TEMPORAL DYNAMICS OF BIOMASS AND PRIMARY PRODUCTION OF PHYTOPLANKTON IN RELATION TO SOME PHSICO-CHEMICAL FACTORS IN LAKE KORIFTU, ETHIOPIA.

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By

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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 acknowledge.

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ABSTRACT

Biomass and Photosynthetic productivity of phytoplankton in relation to the physical and chemical conditions of the water column in Lake Kuriftu were studied from August, 2005 to April 2006. All the physical, chemical and biological parameters measured varied spatially and temporally. The Lake's transparency (Z_{SD}) was always less than 0.6 m with smaller values coincident with periods of rainfall and negatively correlated (r=-0.36) with phytoplankton biomass. The chemistry of the lake was basically similar to the dilute East African lake waters, with maximum pH and total alkalinity values of 8.8 and 3.1 meq/l respectively. The inorganic nutrients, which were of moderately high levels varied temporally as a function of hydrological, hydrographic and biological conditions of the lake. The phytoplankton community which was consistently dominated by cyanobacteria exhibited low species diversity. 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. The light-saturated rate of photosynthesis (A_{max}), which was positively and strongly correlated with phytoplankton biomass, ranged from 571 to 1136 mg O_2 m^{-3} h^{-1}. Biomass-specific rate of photosynthetic productivity at light saturation (P_{max}) ranged from 18.78 to 33 mg O_2 (mg Chl a)$^{-1}h^{-}1$, while the hourly integral photosynthetic production ($\sum A$) which was positively and strongly correlated with biomass and $_{Amax}$, varied between 0.686 and 1.05 g O_2 m^{-2} h^{-1}. The factors responsible for the observed spatio-temporal variations in the physical,chemical and biological features of the lake are discussed.

1. INTRODUCTION

The availability and sustainable use of natural resources determines the food security situation of a country. In a world of ever increasing human population where food production is not meeting demands, study of productivity at all levels of the food chain becomes essential. In order to meet the growing food requirements of the world population great effort is necessary in the development and utilization of the biological wealth of the aquatic environment. It is from this point of view that the study of aquatic productivity at the beginning of food chain becomes a logical starting point.

Research on aquatic, as on terrestrial ecosystems, is increasing in intensity. Aquatic ecosystems have received attention as actual and potential sources of food. The exploitation of aquatic resources for human food involves a wide range of studies. The functioning of the phytoplankton community is also of both practical and theoretical interest. Comparative studies of several sets of variables (Henderson *et al*., 1973; Oglesby, 1974 Melack, 1976b) suggested that the potential fish yield of an aquatic ecosystem might be related to several simple indicators of productivity.

Melack (1976b) and Oglesby (1977) have, however, concluded that primary productivity is, theoretically and empirically, a better predictor of fish yield in lakes than other suggested variables. Both authors provided linear regression equations relating fish yield and primary productivity. Other methods of relating fish yield to nutrient concentration and primary productivity (Henderson *et al*., 1973; Ryder, 1974) reinforced the concept of the dependence of potential fish yield on lake's primary productivity.

The study of energy transfer in lakes and reservoirs is based on the measurement of primary productivity of phytoplankton and the environmental variables, which limit or control this productivity. Primary productivity of aquatic ecosystems is basically dependent upon the photosynthetic activity of autotrophic organisms (Wetzel and Likens, 1979). For this reason, the measurement of primary productivity of natural waters is based upon the measurement of photosynthetic activities (Fogg, 1980), which are primarily due to algae but also possibly due to photosynthetic bacteria (Fogg, 1980).

Phytoplanktons are the major primary producers in many aquatic systems and are an important food for consumers (Reynolds, 1984). Through the process of photosynthesis these microscopic plants nourish the entire food web of the oceans. The life of all animals that live in the sea and fresh water depends on phytoplankton for energy, carbon and minerals. The global carbon cycle, which regulates the temperature of our planet, and the life-sustaining oxygen, which is essential to the metabolism of all aerobic organisms, are controlled by the photosynthetic activity of the phytoplankton.

