS AND METHODS

Sampling sites

Three sampling stations were selected based on their unique physical and biological characteristics. The sites are: open (OP) and shore (SH), situated in the middle and margin of the lake and inshore (IO) located near the pumping station at the northwestern shore which was planned to transfer lake water into the River Awash during over flow of the lake. The abbreviation mentioned above will be used throughout the paper.

Field sampling procedures

Plankton samples were collected monthly with plankton net of 64 μ m and 25 μ m mesh size, for zooplankton and phytoplankton except May and August, respectively. For phytoplankton biomass and nutrient analysis, water samples were taken using one liter plastic bottles from the surface of the lake (as the lake is frequently turbid). The study was conducted at the three selected sites of Lake Beseka from October 2004 to September 2005.

3.1. Physico- chemical analyses

3.1.1. *In-situ* physico - chemical measurements

Electrical conductivity was determined with a field conductivity meter (model: WTW LF 191). *In situ* pH and temperature measurements of the lake surface water were measured using a portable digital pH meter (Hanna, 9024). Lake water transparency (vertical visibility) was measured with a standard Secchi disc of 25cm diameter quartered black and white alternately. Phenolphthalein and total alkalinities were

determined on site by titration with 0.1N HCl to a pH of 4.5. Phenolphthalein and mixed bromocresol green-methyl red indicators were used as endpoint for measurement of the two (P_A and T_A) alkalinities. The proportion of OH^- , CO_3^{2-} , and HCO_3^{2-} , are worked out from standard alkalinity tables.

3.1.2 Laboratory chemical analysis

The analysis of the various chemical parameters (nutrients and turbidity) was carried out with HACH- portable spectrophotometer (DR/2010). The method used for the measurement of nitrate, phosphate, and turbidity are outlined in the HACH portable manual. The methods used were Cadmium Reduction (0-4.5 mg/L), for nitrate and Ascorbic Acid (0-2.5mg/l PO_4^{3-}) for phosphate, respectively. The values in brackets are the sensitivity ranges of measuring methods. Silicate was determined as its molybdate reactive complex as outlined in Wetzel and Likens (1979).

3.2 Phytoplankton species composition

For identification of phytoplankton, samples were taken using a 25 μ m phytoplankton mesh net from surface water and fixed with Lugol's solution. The phytoplankton taxa were identified to genus level and when possible to the species level using references such as Hindak (2000) and Komarek and Cenberg (2001).

3.3 Estimation of phytoplankton biomass

For pigment analysis, samples were collected from the surface using 1L plastic bottles at each station and transported to the laboratory (AAU) in an icebox. Phytoplankton biomass was estimated as Chlorophyll *a* concentration. Appropriate volumes of phytoplankton samples collected with a Ruttner sampler were filtered onto glass fiber filters (Whatman GF/C) and extracted in 90% cold acetone. The filters were manually ground with a glass rod in a small volume of 90% acetone to enhance or to reduce time of extraction. The algal material was placed in a parafilm-covered tube and centrifuged at 3000 rpm for 10 minutes. The extract was then decanted into a 10 ml volumetric flask and made up to the mark with 90% acetone. The absorbance of centrifuged pigment extracts was measured spectrophotometrically at 665 and 750 nm. The optically equivalent concentrations of chlorophyll *a* values were calculated by using the approximate equation of Talling and Driver (1963).

3.4 *In situ* measurements of Primary Production

Primary production was measured by the Light and Dark bottle technique and the Winkler method of oxygen determination (Mackereth *et al.*, 1978). In all cases, water samples were taken from the surface of open site, and siphoned into 250ml light and dark Pyrex glass bottles under reduced light conditions. Duplicate clear bottles were attached to a suspension line prepared for this purpose, at each of the four established depths distributed within the euphotic zone (0.0, 0.25, 0.5, and 1m).

The lower limit of the euphotic zone was approximated at 1m throughout the sampling period. To avoid shading, the arms of the suspension line, intended for the different depths of incubation, were made in such a way that they project out in alternative directions. Dark bottles were also incubated at 0.0 and 1 m. The incubation usually lasted for 3 hours, around mid-day. Dissolved oxygen concentration was fixed immediately by Winkler (A and B) reagents. In the laboratory the samples were titrated within 24 hours using starch indicator and dilute 0.0125N thiosulphate solution. Gross photosynthesis was estimated from changes in oxygen concentration in dark and light bottles.

3.5 Zooplankton sampling

3.5.1 Sampling procedures

Zooplankton samples were collected (from depth 4.5 - 5m) by means of vertical hauls from each station. Three vertical hauled net samples were taken at each stations using No. 25 (64 μ m mesh) plankton net with a diameter of ca. 30 cm. Immediately after concentrating, the samples were preserved with 4-5% neutral formalin in 250 ml cod end plastic bottles. The tow length used is ca. 4.5 m, which is long enough to assume a net efficiency of 100%.

3.5.2 Zooplankton identification and quantification

Species were identified using standard methods and references, mainly keys of Defaye (1988). For the estimation of abundance, a sub-sample was drawn from each well-mixed sample using a wide- mouthed pipette. The sub-sample was poured into a gridded petridish with grid (15 grids) and counted at 50X magnification using WILD

dissecting stereomicroscope. Three grids were counted and the average value was taken.

The volume of water filtered through the net was determined using the formula ($V = \pi r^2 h$), where "r" is the radius of the net mouth and "h" is the tow length from which the samples were taken. Based on this, the number of organisms per m^3 of the lake was calculated after the necessary correction factors were extrapolated, and then, the number of each category of zooplankton in the lake was expressed as individual per m^3 .

3.6 statistical analysis

To determine if seasonal changes in abundance occur through time and were statistically significant, a one-way classification analysis of variance (ANOVA) was performed. Moreover, the relations between different parameters were estimated by Pearson correlation.

4. Results and Discussion

4.1. Physical features of the lake

Appendix 1 presents data for certain physical parameters of the lake. The lake showed variation in surface water temperature during the study period with the highest record of 31°C in December and the lowest of 24°C in July, 2005 (Fig. 6). There was no pronounced inter-station difference in temperature. The water temperature pattern observed in the lake was not very different from those in other Ethiopian lakes. In Ethiopia, usually higher water temperature is observed in the dry season and lower temperature in wet season (Eshete Dejen *et al.*, 2004).

The lake's transparency during the period varied from 0.42m to 0.63m at open site during the study period. The lowest Secchi depths (Z_{sd}) was recorded at shore. The euphotic depth (Z_{eu}) fluctuated irregularly during the study period (see Fig. 6). This occurred probably because of frequent turbid condition of the lake and might be affected by air mass loaded with dust and daily sand storms. According to many previous studies, lower water transparency is attributed to high concentration of suspended matter in tropical lakes (Kasshun Wodajo and Amha Belay, 1984). According to Brook Lemma (1995) the observed temporal variation in Z_{sd} in Lake Alemaya is mainly attributed to the corresponding fluctuations in turbidity caused by suspended materials of organic and inorganic origin between the dry and rainy seasons.

Turbidity (measured in NTU) varied considerably between 27 and 88NTU. The lowest turbidity was 27 NTU at open site in December and the maximum was 88 NTU at the shore in April (Appendix 1). Turbidity varied between sampling stations with higher values in the shore than other site (OP). This condition has similar pattern with result of Eshete Degen *et al.* (2004) for Lake Tana. During sampling period, water transparency was low at the shore (Fig. 6). The lower water transparency at SH could be the result of higher turbid conditions at the shore. This station might receive a charge of sediments that were dislodged from the surrounding land during heavy wind blow.

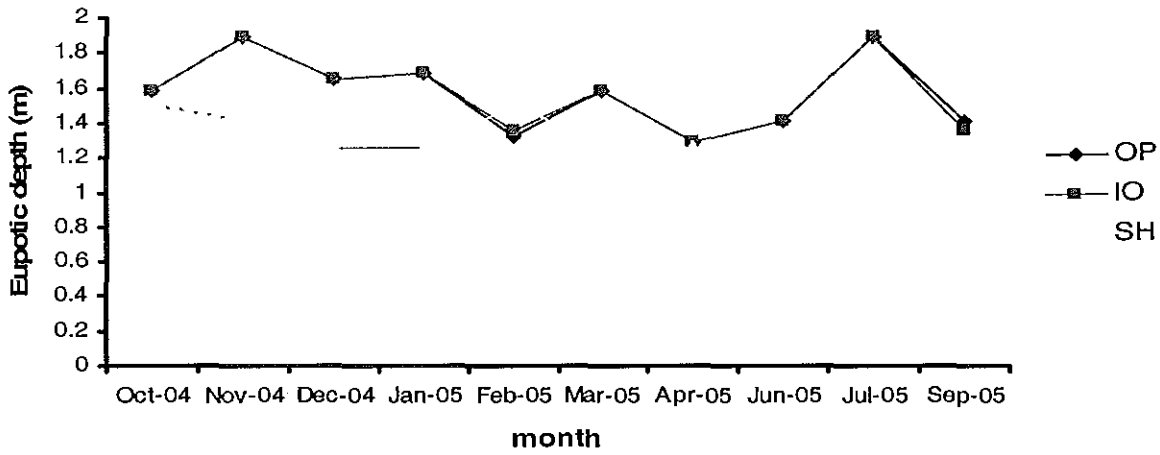
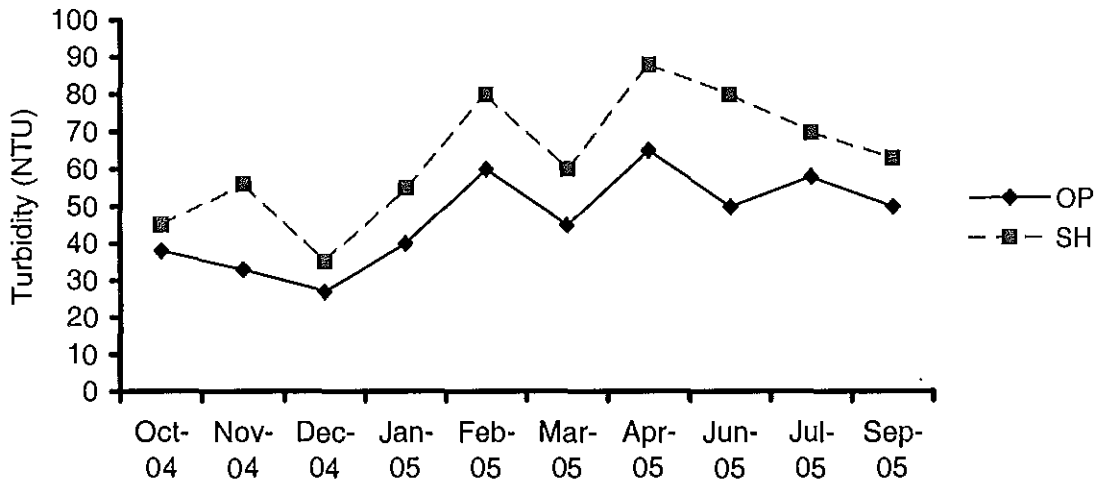


Fig .6. Seasonal variations in turbidity and Euphotic depth in Lake Beseka at three stations

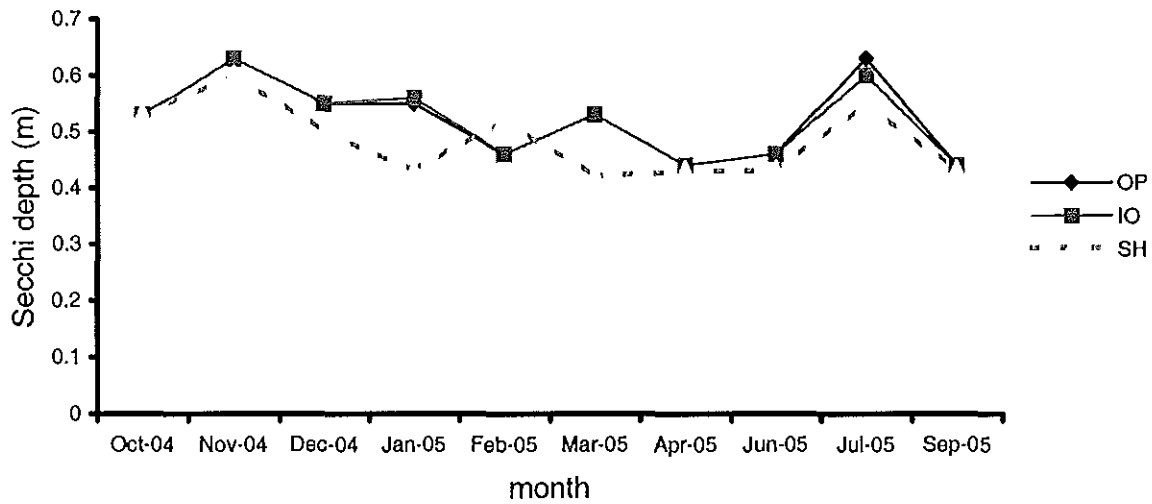
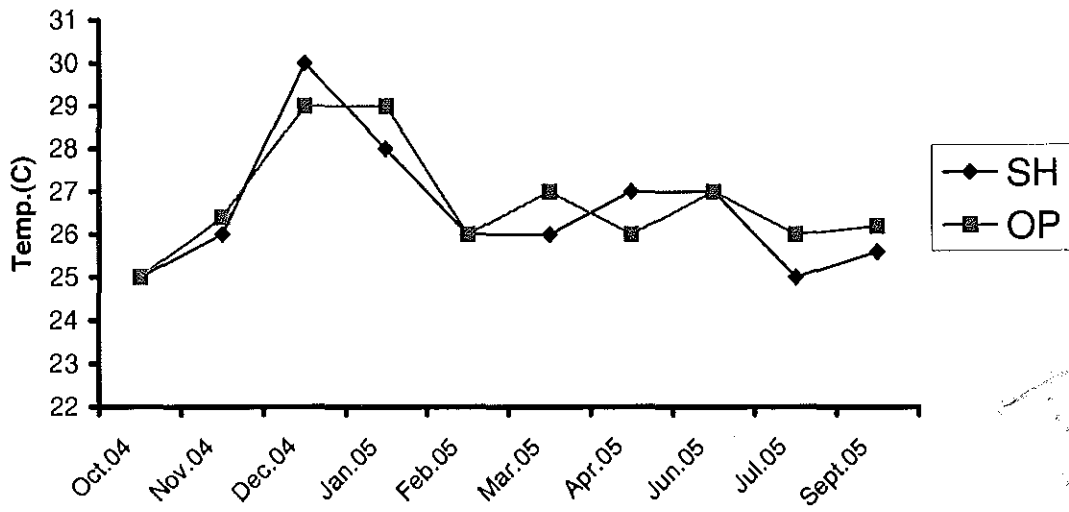


Fig.7. Seasonal variations in Temperature and Secchi depth in Lake Beseka at three stations

4.2 Chemical features of Lake Beseka

Lake Beseka is a shallow closed sub-saline lake. Dispersed humic matter was found at the shore of the lake (personal observation). The chemical data for Lake Beseka, measured during the study period, are given in Appendix 2. Total alkalinity (T_A) of the lake ranged from 34 to 41 meq/l. The highest T_A (41 meq/l) was recorded at the open station (Fig. 8) in November 2004 while the lowest was recorded again at SH in March 2005. Phenolphthalein alkalinity (P_A) ranged from 11- 18.3 meq/l. As compared with other rift valley lakes the alkalinity of Lake Beseka is higher than many Ethiopian lakes; for instance, 16 meq/l in Lake, Hora and 2.9 meq/l in Lake Kilole (Zinabu Geberemariam et al., 2002). The reason for the high alkalinity in Lake Beseka may be related to the dominance of OH^- ions in the lake water. During the whole study period the alkalinity test results indicated that carbonate and hydroxide ions were found dominantly in the lake water.

The values for electrical conductivity varied between $6332 \mu\text{Scm}^{-1}$ and $7438 \mu\text{Scm}^{-1}$ (Fig. 7). The highest value was recorded in September and lowest value in April at the shore site. Lower conductivity values were recorded in April 2005 at all and exceptionally during the wet period at OP in July. The reason for high conductivity values during the wet season at IO and OP could be organic matters that are washed from catchment area. The lower value of conductivity in April also may be related with high rainfall. The seasonal mean value recorded at SH is higher than that of OP and IO (Fig. 8). According to earlier studies on Lake Beseka water chemistry, the total ionic content of the lake has decreased by tenfold over the past two decades. In the present study the mean value of conductivity ($7020 \mu\text{Scm}^{-1}$) is even less than recent studies in the lake.

Although the conductivity of Lake Beseka has decreased over the last two decades, the average value is still higher compare to some Ethiopian Lakes. For example, Lakes, Chamo and Abaya (Talling and Talling, 1965), Hayq, Cheleklaka (Wood and Talling, 1988), which had about 890 to $1000 \mu\text{Scm}^{-1}$.

In this study the electrical conductivity was strongly correlated ($r= 0.96$, $P=0.453$) with total alkalinity. This view is supported by the result of the study made by Zinabu Gebremariam *et al.*, (2002) in rift valley lakes where they found that among cations sodium shows close correlation ($r =0.94$, $P= 0.367$) with conductivity in all studied lakes. This condition seems to be particularly likely for Lake Abijata where the highest conductivity value is mainly due to high Na^+ ion concentration.

There was less variation in conductivity among sampling sites. Conductivity was high in wet season at IO and SH whereas at OP its value coincided with dry season (Fig. 7). The seasonal pattern of conductivity has almost the same trend with pH and alkalinity and is consistent with earlier reports for Ethiopian Lakes (Wood and Talling, 1988; Zinabu Gebre- Mariam, *et al.*, 2002). pH values varied between 9.1 and 9.51 during the study period.. During the study period, the seasonal variations have the same trend with electrical conductivity. There was slight difference in pH between sampling sites. In this study the pH values were found to be slightly lower than those in earlier reports (Elizabeth Kebede and Willen, 1998 9.65; Reimann *et al.* 2002, 9.55). The main reason for decreasing conductivity is probably due to the sharp rise in water level of the lake (Elizabeth Kebede and Willen, 1998; Tenalem Ayenew, 2004.)

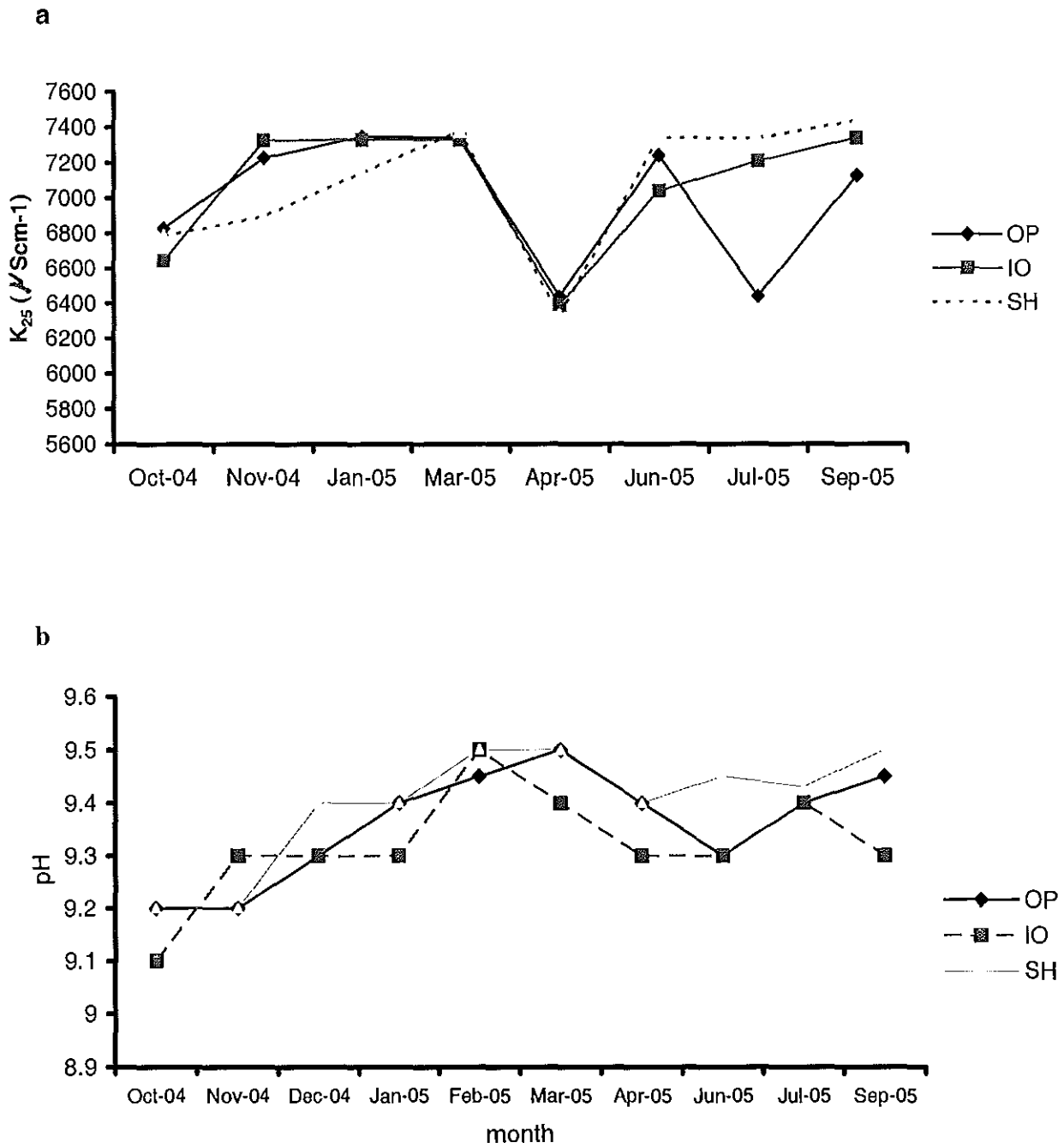


Fig .8. Seasonal variation of electrical conductivity (a) and pH (b) at the three stations during Oct, 04 to Sept ,05.

4.2.1. Major nutrients

The concentration of major nutrients showed fluctuation during the study period. The concentration of $\text{NO}_3\text{-N}$ significantly varied (see Table 3, ANOVA, $P < 0.05$) in sampling months. The lower $\text{NO}_3\text{-N}$ concentrations were recorded during dry season and in wet season in July at SH and OP. The lower concentration in wet season coincides with higher chlorophyll concentrations. This suggested that utilization of phytoplankton probably result in nitrate minimum during this period. According to Reynolds (1984) surface concentrations of nitrate are often temporarily declined during algal blooming; for example, 'spring blooming' result in decrease in nitrate concentration in temperate lakes. In spite of the concentration of $\text{NO}_3\text{-N}$ varied between stations from 400-870 $\mu\text{g/l}$ at site OP, 500-800 $\mu\text{g/l}$ at IO and 430-900 $\mu\text{g/l}$ at SH (see appendix 4), statically there were no variation (ANOVA, $P > 0.05$) between sampling stations.

Earlier studies have reported that nitrate limitation is very common in tropical lakes (Lewis, 1996; Talling and Lemolla, 1998). However, in the present study concentration of nitrate was higher than most African lakes (Melack and Kilham, 1974; Melack, 1979) including Ethiopian lakes, Lakes Chamo (10 to 60 $\mu\text{g/l}$; Eyashu Sumbulo, 2004), Lake Kilole (none, Wood *et al.*, 1984), Lake Hora (15 $\mu\text{g/l}$; Zeinabu Gebere-Mariam *et al.*, 2002) and Lake Ziway (200 - 680 $\mu\text{g/l}$, Getachew Beneberu, 2005).

The concentration of soluble reactive phosphorus (SRP) were in the present study (1-2.9 mg/l) is higher than previous reported values of this lake (Elizabeth Kebede and Willen, 1998; Reimann *et al.*, 2002) and other rift valley lakes, Langanjo (16.3 – 83 $\mu\text{g/l}$; Amaha Belay and Kasshun Wodajo, 1982), Awassa (4-16 $\mu\text{g/l}$; Zinabu Gebre Mariam and Taylor, 1989) and Ziway (211.4 $\mu\text{g/l}$, Getachew Beneberu, 2004). The remarkably high levels of SRP in Lake Beseka is probably associated with phosphatic minerals present in the catchment and the effect of detergents used for washing vehicles at the shore and fertilizers from the farmland. Although nutrient excretion by animals has not been studied in detail in Ethiopia's lakes, aquatic organisms play a critical role either in reduction or rise of phosphate (Ganf and Blazka, 1974). In this view, the excretion from birds (which feed on fish offal) and crocodiles probably contribute high phosphate concentration in the lake.

Phosphate concentration significantly varied (ANOVA, $P < 0.05$) during the study period. The maximum concentration of $\text{PO}_4\text{-P}$ was recorded in April at all stations and the values were irregularly fluctuated during the dry period. Like nitrate, the concentration of SPR did not vary statistically between sampling sites.