Tropical lakes, particularly those in Africa are known for their high primary productivity of phytoplankton. The studies on phytoplankton photosynthesis in tropical Africa, particularly in the soda lakes of East Africa, have come up with reports of exceptionally high photosynthetic activity. Melack and Kilham (1974) suggested that in lakes not enriched by human activities, gross photosynthetic rates of 30 g O_2 m^{-2} d^{-1} (ca. 11 g C m^{-2} d^{-1}) or greater are seldom encountered. However, these authors have reported gross photosynthesis as high as 36 g O_2 m^{-2} d^{-1} (ca. 13 g C m^{-2} d^{-1}) for Lake Nakuru, in Kenya, by the diurnal free-water technique. More recently, Melack (1979a, 1981) reported similar values for the phytoplankton of Lake Simbi (Kenya). Exceptionally high algal photosynthetic rate in the order of 43-57 g O_2 m^{-2} d^{-1} (Ca. 16-21 g C m^{-2} d^{-1}), has also been reported by Talling *et al*., (1973) for Lake Arenguade, an Ethiopian soda lake whose phytoplankton community was dominated by *Spirulina platensis*. These authors attributed the high photosynthetic rates of this blue-green alga to a combination of high chlorophyll a content of the euphotic zone ($\sum$ B) and high photosynthetic capacity (P_{max}). The tropical situation of high temperature and irradiance, high phosphate concentration, and especially the considerable reserves of carbon dioxide in these soda lakes might have also favored the observed high photosynthetic productivity

The shallow well-mixed freshwater lakes of equatorial Africa, such as Lake Chilawa, Zambia, (Z = 3m, Howard-William and Henton, 1975), Lake Naivasha, Kenya, (Z = 4m, Gaudet, 1977), and Lake George, Uganda, (Z = 2.5m, Ganf and Viner, 1973) are also known for their high productivity. These lakes contain extensive areas of littoral zone and

a large portion of the rainy season results in increased offshore levels of nutrients with a subsequent increase in primary productivity (Gaudet and Muthuri, 1981a; Howard-William and Lenton, 1975).

Primary productivity and biomass of phytoplankton are affected by an array of chemical, physical, and biological factors. There is no doubt that in general the more frequently a lake is stirred by winds to the bottom, the faster the nutrients are recycled from the mud into the photosynthetic zone where they may accelerate the rate of productivity (Talling and Lemoalle, 1998). The depth of the water is thus, in principle, negatively correlated with the rate of productivity (Cole, 1983). Lake Shalla in Ethiopia has gross chemistry, which is remarkably similar to that of one of the productive lakes in the Ethiopian Rift Valley –Lake Abjata, but it is the least productive, which is due to its great depth (Amha Belay and Wood, 1984).

Critical observations made by different authors, particularly on shallow tropical lakes, have pointed out the important determinants of algal biomass and photosynthetic activity. Vincent *et al*., (1986) singled out that flood related changes in nutrient supply and abiotic turbidity are the over-riding factors in shallow well-mixed lakes such as Lake Chilwa. Moss and Moss (1969) also believed that these marked hydraulic forces result in a strong seasonal fluctuation of algal biomass and abrupt inter-annual differences in productivity.

Vincent *et al*., (1986) emphasized that the muted seasonal variation of light and temperature in tropical lakes often explains only a small portion of the variation in primary productivity compared to that in temperate counterparts. It is rather, temporal variability in rainfall and wind, which appear to be the most probable cause of variation in algal biomass and photosynthetic activities of tropical lakes (Talling, 1966, Lewis, 1974; 1979b; Pollingher, 1986; Talling and Lemoalle, 1998). Winds generate high turbulence, which culminates in mixing; as a consequence recirculation of nutrients and resuspension of algae occur. Rains increase the volume of inflows and the supply of nutrients and inorganic turbidity, all of which influence primary productivity.

The dynamics of phytoplankton standing stock and productivity in African lakes was reported to vary intimately with the fluctuation in water level (Lemoalle, 1975, Melack 1976a). Melack (1976a) found positive correlation between level of primary productivity and changes in water level. He showed that offshore primary productivity generally increased with increased rainfall and river discharges. Lemoalle (1975), however, found an inverse relationship between lake water level and algal productivity during his work on the polymictic lake, Lake Chad. This relationship may exist because in the shallower water column wind-induced mixing more effectively circulates nutrients.