Molybdate reactive Silica as (SiO_2) varied from 18 to 55 mg/l at OP 11 to 78 mg/l at IO and 8-63mg/l at SH. The concentration seasonally varied and high concentration values were observed during dry season from December 2004 to February 2005. The high concentrations of silicate during the dry months were higher at IO and this pattern was changed from February to June 2005. High silicate values are recorded in Lake Beseka compared to other Ethiopian Rift valley lakes. One possible reason could be recycling from diatoms. As Talling and Talling (1965) pointed out concentrations over 10 mg/l SiO_2 are common in the African lakes because of high mobility of silica in most tropical soil and volcanic lava, as well as due to enhanced dissolution of silicate salts in water of high pH and alkalinity. The concentration of silicate was low during wet period and this might be related to other factors rather than uptake by phytoplankton

A persistent decline of silicate concentration was reported for many Ethiopian lakes (Zinabu Gebremariam *et al.*, 2002), although not such data are available for Lake Beseka. According to some authors, the reason for decline might be related to increasing phytoplankton growth and disruption in Si regeneration from sediments (Hecky And Kilham, 1973). However, silicate concentration is higher in tropical lakes than temperate ones (Zinabu Geberemariam *et al.*, 2002).

Table 3 Analysis of variance: for nutrients and phytoplankton biomass between stations

NITRATE

Source	DF	SS	MS	F	P
Factor	2	40053	20027	0.94	0.405
Error	27	577642	21394		
Total	29	617695			

PHOSHATE

Source	DF	SS	MS	F	P
Factor	2	0.954	0.477	3.07	0.063
Error	27	4.201	4.201	0.156	
Total	29	5.133	5.155		

SILICATE

Source	DF	SS	MS	F	P
Factor	2	137	68	0.20	0.823
Error	24	8360	348		
Total	26	8497			

Phytoplankton biomass

Source	DF	SS	MS	F	P
Factor	2	14.87	7.43	1.40	0.264
Error	27	43.30	5.31		
Total	29	158.17			

Table 4 Analysis of variance: for nutrients between sampling months

NITRATE

Source	DF	SS	MS	F	P
Factor	9	501808	55756	9.56	0.000
Error	20	116651	5833		
Total	29	618459			

PHOSPHATE

Source	DF	SS	MS	F	P
Factor	9	2.788	0.310	2.81	0.026
Error	20	2.209	0.110		
Total	29	4.997			

SILICATE

Source	DF	SS	MS	F	P
Factor	8	7562.5	945.3	14.46	0.000
Error	18	1176.7	65.4		
Total	26	8739.2			

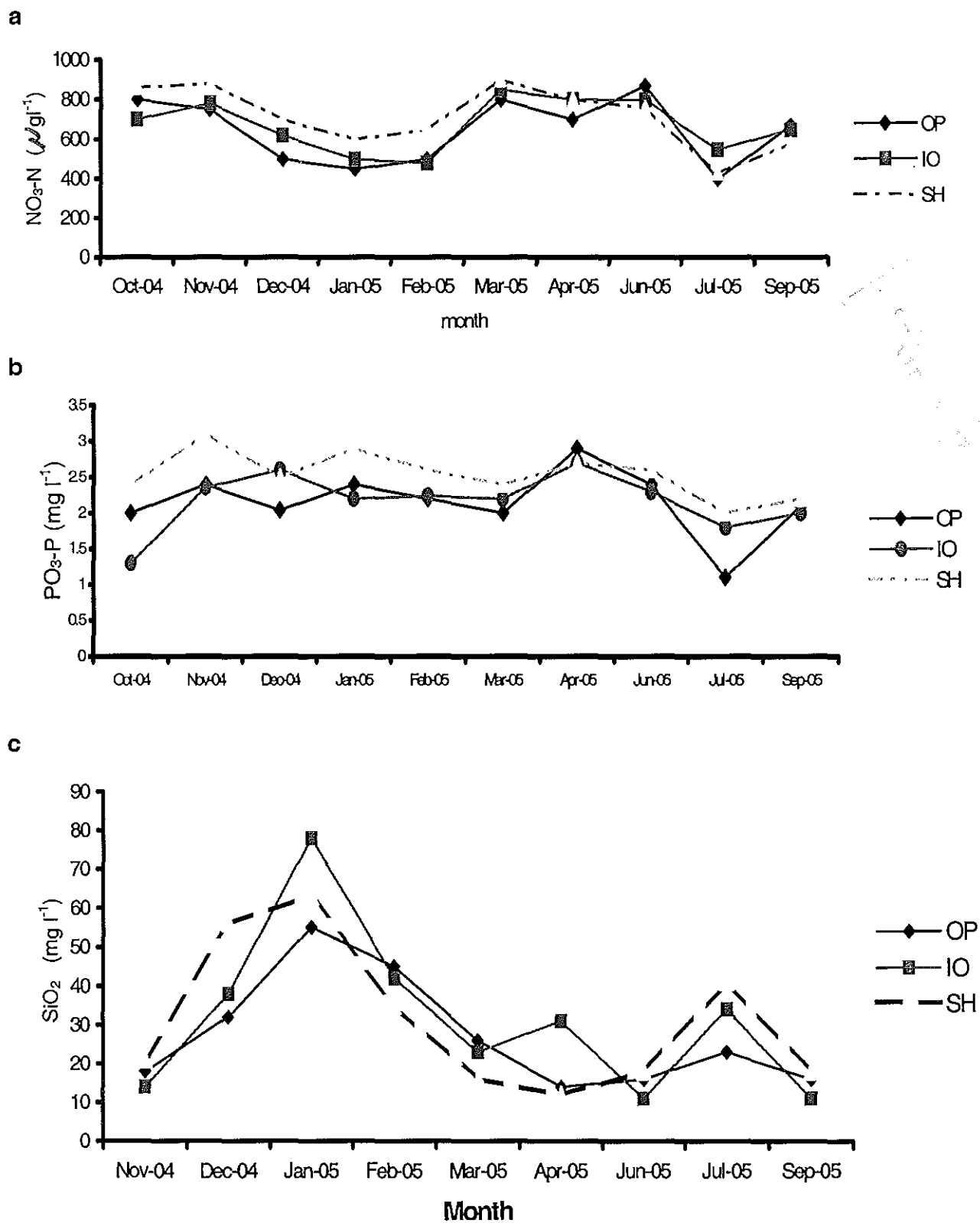


Fig.9. Seasonal variation of nutrients Nitrate (a), Phosphate (b) and Silicate (c) at three stations in Lake Beseka (Nov, 04 - Sept-05)

4.3 Composition and primary production of phytoplankton

4.3.1 Composition of the major phytoplankton species

Table 5. Presents a list of the most commonly encountered phytoplankton species in Lake Beseke.

Table 5. List of the identified phytoplankton groups during sampling period in

Lake Beseke(+ refers to less common, ++ -common, ++++ dominant)

Diatoms	Blue –green algae	Green algae
<i>Navicula</i> (++++)	<i>Microcystis</i> (+++)	<i>Cosmarium</i> (+++)
<i>Cymbella</i> (+)	<i>Oscillatoria</i> (++)	<i>Scenedesmus</i> (++)
<i>Thalassisira</i> (++)	<i>Anabaena</i> (++)	<i>Botryococcus</i> (+)
<i>Cyclocella</i> (+)	<i>Rivularia</i> (+)	<i>Asterococcus</i> (+)
<i>Surirela</i> (+)	<i>Lyngbya</i> (+)	<i>Pediastrum</i> (+)
<i>Melosira</i> (+)		

4.3.2 Phytoplankton biomass

Phytoplankton biomass estimated as chlorophyll a concentration exhibited some temporal variation with minima corresponding to low concentration of nitrate and phosphate (Fig. 10). Phytoplankton biomass varied over the study period from 7 to 17mg chl $a\ m^{-3}$ (mean 12 mg chl $a\ m^{-3}$) with the persistence high values recorded between March and July and decreasing values recorded at OP site in January (see Appendix 3). There was also gradual decrease in algal biomass values between October 2004 and January 2005. An increase in phytoplankton biomass was also observed during the wet periods (June – July, 2005) and dry periods (February to March). The high values in wet period may be related with nutrient input from various sources during the rainy time. There was no significant variation (see table 3, $P < 0.05$) between sampling sites.

In the present study, the phytoplankton biomass values in Lake Beseka are slightly lower than earlier reports, (27mg chl. $a\ m^{-3}$; Elizabeth Kebede and Willen, 1998; 19 mg chl. $a\ m^{-3}$; Gashaw Beyene, 2005) but it is comparable to some other Ethiopian lakes, for example, Lake Langano (Elizabeth Kebede and Willen, 1998). However, the mean algal biomass value of Lake Beseka is lower than those reported for some African lakes, including Nakuru, Kenya (330 mg chl $a\ m^{-3}$; Melack and Kilham, 1974), George, Uganda (250 mg chl $a\ m^{-3}$; Ganf and Horne 1974) and Ethiopian lakes, Kilole (100-112 mg chl $a\ m^{-3}$; Wood *et al.*,1978), and Arenguade (212 mg chl $a\ m^{-3}$; Zinabu Geberemariam *et al.*,2002).

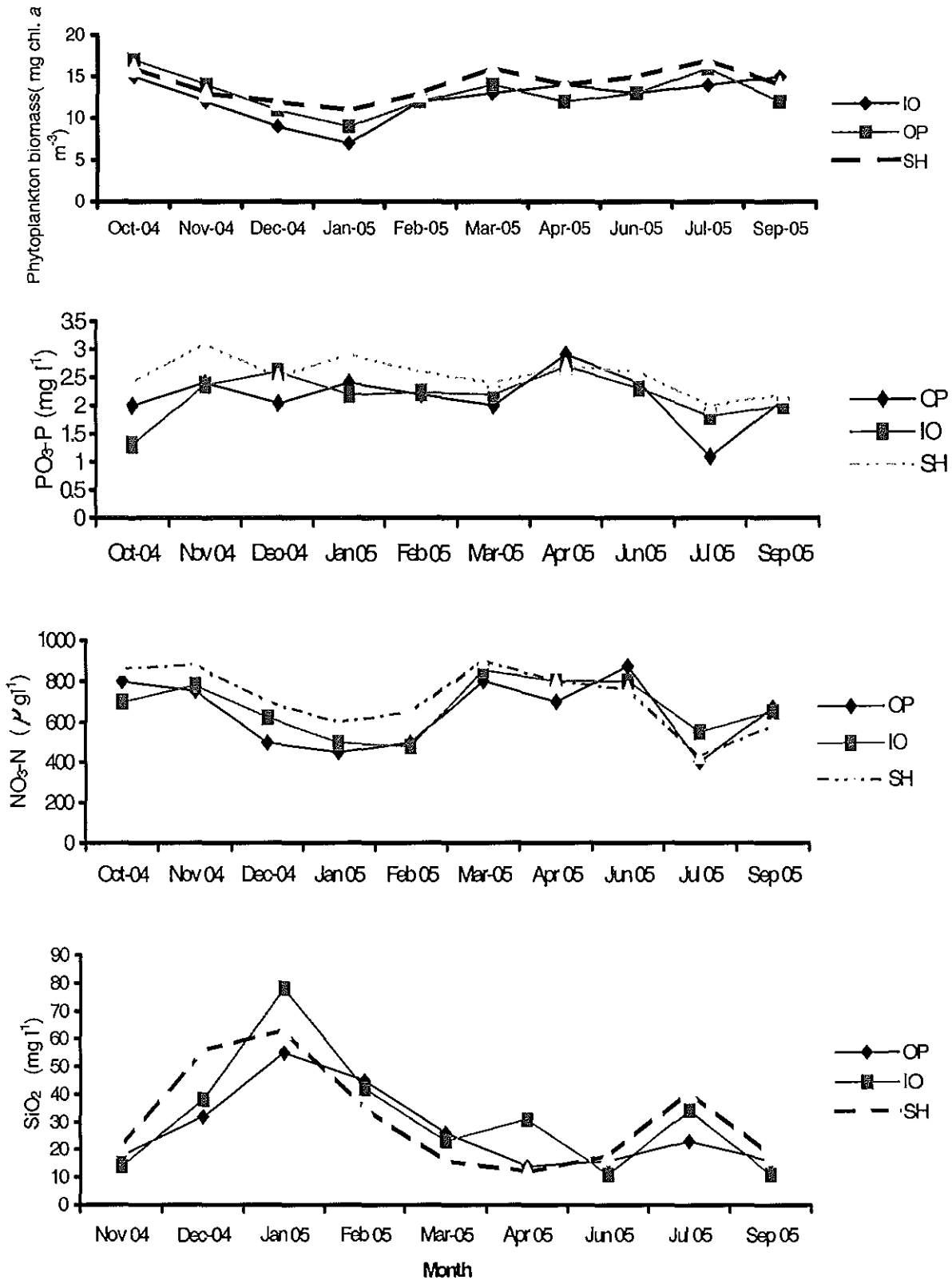


Fig. 10. Seasonal variation of phytoplankton biomass and nutrients at three stations (Oct-04 - Sept-05)

4.3.3. Phytoplankton production

The depth distribution of gross photosynthesis per unit water volume (A , $\text{mg O}_2 \text{ m}^{-3} \text{ h}^{-1}$) shown in Fig. 12 was of a typical pattern for tropical phytoplankton. The depth profiles of gross photosynthesis ranged from surface to lower limit (1m) in the extent of the depth enclosed by euphotic zone. During the study period all (except November and September) monthly incubations showed maximum photosynthetic production at sub- surface (0.25m)

The suppression of photosynthetic activities at the lake surface is a common feature of photosynthesis-depth relation in tropical lakes (Talling and Lemolla, 1998). It has also been reported for many Ethiopian lakes by Girma Tilahun (1988) and Demeke kifle and Amha Belay (1990). Photoinhibition is the major explanation for suppression at surface rates and that the intensity of light at the surface exceeds the compensatory abilities of the phytoplankton (Lewis, 1974). Besides this, Talling (1965) has suggested that sedimentation might also play a role in suppression of photosynthesis near the surface of lakes.