Solar radiation is of fundamental importance to the entire dynamics of an aquatic ecosystem (Kirk, 1994). Nearly all the energy that controls the metabolism of lakes comes directly from solar energy (Wetzel, 1983). Light intensity has received the most extensive attention of all the physical factors controlling aquatic primary productivity (Stengel and Soeder, 1975) and it can directly influence the physiology and species composition of phytoplankton (Huntly, 1982). Solar radiation has critical role, both as a source of energy for photosynthesis and as a more indirect determinant of water temperature, thermal stratification and associated chemical variations in inland water bodies (Talling, 1965).

Blooms of blue-green algae are favored by the high temperature of the warmer months of the year (Huntley, 1982). In addition to light energy, phytoplanktons are dependent upon adequate supply of nutrients (Fogg, 1975). In order to better understand factors controlling productivity in aquatic ecosystems, it is useful to study nutrient limitation in geographically diverse areas, where the geology of the watersheds and the atmospheric depositions differ substantially (Hecky and Kilham, 1988).

Algal cells require elements in relatively fixed proportions in order to reproduce (Hecky and Kilham, 1988). The various nutrients required by algal cells for growth and multiplication may not always be found in relative proportions required by phytoplankton (Hecky and Kilham, 1988). Phosphorous and nitrogen in all groups and silicon in diatoms are regarded as growth –limiting nutrients. It is known that increasing incidences of

harmful algal blooms (HABs) in marine coastal waters and fresh waters are related to changes in nutrient loading, particularly of nitrogen and phosphorus, from human activities (Smayda, 1990).

In an attempt to review factors related to temporal variability, Talling (1986) has generalized phytoplankton seasonality in the tropical belt of Africa. He suggested that seasonality in algal biomass and productivity is usually dominated either by hydrological factors (water input-output) or hydrographic factors (water column structure and circulation).

Although there has been increasing attention, particularly in recent years, to the seasonal course of limnological events in Ethiopia (Prosser *et al*., 1968; Wood *et al*., 1976; Kassahun Wodajo, 1982; Demeke kifle, 1985; Tilahun Kibret, 1985; Elizabeth Kebede, 1987;Girma Tilahun, 1988), the research works published so far on physical, chemical and biological features of Ethiopian lakes need revisits, synthesis and comparison in a wider context.

Compared to many other countries in the world, Ethiopia is endowed with a large number of standing water bodies, whose sustainable use can contribute to the economy of the country. The lakes are critical to the survival of local communities as they are the actual and potential sources of food and income. Furthermore, their range of variations in morphometry, physical and chemical features offers opportunities for superb comparative limnological studies.Despite their importance, the limnology of some of the Ethiopian lakes is unexplored. Lake Kuriftu is one such lake, which has not received attention in spite of its potential economic importance.

A large number of studies have been made on the community structure and primary productivity of phytoplankton in various East African lakes (Talling and Lemoalle, 1998). However, very little has been done on this aspect in Ethiopian lakes. Wood and Talling (1988) have compiled the sporadic information on the dominant and most common species of planktonic algae reported in various limnological papers. The

systematic studies conducted on phytoplankton of Ethiopian lakes are few and include those of Tsegaye Mihrete-Ab (1988), Elizabeth Kebede and Amha Belay (1994) and Elizabeth Kebede and Willen (1998).

Although primary productivity of phytoplankton in Ethiopian lakes is one of the well-studied aspects, only few studies were conducted on long-term basis. The long term investigations on primary productivity of phytoplankton include those of Talling *et al.*, (1973) in Lakes Kilole and Arenguade, Amha Belay and Wood (1984) in five Ethiopian Rift Valley Lakes, Demeke Kifle (1985) and Demeke Kifle and Amha Belay (1990) in Lake Awassa, Girma Tilahun (1988) in Lake Ziway, Eyasu Shumbulo (2004) in Lake Chamo and Girma Tilahun (2006) in Lakes Awassa, Chamo and Ziway. Published information on the photosynthetic primary productivity, algal biomass and species composition of phytoplankton in Lake Kuriftu is, however, not well studied.

In order to obtain adequate understanding of the temporal dynamics of the lake biology and the underlying environmental variables, one needs to study the changes in species composition, relative abundance, primary productivity and biomass of phytoplankton in relation to some physico –chemical factors.

The purpose of this research study was, therefore to study the temporal dynamics of photosynthetic productivity of phytoplankton in relation to some physico-chemical factors in Lake Kuriftu.