Photosynthetic characteristics

Fig.11 shows the seasonal variation in maximum rate of gross photosynthesis (A_{max}), specific rates at light- saturate photosynthesis capacity (ϕ_{max}) and hourly rate of integral photosynthesis (ΣA , $\text{mg O}_2 \text{ m}^{-2} \text{ h}^{-1}$) in relation to phytoplankton biomass (B). Maximum photosynthetic rate (A_{max}) varied over the study period from 166 to 273 $\text{mg O}_2 \text{ m}^{-3} \text{ h}^{-1}$ (Appendix 5). The highest rate was recorded in February and the lowest in January. A_{max} in Lake Beseka was negatively correlated ($r = -0.121$ $P = 0.256$) with phytoplankton biomass. Similarly negative or weak correlations were found with phytoplankton standing crops in Lake Chamo ($r = 0.3$; Eyasu shumblo, 2004). Ziway ($r = 0.36$; Girma Thilhun; 1988), Awassa ($r = -0.088$; Demeke Kifle and Amha Belay, 1990).

However, much higher correlations were observed in Kenyan lakes (Melack, 1979) and Welsh lakes ($r = 0.450 - 0.67$; Pentecost and Happywood, 1978). In the present study, the A_{\max} values for Lake Beseka are much lower than those reported for some Ethiopian lakes, Arenguade ($30,000 \text{ mg O}_2 \text{ m}^{-3}\text{h}^{-1}$; Talling *et al.* 1973), Kilotes ($11190 \text{ mg O}_2 \text{ m}^{-3}\text{h}^{-1}$; Talling *et al.*, 1973) and other African lakes Nukuru ($2500 \text{ mg O}_2 \text{ m}^{-3}\text{h}^{-1}$; Melack and kilkham, 1974) and Simba ($1400 \text{ mg O}_2 \text{ m}^{-3}\text{h}^{-1}$; Melack, 1979) in Kenya.

Specific rates of photosynthesis (ϕ_{\max}) ranged from 13 - 23.8 $\text{mg O}_2 (\text{mg Chl a})^{-1} \text{ h}^{-1}$ (see Appendix 5). The maximum specific rate (ϕ_{\max}) for Lake Beseka corresponds to lowest algal biomass. The mean value of the lake 18 $\text{mg O}_2 (\text{mg Chl a})^{-1} \text{ h}^{-1}$ can be put under tropical range (see table 6).

Table 6. Specific rates of photosynthesis (mean values (ϕ_{\max}) for some Ethiopian and African lakes).

	(ϕ_{\max}) values ($\text{mg O}_2 (\text{mg Chl a})^{-1} \text{ h}^{-1}$)	References
Ethiopian lakes		
Ziway	6.6 -28.8	(Getachew Benebru, 2005)
Abijata	13-23.8	(Amha Belay and Wood, 1982)
Chamo	16.3 -34	(Eyasu Shumbolo, 2004)
kilole	16.3 -33.7	Talling <i>et al.</i> , (1973)
Present study	13 - 23.8	
African lakes		
Nakuru, Kenya	15- 17	(Melack and Kilham, 1974)
Sonachi, Kenya	15 -17	(Melack, 1979)
Victoria, Uganda	14--35	Talling <i>et al.</i> , (1965)

In the present study ϕ_{\max} has significantly correlated (see Appendix 6.2 ANOVA $P < 0.05$) with phytoplankton biomass; Similarly, the highest photosynthetic capacity that conversely associated with low phytoplankton biomass reported for lakes Chamo (Eyasu Sumbulo, 2004) and Lake George Uganda (Ganf and Horne 1975).

Talling (1965) and Ganf and Horne (1975) found maximum photosynthetic rates (up to $31 \text{ mg O}_2 (\text{mg Chl a})^{-1} \text{ m}^{-3} \text{ h}^{-1}$) from warm tropical lakes in Africa whereas in temperate lakes the values rarely exceeded the equivalent of $20 \text{ mg O}_2 (\text{mg Chl a})^{-1} \text{ m}^{-3} \text{ h}^{-1}$ (Bindloss, 1974). Various explanations have been given to the relatively high values of the photosynthetic capacity observed in tropical saline lakes, nutrient concentrations, light history (Harris and Lott, 1973) and temperature (Berman and Pollinger, 1974). In the case of tropical lakes high temperature has a pronounced effect to high photosynthesis capacity. Although Lake Beseka is a saline lake, in the present study, it did not show high photosynthesis production. The dark brown color of the lake might play a role in suppression of photosynthesis by increasing attenuating the light penetration depth of the lake.

Areal production

The area enclosed by each successive depths is a measure of the integral photosynthesis per unit area (ΣA , $\text{mg O}_2 \text{ m}^{-2} \text{ h}^{-1}$). Values were estimated by grid numeration analysis (Osion, 1960). Hourly integral photosynthesis ΣA ranged from 66–174 $\text{mg O}_2 \text{ m}^{-2} \text{ h}^{-1}$. The values steadily rose from December to February and declined in March and rise again from June to September 2005. (Fig.10). The peak values of ΣA were observed in February and the lower in June. The seasonal higher value seems to have the same seasonal pattern with maximum photosynthetic values. The positive and strong correlation ($r = 0.871$, $P = 0.05$) between A_{\max} and ΣA seems to agree with the conclusion that gross photosynthesis per unit area is influenced by light saturated rate of photosynthesis.

The highest value of ΣA in the lake occurred concomitantly with higher A_{\max} . In the present study, ΣA values ($118.5 \text{ mg O}_2 \text{ m}^{-2} \text{ h}^{-1}$) are much less than some African lakes, Nakuru, Kenya range between $100 - 300 \text{ mg O}_2 \text{ m}^{-2} \text{ h}^{-1}$; Melack,1979) Reshitani,Tanzania ($2510 \text{ mg O}_2 \text{ m}^{-2} \text{ h}^{-1}$; Melack and Kilham,1971) and Ethiopian Lakes, Ziway ($57.4-726 \text{ mg O}_2 \text{ m}^{-2} \text{ h}^{-1}$; Getachew Beneberu, 2005) and Lake Arenguade ($1430-2560 \text{ mg O}_2 \text{ m}^{-2} \text{ h}^{-1}$; Talling *et al.*,1973). Although many saline lakes in tropical region can attain exceptionally high ΣA , the low values in Lake Beseka again might be associated with its color. Light may not penetrate deep in the lake because of the dark brown color of the lake water.

Daily production rates per unit area ($\Sigma\Sigma A, \text{ g O}_2 \text{ m}^{-2} \text{ d}^{-1}$) were estimated from the hourly integral rates. The empirically derived factor of 0.9 and multiplied by the number of hours of sunlight (10hr) and the production multiplied by the hourly rates per unit area

The calculated daily rate of photosynthesis ($\Sigma\Sigma A$) values range from $0.61-1.57 \text{ g O}_2 \text{ m}^{-2} \text{ d}^{-1}$. The seasonal fluctuation of $\Sigma\Sigma A$ shows more or less the same pattern and has strong correlation ($r= 0.9, P = 0.453$) with ΣA values. The highest daily rate of photosynthesis ($1.57 \text{ g O}_2 \text{ m}^{-2} \text{ d}^{-1}$) corresponds to A_{\max} of 273 in February. The mean $\Sigma\Sigma A$ value in Lake Beseka is very close to those reported for Lakes, Waldesa, Canada ($1.13 \text{ g O}_2 \text{ m}^{-2} \text{ d}^{-1}$, Hammer, 1981) and less than most of rift valley Lakes, Ziway ($0.52 - 6.53 \text{ g O}_2 \text{ m}^{-2} \text{ d}^{-1}$; Getachew Benberu, 2005), Abijata ($5.6 \text{ g O}_2 \text{ m}^{-2} \text{ d}^{-1}$, Amha Belay and Wood, 1984) and Awassa ($3.3 - 7.8 \text{ g O}_2 \text{ m}^{-2} \text{ d}^{-1}$; Demeke Kifle and Amha Belay,1990). According to Reynold (1984), the daily-integrated gross photosynthesis depends upon light insolation and temperature. Moderately increasing temperature and freely available CO_2 also enhances daily-integrated gross photosynthesis.

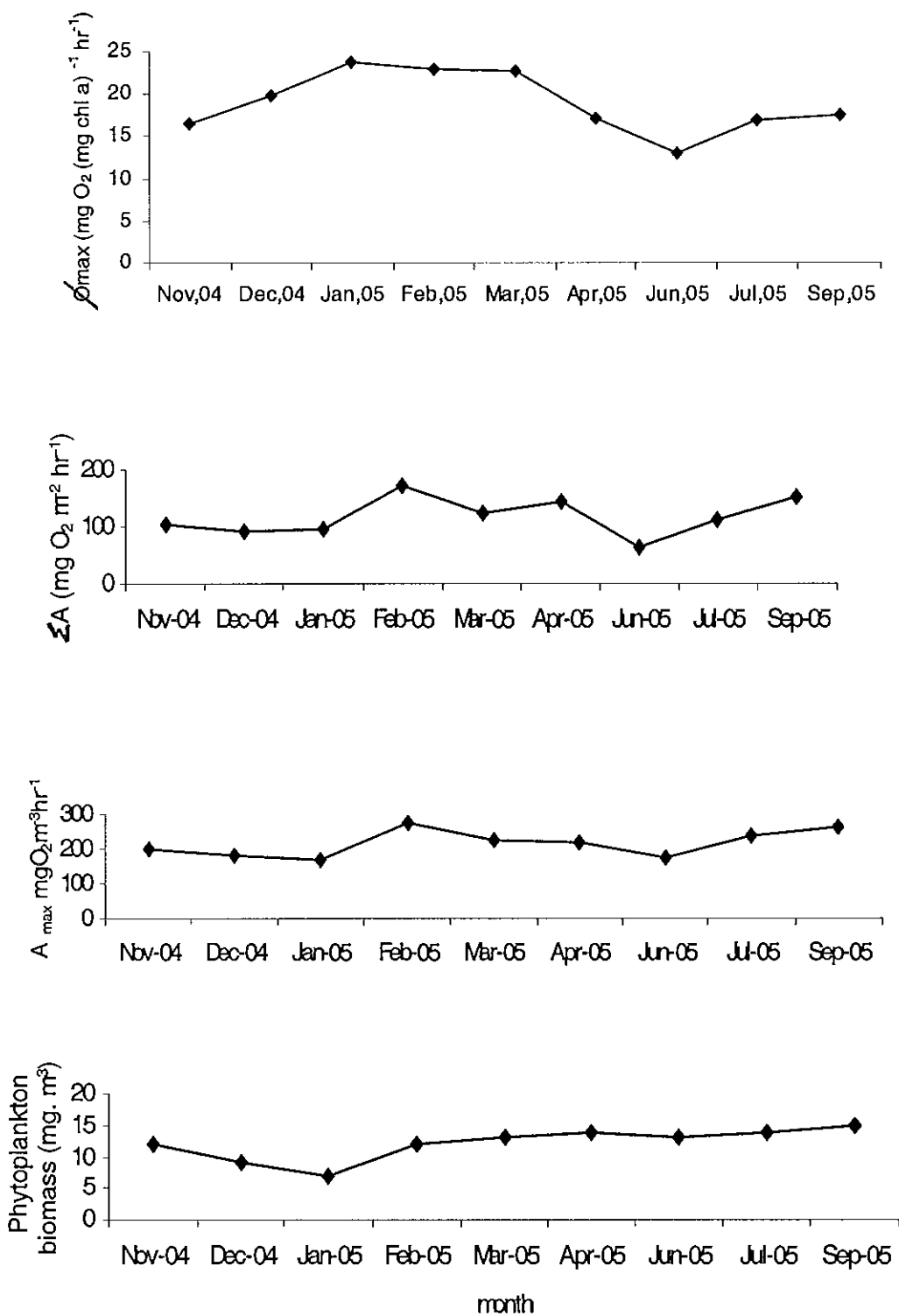


Fig. 11. Seasonal variations of photosynthesis capacity (ϕ), hourly integral (ΣA) and maximum rate of gross photosynthesis (A_{max}) with phytoplankton biomass in Lake Beseka (Nov, 04 – Sept 05).