2. OBJECTIVES

2.1. General Objective

-To investigate the temporal and spatial dynamics of phytoplankton in relation to some physico-chemical factors in Lake Kuriftu.

2.2. Specific Objectives

_To assess the physical and chemical water quality of the lake over the study period .

_To investigate the species composition of phytoplankton

_To estimate the biomass and photosynthetic productivity of phytoplankton

_To identify the environmental factors that bring about variations in phytoplankton productivity

_To recommend suitable management strategies for Lake Kuriftu

3. DESCRIPTION OF THE STUDY AREA

Lake Kuriftu (Fig.1) is one of the lakes found in and around the town of Bishoftu. It is 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) (Brook Lemma *et al*., 2001) lake formed by diverting and damming the tributary of the perennial Mojo River, Belbela River, for the irrigation practice in the area (Seifu Kebede *et al*., 2001). Some limnological features of the lake are given in Table 1.

The lake gains water primarily from the Belbela River, 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, varying around about 850mm per annum (Rippey and Wood, 1985), high incident solar radiation and low relative humidity. The region has two rainy periods, the minor one extending roughly from February to April and the major one beginning in June and ending in September (Rippey and Wood, 1985.)

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 include *Accacia abyssinica, Jacaranda mimosifolia* and species of *Eucalyptus* and *Juniperus*.Macrophytes including *Passifloraceae* and *Passiflora subpeltata ortega* are observed.

The zooplankton of Lake Kuriftu is composed primarily of rotifers, some cladocerans and a few copepods (Brook Lemma *et al*., 2001; Girum Tamire, 2006). The piscifauna of the Lake is constituted by tilapia (*Oreochromis niloticus. L)* and common carp (*Cyprinus*

carpio. L). Some birds (pelicans and ducks) are often seen on the lake (personal observation).