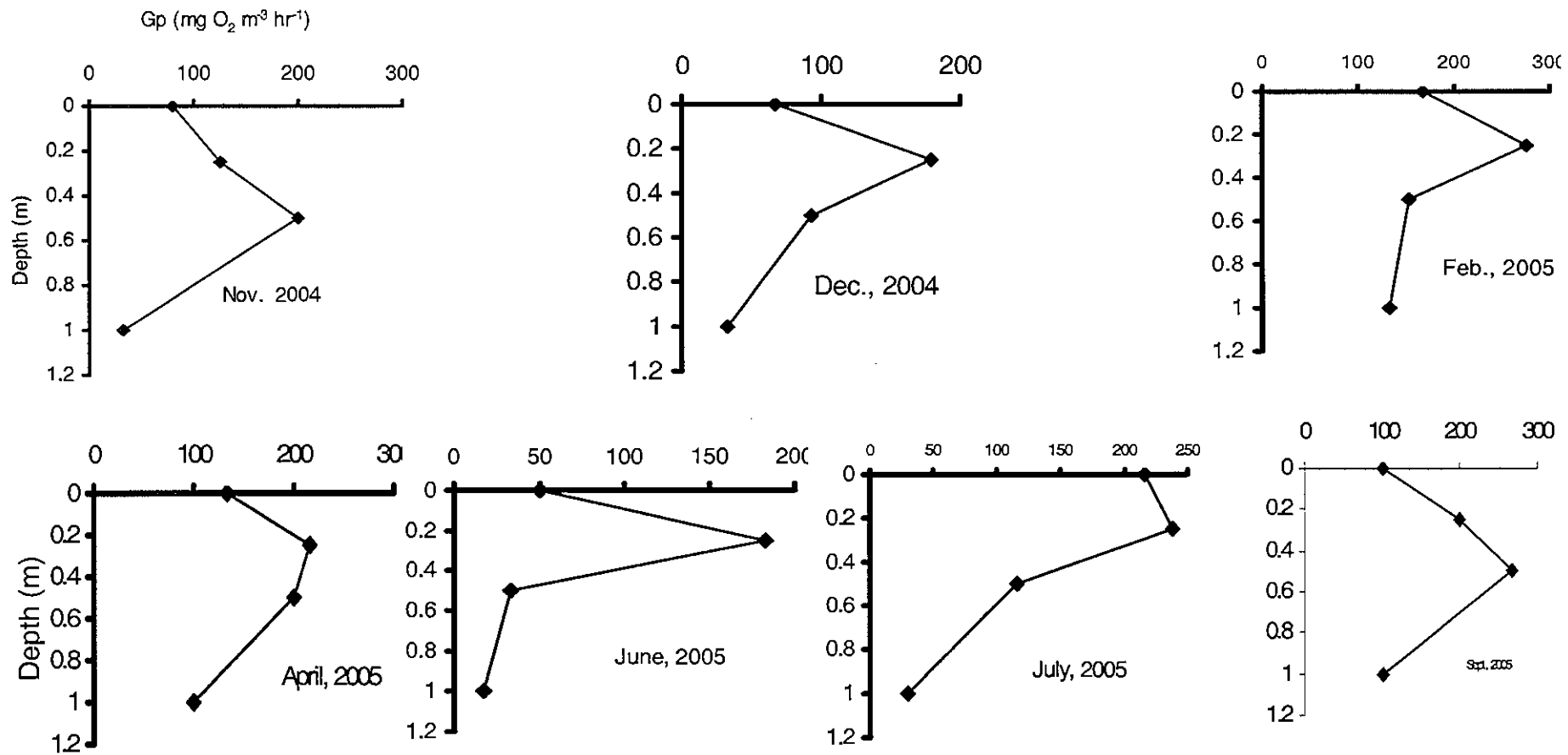


Fig . 12. Depth profiles of gross photosynthesis during the study period at the open site.

4.4. Zooplankton composition and abundance

4.4.1 Species composition

A total of six genera of crustaceans and two genera of rotifers were identified in Lake Beseka. Out of the six genera, two Cyclopoids (*Thermocyclops* and *Mesocyclops*) and one Harpacticoid represented copepoda and *Daphnia*, *Moina* and *Diaphanosoma* represented cladocera while *Branchionus* and *Keratella* represented Rotifera.

Table 7. List of zooplankton taxa identified from Lake Beseka

Copepoda	Cladocera	Rotifera
<i>Mesocyclops</i> sp. <i>Thermocyclops</i> sp. <i>Harpacticoid</i> (rare)	<i>Daphnia</i> sp. <i>Diaphanosoma</i> sp. <i>Moina</i> sp.	<i>Branchionus pliciatilis</i> <i>B. dimidiatus</i> <i>B. variabilis</i> <i>B. leydigii</i> <i>Keratella tropica</i>

4.4.2 Spatial and temporal dynamics of major zooplankton groups

Cyclopoid copepods

Cyclopoid copepods were the most abundant taxa in Lake Beseka. They showed significant seasonal variation (see Table 8 ANOVA $P < 0.05$). The abundance fluctuated irregularly in the dry season and increased during wet period. Although the density of cyclopoid in the open (OP) water was higher than those of the other two sites (IO and SH, a result from statistical analysis does not show significant variation between sampling stations).

Likewise, many tropical lakes, *Mesocyclops* were the dominant group than other zooplankton community in Lake Beseka; the reason for the dominance of *Mesocyclops* may be their feeding behaviors and defence mechanisms. Many studies support the decreased susceptibility of *Mesocyclops* to fish predation (Twombly and Lewis, 1987; Waya, 2002). For example, in Lakes Wamala and Nabugabo, (Tanzania) *Mesocyclops* is a dominant group because it has sensory hairs on the antennae, which enables it to detect any water movement, and it can move away with a great speed from the line of attack by fish (Waya, 2002).

The abundance of cyclopoids was extremely low and fluctuated irregularly during dry seasons; however the conditions reversed and were extremely high in wet season (Fig. 14). This could be associated with food conditions and predation. Similar result was reported from other Ethiopian lakes such as Langano and Abjata (Kasshun Wodajo and Amha Belay, 1984) and Ziway (Getachew Beneberu, 2005).

Nauplii and copepodite stages were counted separately. They had more or less similar temporal variability pattern during the study period (Fig. 14). The abundance of both stages showed irregular fluctuation with monthly maxima in September 2005 at SH. The high variability of both stages during the dry season might be related to horizontal distribution and mortality due to predation.

4.4. Zooplankton composition and abundance

4.4 .1 Species composition

A total of six genera of crustaceans and two genera of rotifers were identified in Lake Beseka. Out of the six genera, two Cyclopoids (*Thermocyclops* and *Mesocyclops*) and one *Harpacticoid* represented copepoda and *Daphnia*, *Moina* and *Diaphanosoma* represented cladocera while *Branchionus* and *Keratella* represented Rotifera.

Table 7. List of zooplankton taxa identified from Lake Beseka

Copepoda	Cladocera	Rotifera
<i>Mesocyclops</i> sp. <i>Thermocyclops</i> sp. <i>Harpacticoid</i> (rare)	<i>Daphnia</i> sp. <i>Diaphanosoma</i> sp. <i>Moina</i> sp.	<i>Branchionus pliciatilis</i> <i>B. dimidiatus</i> <i>B. variabilis</i> <i>B. leydigii</i> <i>Keratella tropica</i>

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Copepodites and nauplii exhibited slight difference in abundance pattern among the three sites. The number of copepodite higher was at OP than IO. But in the case of nauplii, the number was higher at IO than OP; however, both of them increased at SH than the other two stations in wet period.

Table 8 Analysis of variance: cyclopoid abundance between sampling stations and months

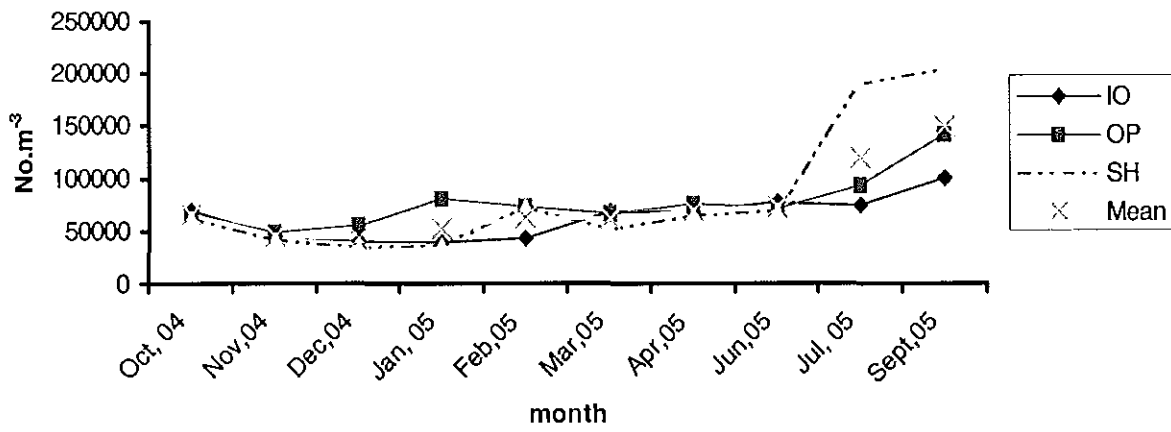
Between sampling stations

Sources	DF	SS	MS	F	P
Factor	2	16543100400	8271550200	1.13	0.339
Error	27	1.98159E+11	7339209532		
Total	29	2.14702E +11			

Between sampling months

Source	DF	SS	MS	F	P
Factor	9	12259390400	1362154489	4.44	0.003
Error	20	6132198795	306609940		
Total	29	18391589195			

a



b

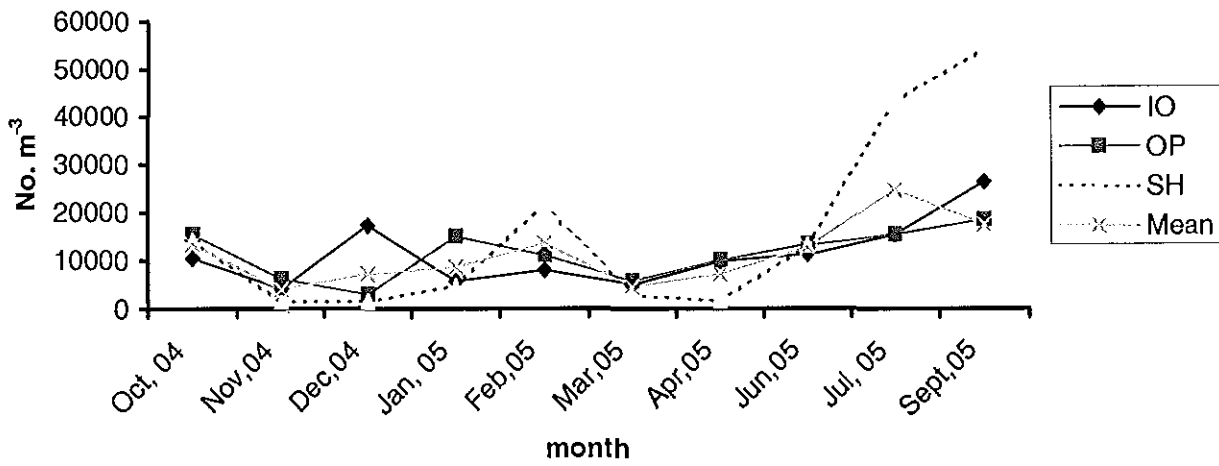
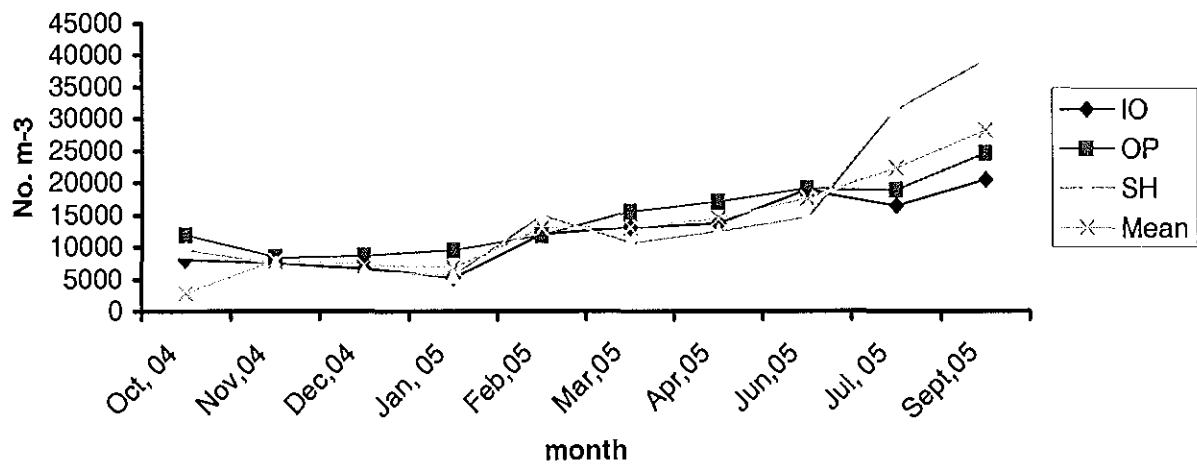