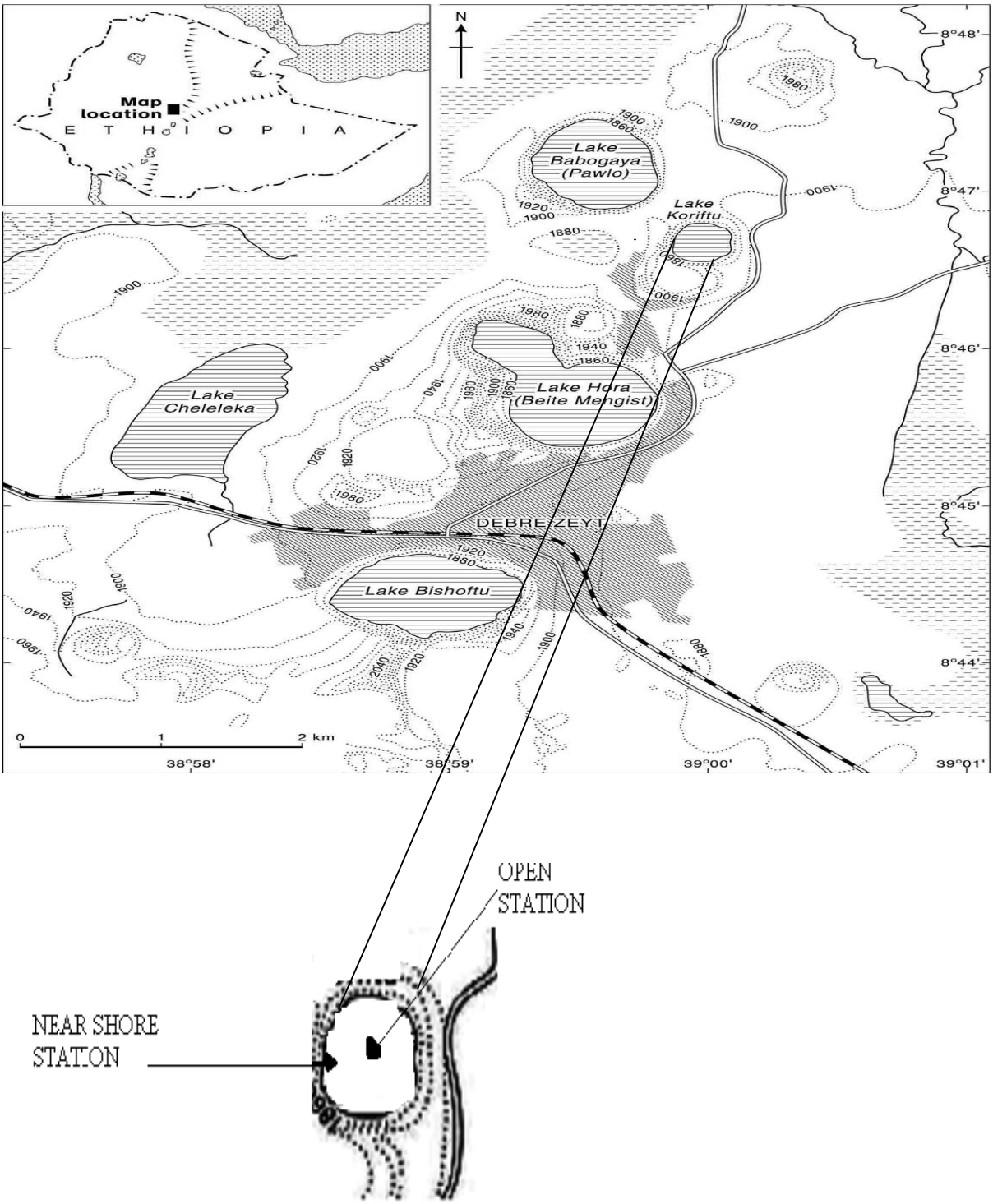

Fig.1 Map showing the relative location of Debre Zeit Lakes with the sampling stations in lake Kuriftu indicated. [source: Lamb (2001)].

Table 1. Some limnological features of Lake Kuriftu

Parameter	Value	Source
Altitude (m)	1860	Seifu Kebede *et al*., 2001)
Area (km^2)	0.4	Brook Lemma *et al.*, (2001)
Maximum depth (m)	6.0	»
Mean depth (m)	2.0	»
Volume (m^3)	3.0 X 10^6	»
Secchi depth (m)	0.15-0.20	»
pH	7.9-8.4	»
Conductivity, K_{25} (μ S cm^{-1})	319	Zinabu Geberemariam *et al*., (2002)
Alkalinity (meq l^{-1})	2.89	»
Salinity (gl^{-1}))	0.26	»
Cations ((meq l^{-1})	3.187	»
Na^+ (meq l^{-1})	1	»
K^+ (meq l^{-1})	0.154	»
Ca^{++} (meq l^{-1})	1.25	»
Mg^{++}(meq l^{-1})	0.783	»
Cl^- (meq l^{-1}))	0.571	»

METEOROLOGICAL DATA

The Meteorological data for the study lake area were obtained from National Meteorological Services Agency of Ethiopia. The temporal variations in mean monthly maximum and minimum air temperature and monthly rainfall of the study lake area during the study period are shown in Fig. 2.

The mean monthly minimum air temperature varied from 3.4 ^{o}C to 13.6 ^{o}C in the months of December and August, 2005 respectively, while the mean monthly maximum air temperature ranged from 24 ^{o}C to 29 ^{o}C in July, 2005 and February, 2006 respectively. The highest mean monthly maximum air temperature was recorded in February, 2006 coincident with a monthly rainfall of ~110 mm.

The monthly rainfall of the lake region varied from 2.9mm of November, 2005 to 186.7mm of August, 2005 with the rainy periods being broadly similar to those described in Rippey and Wood (1985) although there was unusually no rain in March, 2006. Wind also has impact on variation of nutrients directly, but due to there is no data it is impossible to describe it.