Fig.13. Seasonal variation in abundance of total zooplankton (a) and cyclopoid eggs (b) during the sampling period at the three stations

a



b

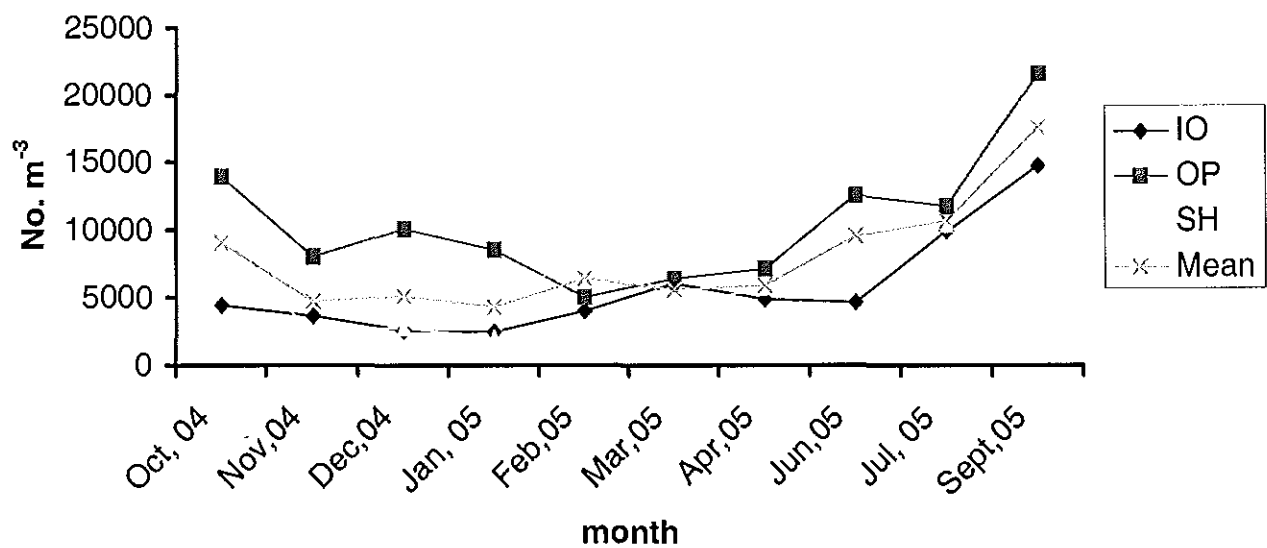
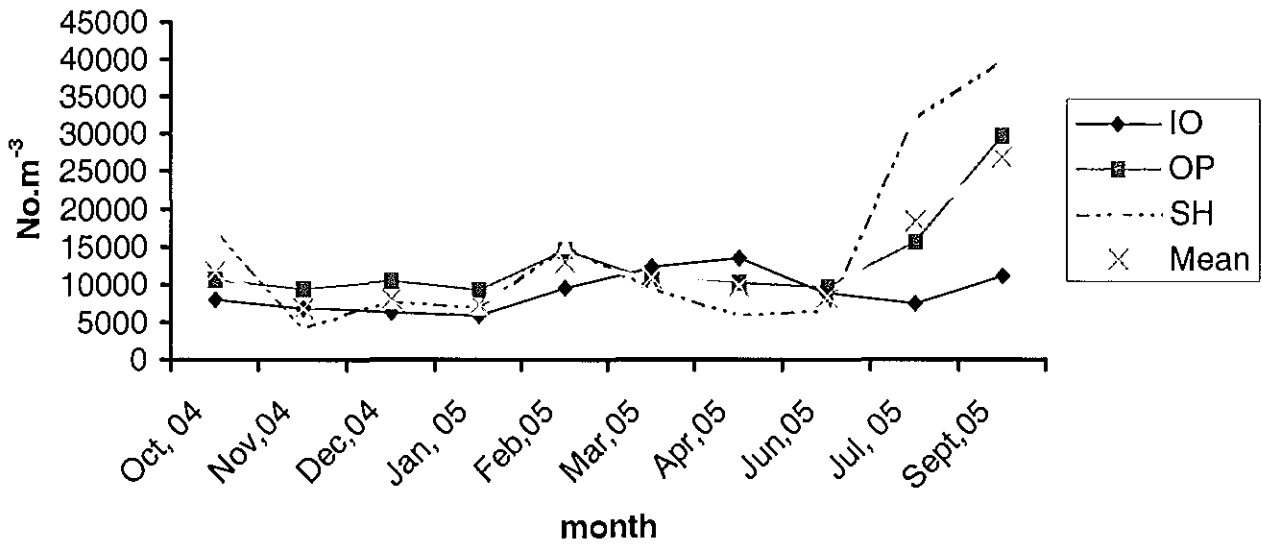


Fig.14. Seasonal variation in abundance of adult male (a) and female (b) cyclopoids during the sampling period at three stations in Lake Beseka.

a



b

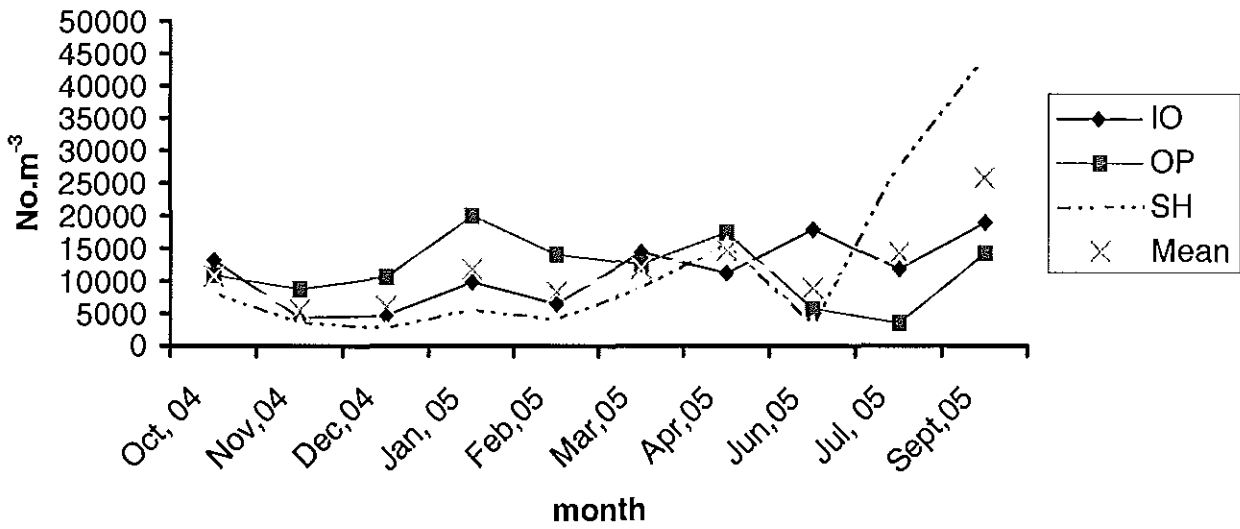


Fig.15. Seasonal variation in the abundance of cyclopoid copepodites (a) and nauplii (b) in Lake Beseka during the sampling period

Cyclopoid egg stock of in Lake Beseka fluctuated between 1487 m⁻³ and 53,962 m⁻³ in September 2005 in November , respectively (Appendix 7). Egg production was moderately high and amounted to 14% of the total cyclopoid production. Since there is direct relation between egg production and its number; the egg production rate in Lake Beseka is higher than that in some other Ethiopian lakes. For instance, in Lake Awassa, egg production amounted to less than 5.3% of the total cyclopoid production (Seyoum Mengestou, 1989). Egg production in Lake Beseka is however, less than that of many tropical lakes. Lewis (1977) reported that in some tropical lakes, egg production made up more than half of the cyclopoid production. Results from this study, suggest that lower egg production in Lake Beseka might be related to low primary production and poor food condition in the lake.

In the present study irregular fluctuation and maximum egg stock was recorded during dry and wet period, respectively (July to September) (Fig, 13). The higher number of egg stock during wet season might be related to high number of female Cyclops and good food condition. Although high egg number was recorded in wet period, in some months in dry period the egg ratio (egg. female⁻¹) showed there was high egg stock (Fig. 16). This is possibly due to temperature. In this study temperature was positively correlated ($r= 0.05$, $P =0.31$) with egg production. Waya (2002) in Tanzanian Lakes and Seyoume Mengistou (1991) in Lake Awassa observed that the development and production of eggs increased with increasing temperature. The egg stock again showed no variation between sampling sites. (See, table 10)

Sex ratios for cyclopoids (female: male) in Lake Beseka were mostly less than 1 at all stations. Low monthly average sex ratios were recorded during the dry period (February to April) and the high sex ratio was recorded in October 2004. The sex ratio value at OP higher during October to January, 2005 and July to September than IO and SH. However the seasonal patterns were reversed during April and June when the value was higher at SH.

Generally, the data (Appendix -6) suggested that in most of sampling months males are more abundant than females in the lake, especially during February to April, 2005. The

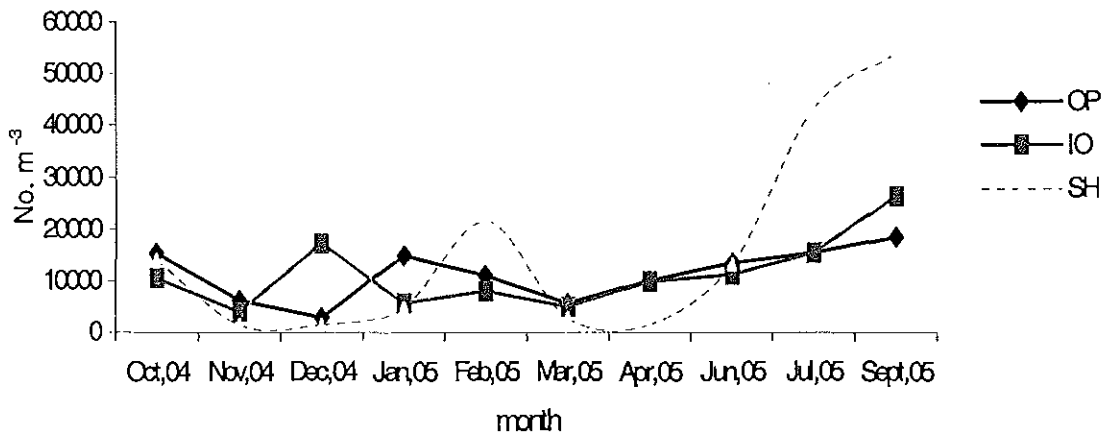
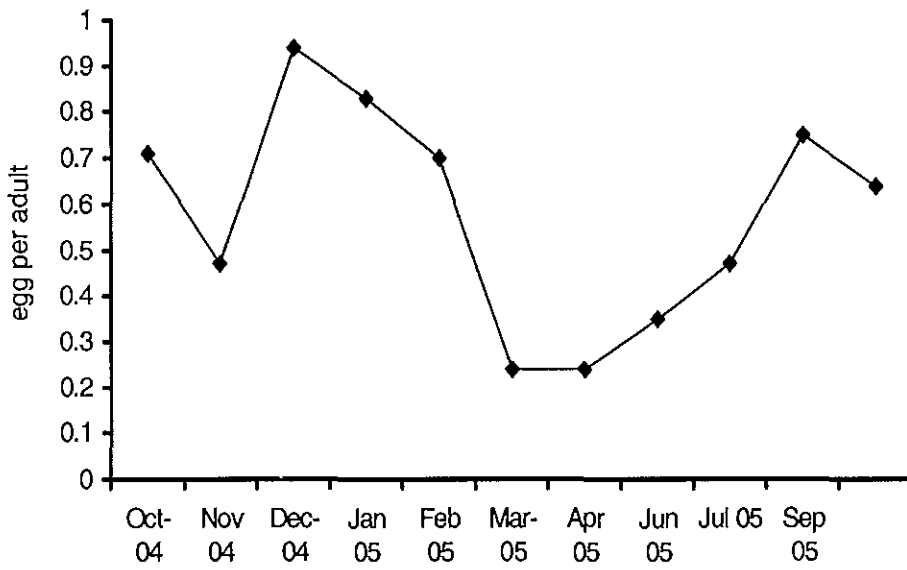


Fig. 17. Seasonal variation in cyclopoid mean egg ratio (a) and egg stock (b) at the three stations in Lake Beseka during the sampling period.

Cladocera

The cladoceran community in Lake Beseka is dominated by the genus *Moina*. Cladoceran abundance in the lake is low (maximum, 20443 ind. m⁻³) compared with other tropical lakes including those in Ethiopia. Much higher values have been reported from other African lakes, such as 19- 150,000 m⁻³ in Lake Chad (Carmouze *et al.*, 1983,) and 5- 70,000 m⁻³ in Lake Navasha (Mavuti and Litterick, 1981). However, the abundance is comparable with some Ethiopian lakes, Awassa (18,000 m⁻³, Seyoum Mengestou, 1989); Langano and Abiata (20 - 24 x 10³ m⁻³; Kasshun Wodajo and Amha Belay, 1984).

Cladocerans exhibited a significant seasonality (ANOVA, P<0.05) in their abundance. The number of cladocerans in the lake showed irregular fluctuations patterns in the dry season. This pattern; however, was changed during the wet period when the number increased drastically at all sampling stations. In January and February the number of cladocerans was high possibility localized favorable conditions.

The increased cladoceran abundance in lake Beseka during the wet period might be associated with allochthonous organic matter input that are favoring the growth of some phytoplankton into the lake. Consequently, phytoplankton species in the lake may be shifted, which are edible by filter-feeder cladocerans. Kasshun Wodajo and Amha Belay (1984) and Seyoum Mengestou (1989) found wet period peak of cladoceran populations in Lakes Abjata and Langano, and Awassa, respectively. This peak occurred after inflows of catchment flood that bring particulate organic matter to the lakes. Particulate organic matter serves as a medium for the growth of bacteriophytes that are a good source of food for cladocerans. Likewise, in this study the cladoceran population density has positive correlation ($r= 0.661$ $P= 0.043$) with phytoplankton biomass, which suggests that abundance is pronouncedly determined by the status of food in the lake.

Results of Pearson correlation also demonstrated that physical and chemical parameters are correlated with cladoceran numbers. The abundance of cladocerans showed negative correlation with turbidity ($r=-0.62$, $P=0.421$) and temperature ($r = 0.123$, $P= 0.034$). A similar result of negative correlation of turbidity and temperature on cladocera was observed in Lake Tana (Eshete Dejene *et al.*, 2004). Beaver and Havens (1996) noted that cladocerans displayed lowest densities during mid summer and attributed this to a deleterious effect of high temperature on some cladocerans, especially *Daphnia*, in temperate lakes.

In this study, cladocerans abundance showed no variations among sampling sites (See ANOVA, $P> 0.05$). Generally, Results from this study indicated that the main reasons for the higher density of cladocerans in wet period at the all stations are not only related to availability of food but also environmental factors such as temperature.

Table 10 Analysis of variance: cladoceran abundance between sampling stations and months

<u>Between sampling sites</u>					
Source	DF	SS	MS	F	P
Factor	2	54762657	27381328	0.79	0.462
Error	27	931579970	34502962		
Total	29	986342627			

<u>Between sampling months</u>					
Source	DF	SS	MS	F	P
Factor	9	587961642	65329071	3.62	0.008
Error	20	360656385	18032819		
Total	29	948618027			

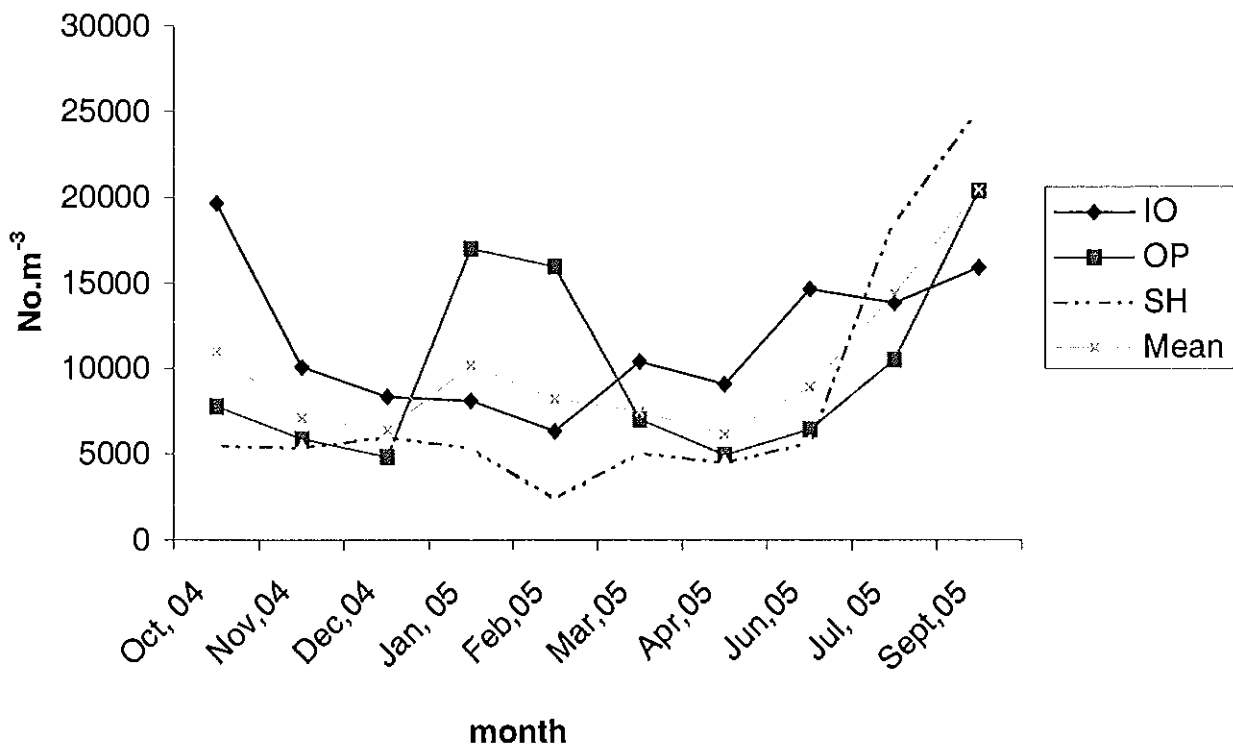


Fig.18. Seasonal variation in abundance of cladocera at three sampling sites during the study period in Lake Beseka.

Rotifera

Rotifers were the second numerically important zooplankton in Lake Beseka. The maximum mean value of rotifer density in Lake Beseka was $40,000\text{m}^{-3}$. This is low compared to values reported for some Ethiopian lakes earlier (e.g. Lake Awassa, $3.15 \times 10^5/\text{m}^3$. Taylor and Zinabu Gebremariam, 1989), but comparable to the same lake reported by Seyoum Mengestou in 1989 ($50,000/\text{m}^3$)

Brachionus was the most common genus encountered during the study period in Lake Beseka. The same was observed in many tropical lakes. According to Fernando (1980), *Brachionus* typically constitutes more than 50% of the total rotifer assemblage, numerically, in tropical lakes. This is because it has a wide range of tolerance to alkalinity and salinity; which is probably the same reason for its dominance in Lake Beseka (Hutchinson, 1967).

The abundance pattern of rotifers is almost similar to that of cladocerans (Fig. 19); it showed irregular fluctuations during the dry period, with maximal wet season, and lower in the dry season. This result is in line with the findings of Kassahun Wodajo and Amha Belay (1984) for Ethiopian lakes Abiata and Langano. These authors found that the number of rotifers fluctuated irregularly without any marked pattern during the dry period. Irregular variation during this period is probably because rotifers have very short of life spans and are opportunistic in their reactions to any change in environmental conditions. In the present study, rotifer populations were predominantly controlled by shifts in food resources that occurred as changes in transparency and chemistry affected the phytoplankton community.

When food becomes scarce in dry period, predation pressure of cyclopoid and fish is highly enhanced in the lake. This could be one of the reasons for the modest number of rotifer during the dry period. *Brachionus* is an important component of the diet of the copepodite stage of *Mesocyclops* (Fernando, 1994) and *Oreochromis niloticus* (Semeneh Belay, 1988)

Higher nutrient and chl. a concentration values were recorded in the wet period. This is likely due to the addition of organic matter from the catchment area. The maximum values in the rainy season coincided with the increase in Chl. a biomass.

As other zooplankton taxa the abundance of rotifers was not varied significantly between the three sampling stations (Table 11). But very less monthly fluctuations of rotifer densities were observed in SH and IO, this is may be these stations were highly exposed to environmental and human impacts such as the water pumping activity and washing vehicles and clothes. These activities could change the physical and chemical conditions of the area. Consequently, the dynamics of rotifer abundance could be high.

Table 11 Analysis of variance: rotifers abundance between sampling stations and months

<u>Between sampling sites</u>					
Source	DF	SS	MS	F	P
Factor	2	66331513	33165756	0.56	0.580
Error	27	1608532992	59575296		
Total	29	1674864505			

<u>Between sampling months</u>					
Source	DF	SS	MS	F	P
Factor	9	1143743872	127082652	4.77	0.002
Error	20	532793447	26639672		
Total	29	1676537319			

GENERAL DISCUSSION

Generally, Lake Beseka has less productive character as the measured phytoplankton biomass and production rates seem to suggest. This observation is also strengthened by observation of limited zooplankton numbers and species composition in the lake.

The primary production of Lake Beseka is very low as compared with other saline African and Ethiopian lakes. As other shallow tropical lakes, this situation may be related to different physico-chemical factors. Resuspension of sediments and turbidity could be one of the reasons. In the tropical lakes, Kichirititch, Kenya (Haken *et al.*, 2003) and Langano (Kasshun Wodajo and Amha Belay, 1984), large increase of turbidity coincide with severe reduction in phytoplankton production and presumably zooplankton abundance. This is because of shading of phytoplankton cells by suspended inorganic materials. Another possible reason for low primary production could be high dissolved carbon in the lake. Dissolved organic carbon (DOC) tends to be high in saline lakes (Evan *et al.*, 1996). High DOC may limit phosphorous bioavailability and result in reduced primary productivity rates. According to Bedelu Abera (2005), the DOC content in Lake Beseka is very high.

The total zooplankton standing stock at the three stations was 765,452 m⁻³ (OP), 761,213 m⁻³ (IO) and 637,619 m⁻³ at the SH, respectively. *Mesocyclops* and *Thermocyclops* contributed more than 99% of the (copepoda. *Harpacticoid*, was found in the lake in insignificant numbers; only in two months (November and December 2004). The most common Cladocera was *Moina sp.* Among the rotifers *Branchionus pliciatilus* was the common species. Only *Harpacticoids* is a new finding for Lake Beseka, as it has not been reported so far for the lake.

In the present study, like other individual zooplankton groups, the total zooplankton densities had significant variation (ANOVA, P<0.05). The major increase of total zooplankton coincided with the wet season and declined numbers during the dry season. The abundance pattern of the total zooplankton computed as individuals per M⁻³ increased regularly from November to March and decreased in June followed by sudden increases in September. The peak numbers in September are about 142099 m⁻³ at IO,

and 100846 m^{-3} and 204250 m^{-3} at the SH of the lake. The September peak was followed by a sudden decline in October, which kept declining to February 2005. A sharp rise in density of zooplankton coincides with the rise of lake water during the wet season. Similar results were reported by Twombly and Lewis (1987) and Semenh Belay (1988), from Langunala Orsinera, a Venzeuala flood plain lake and Lake Ziway, respectively. The wet season peaks is probably associated with massive inflows that raise the water level and increase food supplies directly by introducing allochthonous organic matter and indirectly by increasing the concentration of inorganic nutrients that are washed out from the catchment area. Nutrient enrichment associated with the seasonal rainfall patterns is a key factor regulating temporal variations in standing stocks of phytoplankton and zooplankton in the tropics. The same account was given by Infante (1982); she found massive increase of crustacean population during the rainy season in Lake Valencia, Venezuela. Rainfall appeared important in determining variation in composition of zooplankton in Lake Beseka. It had direct effect on zooplankton density and phytoplankton biomass. The correlation between rainfall and zooplankton density ($r=0.643$, $P=0.231$) suggests that rainfall is one of climatic factors regulating zooplankton dynamics in Lake Beseka.