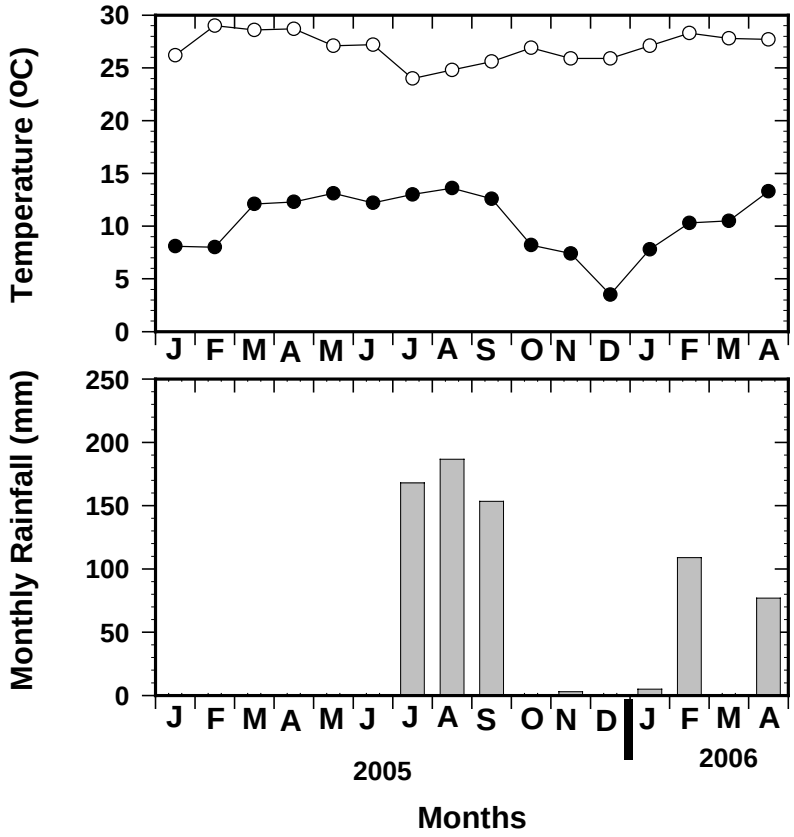

Fig. 2. Meteorological data of Lake Kuriftu: mean maximum (open circle) and minimum (closed circle) air temperature and mean monthly rainfall. (Source: Ethiopian Meteorologicla Service Agency)

4. MATERIALS AND METHODS

4.1. Sampling protocol

The sampling stations of the present study were selected from contrasting segments of Lake Kuriftu. Two sampling stations were selected: one from an area of high human impact (near-shore station) and another from a relatively less impacted area (central station). Water samples were collected at least once a month from the two stations with a bottle sampler (Ruttner). The water samples were collected from selected depths (0.00, 0.5, 1.0, 1.5, 2.0 m) distributed within the euphotic zone. Euphotic depth was approximated as "3 times Secchi depth" as this relationship has been found for some lakes and reservoirs (Talling and Lemoalle, 1998). The samples collected from different depths were mixed in equal proportions to produce composite samples and were used for chemical analyses and measurement of biomass as chlorophyll a concentration and photosynthetic productivity of phytoplankton.

4.2 Measurement of physico-chemical parameters in the field

Some physical and chemical parameters, which were believed to have a bearing on the species composition and productivity of phytoplankton, were measured *in situ*.

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* by a portable digital pH meter (Jenway 3200).
- Depth profiles of oxygen and temperature were determined with a digital oxygen meter (Hanna 9024)

Within a few hours of sample collection, carbonate-bicarbonate alkalinity was determined by titration with HCI to a pH of 4.5.

Photo-synthetically Active Radiation (PhAR) incident on a horizontal surface during the incubation period of primary production measurements was recorded with a cosine-corrected LI-COR quantum sensor (LI-190SB) connected to a LI-185B

integrator. The counts of this instrument were converted to E m^{-2} h^{-1} using appropriate factors (Wetzel and Likens, 2000; Kalff, 2002).

4.3. Analysis of inorganic nutrients

Water samples filtered through Glass Fiber filters (GF/C) were used for the analyses of Soluble Reactive Phosphate (PO_4-P), Silica (SiO_2) and Nitrate (NO_3-N). Nitrate-N was determined by the Zinc Reduction Procedure (Nelson *et al.,* 1954) while phosphate and silica were measured calorimetrically by the Ascorbic Acid and Molybdosilicate methods. (APHA *et al*., 1999) respectively.

4.4. Measurement of biological parameters

4.4.1. Species composition and abundance of phytoplankton

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 was made on the basis of the various taxonomic literatures available on phytoplankton (Whitford and Schumacher, 1973; Gasse, 1986; Hindak, 1992a,b; Komarek and Anagnostidis, 2005 and Jeji-Bai *et al*., 2002). 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).

4.4.2. Estimation of phytoplankton biomass

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. The concentration of Chlorophyll a was calculated according to Talling and

Driver (1963) using absorbance measurements made at 665 and 750 nm (See Appendix 5).