In the present study, zooplankton density had significant variation with phytoplankton production; therefore, the results indicated that the total zooplankton dynamics in the lake is also regulated by phytoplankton biomass and primary production. However, other combined factors may also play a role (Fig 20). Similar results have been reported for some Kenyan lakes (Haken *et al.*, 2003). Zooplankton density fluctuations in these lakes were closely related to the combined effect of annual rainfall pattern, nutrient inputs from catchment and primary production in the lakes.

The seasonal amplitude (ratio between maxima and minima) was higher in SH than OP and IO stations (Fig.11). This could be probably associated with availability and quality and quantity of food because at the shore (SH), the concentration of nutrients and phytoplankton biomass fluctuated more than those at the two stations. Similar result was observed in Lake Ziway (Getachew Beneberu, 2005). This pattern suggests that the total zooplankton abundance in Lake Beseka was, at least in part, regulated by seasonality of

the food conditions. Generally, in the present study, I could not document highly significant influences of other chemical parameters on zooplankton dynamics in the lake.

Table 12 Analysis of variance: total zooplankton abundance between sampling months

<u>Between sampling months</u>					
Source	DF	SS	MS	F	P
Factor	9	30871617256	3430179695	4.46	0.003
Error	20	15370964338	768548217		
Total	29	46242581594			

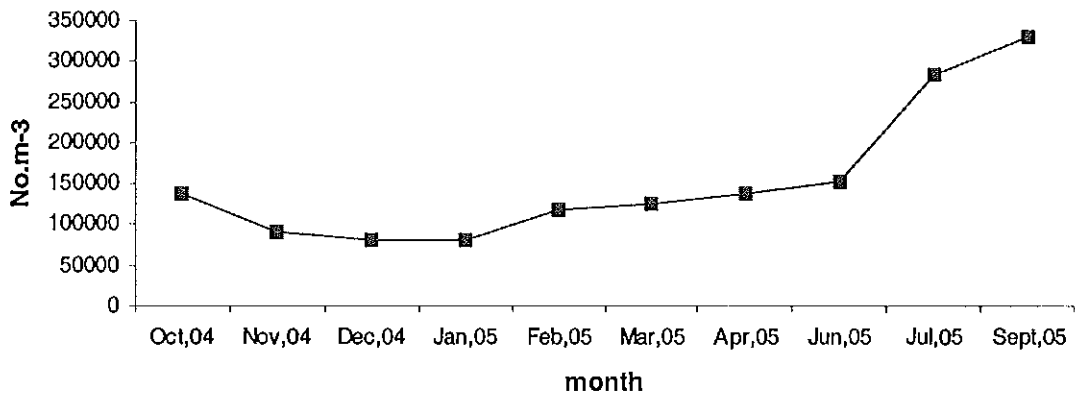
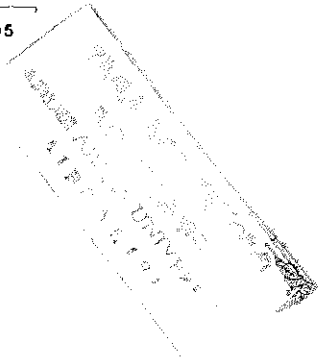
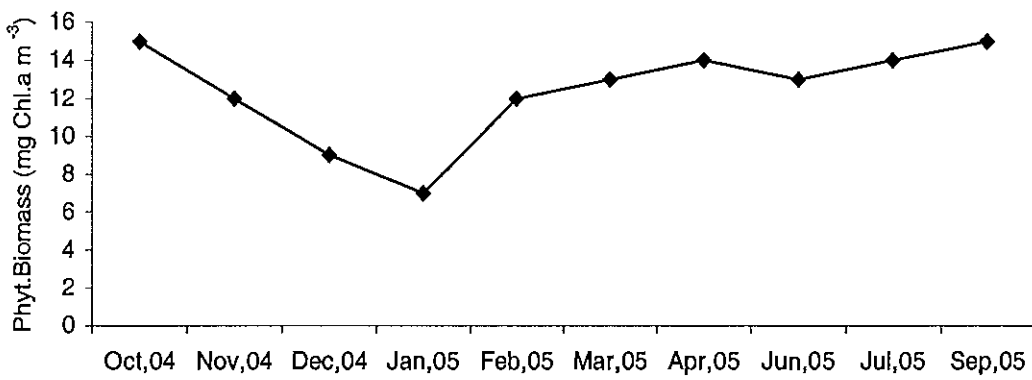
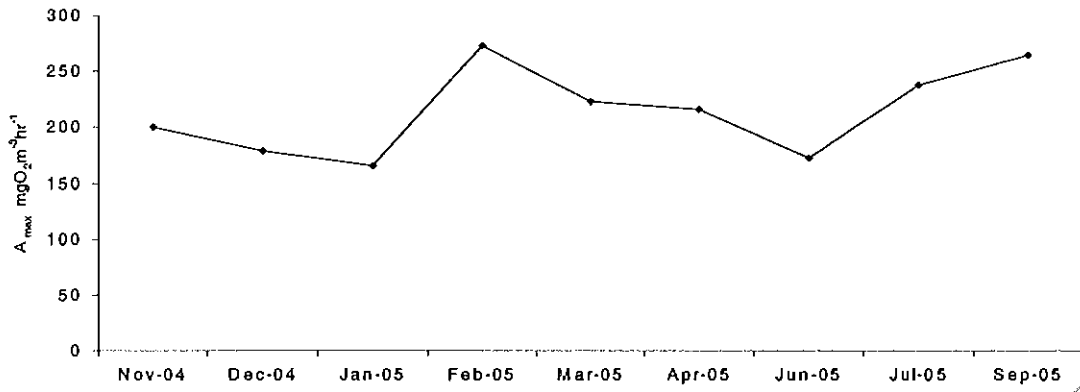


Fig.20. Seasonal variation of maximum primary production, phytoplankton biomass and mean of total zooplankton during the study period in Lake Beseka

CONCLUSIONS

- Zooplankton abundance in Lake Beseka varies significantly with phytoplankton biomass and nutrient concentrations. But, there is no variation between sampling sites. Rainfall pattern was also a key factor regulating seasonal variation in zooplankton numbers. Their highest densities were recorded in the rainy season and lower numbers were recorded in the dry period.
- Cyclopoid copepods accounted for most of zooplankton abundance in the lake. Their maximum abundance was during the wet period and least during the dry period. Much of the cyclopoid population density was contributed by the copepodite and naupliar stages.
- The number of cyclopoid copepod eggs showed almost the same temporal pattern as the parental ones.
- With three genera recorded, cladocerans were the least abundant of the zooplankton taxa in the lake. The maximum abundance of cladocerans was found during the wet period. Among the three genera, *Moina* dominated the cladocera population in Lake Beseka. Data from this study indicated that cladoceran population is strongly correlated with turbidity that negatively affected the cladoceran population
- Rotifera followed the cyclopids in terms of abundance. It was represented only by two genera and dominated by *Brachionus sp.*

- ✓ Studies on the population dynamics and production of zooplankton are useful because the quantification of zooplankton production helps in the understanding of fish production.

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APPENDICES



Appendix 1. Secchi depth (Z_{SD}), euphotic depth (Z_{eu}) and turbidity results of the three stations of Lake Beseka.

Month	Secchi depth (Z_{SD})			Euphotic depth (m)			Turbidity (NTU)		Temp. ($^{\circ}C$)	
	OP	IO	SH	OP	IO	SH	OP	SH	OP	SH
Oct-04	0.53	0.53	0.5	1.59	1.59	1.5	42	45	25	25
Nov-04	0.63	0.63	0.42	1.89	1.89	1.41	33	56	25.6	26
Dec-04	0.55	0.55	0.42	1.65	1.65	1.26	27	38	31	30
Jan-05	0.56	0.56	0.42	1.68	1.68	1.26	40	55	27	28
Feb-05	0.44	0.45	0.5	1.32	1.35	1.5	55	74	26	26
Mar-05	0.44	0.45	0.5	1.59	1.59	1.29	40	56	25	26
Apr-05	0.43	0.43	0.42	1.29	1.29	1.26	57	88	28	27
Jun-05	0.47	0.47	0.44	1.41	1.41	1.32	48	72	27	27
Jul-05	0.63	0.60	0.55	1.89	1.89	1.65	45	60	24	25
Sept-05	0.47	0.45	0.43	1.41	1.35	1.29	50	54	25	25.6

Appendix 2. Conductivity K25 ($\mu\text{S cm}^{-1}$) and pH at OP, IO and SH stations and results at OP and SH stations of Lake Beska

Month	Electrical conductivity (μScm^{-1})			pH		
	OP	IO	SH	OP	IO	SH
Oct-04	6828	6644	6785	9.2	9.1	9.2
Nov-04	7227	7325	6896	9.21	9.31	9.2
Dec-04	-	-	-	9.31	9.3	9.42
Jan-05	7346	7330	7145	9.42	9.31	9.42
Feb-05	-	-	-	9.5	9.51	9.5
Mar-05	7340	7328	7378	9.45	9.4	9.4
Apr-05	6440	6390	6332	9.31	9.25	9.4
Jun-05	7242	7040	7341	9.2	9.21	9.4
Jul-05	6440	7210	7330	9.35	9.4	9.34
Sept-05	7128	7341	7438	9.43	9.25	9.5

Month	Phenolphthalein alkalinity (Meq/l)		Total alkalinity (Meq/l)	
	OP	SH	OP	SH
Oct-04	1405	13.7	37	36
Nov-04	16	14	41	40.5
Dec-04	15	12.5	38.7	36
Jan-05	16	18.3	39	42
Feb-05	14	12.7	35	36
Mar-05	13.8	11	34	35
Apr-05	13.7	16.4	36	37
Jun-05	13.4	12.6	35	36
Jul-05	13.3	13.2	35	36
Sept-05	13	14	37	39

Appendix 3. Biomass of phytoplankton (mg Chl a m^{-3}) at the three stations

Month	Open	Inshore	Shore	Monthly Average
Oct.	15	17	16	16
Nov.	12	14	13	13
Dec.	9	11	12	10.7
Jan.	7	9	11	9
Feb.	12	12	13	12.3
March	13	14	16	13.6
April	14	12	14	12.3
May	-	-	-	-
June	13	13	15	13.6
July	14	16	17	15.7
August	-	-	-	-
September	15	12	14	13.6
Seasonal Average	12.4	11.7	14	

Appendix 7. Average zooplankton abundance (No./ M³) for shore site (SH) sampled over 10 months in Lake Beseka (Oct,04 – Sept,05).

Month >	Copepoda (male)		Copepoda (female)		Copepodite Stages		Nauplii		Cyclopoid eggs		Cladocera (total)		Rotifers (total)		Total Zooplankton	
	No./m ³	%	No./m ³	%	No./m ³	%	No./m ³	%	No./m ³	%	No./m ³	%	No./m ³	%	No./m ³	%
QY.>																
Oct, 04	9629	6.3	8759	11.8	16669	11.5	8245	6.6	14094	7	5473	6.5	24463	14	62332	9.6
Nov,04	7331	4.8	2514	3.4	4173	23	3564	2.9	1487	4.2	5360	6.4	16897	10	41326	5.2
Dec,04	6324	4.1	2779	3.7	7740	5.4	2744	2.2	1492	8.4	5952	7.1	7739	4.6	34770	6.1
Jan, 05	5492	3.6	2033	2.7	6893	4.8	5667	4.5	4800	2.7	5344	6.4	6000	3.5	36229	4.1
Feb,05	15023	9.9	10177	13.7	15023	10.4	4166	3.3	21538	12.1	2400	2.9	4500	2.7	72827	6.8
Mar,05	10597	7	4371	5.9	9400	6.5	9000	7.2	2790	1.6	5030	6.0	10584	6.3	51772	6.4
Apr,05	12443	8.2	5749	7.7	5938	4.1	15597	12.5	1555	1	4487	5.4	18939	11	64708	8.3
Jun,05	14567	9.6	11345	15.2	6574	4.6	3452	2.8	13243	7.5	5643	6.8	14532	8.5	69356	7.4
Jul, 05	31463	20.7	10244	13.8	31951	22.1	27683	22.2	43170	24.3	18654	22	26219	16	189384	19
Sept,05	39328	25.8	16390	22	39939	27.7	44292	35.6	53962	30.4	24972	30	39329	23	204250	2608
Average	15220		7436		14430		12441		17756		83315		16920		76121	