4.4.3. In situ measurement of primary productivity

Primary productivity was measured by the Light and Dark bottle Technique and the Winkler method of oxygen determination (Mackereth *et al*., 1978). Composite samples produced using water samples collected from selected depths distributed within the euphotic zone were used in the estimation of photosynthetic production. Water samples were siphoned into 250 ml Pyrex light (clear) and dark (covered with dark cloth tape) glass bottles under reduced light conditions. Duplicate light bottles were attached to a suspension line prepared for incubation purpose, at each of the established depths distributed within the euphotic zone (0.00, 0.25, 0.50, 1.00, 1.50 and 1.75m). The lower limit of the euphotic zone was approximated as 3 times the Secchi depth. 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 different directions thereby avoiding overlap of bottles of successive depths of exposure. Dark bottles were also incubated at 0.50m. The incubation period usually lasted for three hours around mid-day (between 10:00a.m. to 2:00 p.m.).

4.5. Statistical Analysis

The relationships between the different physico-chemical and biological parameters were tested statistically using Minitab ver.14 and the results are given in Appendix 6.

4.6. Description of symbols

Explanations of the symbols used throughout this thesis as described in Talling *et al*., (1973), Ganf and Horne (1975), Melack (1979), Robarts (1986) and Talling and Lemoalle (1998) are given below:

$\mathbf{Z_{sd}}$; Secchi depth, in m

$\mathbf{Z_{eu}}$; Depth of the euphotic zone, in m

$\mathbf{K_d}$; Mean vertical extinction coefficient of down-welling irradiance, in m^{-2}

B; Phytoplankton biomass, in mg Chl a m^{-3}

A; Rate of gross photosynthesis per unit water volume, in mg O_2 m^{-3} h^{-1}

A_{max}; Light –saturated rate of gross photosynthesis per unit volume of water, in mg O_2 m^{-3} h^{-1}

P_{max} ;(Amax/B) A specific rate of gross photosynthesis at light-saturation, in mg O_2 (mg Chl a)$^{-1}$ h^{-1}

∑**A**; Hourly rate of gross photosynthesis per unit area, in gO_2 m^{-2} h^{-1}

∑∑**A**; Daily rate of gross photosynthesis per unit area, in g O_2 m^{-2} d^{-1}

PAR; Photo-synthetically Available Radiation, in Em^{-2} h-1

5. RESULTS AND DISCUSSION

5.1 PHYSICO-CHEMICAL FEATURES

5.1.1 Physical Parameters

The physical characteristics of Lake Kuriftu during the study period are given in Table 2. Lake's transparency (vertical visibility) varied between 0.35m in April, 2006 of the minor rainy season and 0.6m in December, 2005 of the dry season at the open water station. The Secchi depths (Z_{SD}) of Lake Kuriftu recorded in this study are higher than those measured for the same lake in a previous study (0.15-0.20m; Brook Lemma *et al*., 2001) probably indicating improved vertical visibility (transparency) of the lake.

The high Secchi depth values of Lake Kuriftu are greater 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, 1994), Langano (25-35; Tudorancea et al., 1989) 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 2. Surface Water Temperatures(^{o}C), Secchi depths ($Z_{SD)}$, Mean vertical extinction coefficients ($K_{d,}$)and Euphotic depths(Z_{eu})of the central station in Lake Kuriftu.

Date	**Surface water temperature (^{o}C)**	**Z_{SD} (m)**	**K_d (units m)**	**Z_{eu} (m)**
8-08-05	29	0.51	2.82	1.63
27-08-05	31.5	0.55	2.62	1.75
8-10-05	31.1	0.53	2.72	1.69
15-10-05	31	0.50	2.88	1.59
29-10-05	28.5	0.55	2.62	1.75
19-11-05	26.4	0.55	2.62	1.75
15-12-05	33.3	0.6	2.4	1.92
9-01-06	22.8	0.51	2.82	1.63
5-02-06	ND	0.52	2.77	1.66
1-03-06	30.1	0.55	2.62	1.75
25-03-06	ND	0.58	2.48	1.85
26-04-06	24.2	0.35	4.11	1.12

ND----Not Determined

But, the lakes found in the region of the present study lake, Lakes Kilole ($Z_{SD=}$0.37-1.8m) (Brook Lemma, 1994) and Babogaya ($Z_{SD=}$1.48-4.46m, Yeshiemebet Major, 2006) have much higher transparency 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 extent of resuspension of inorganic particles resulting from wind-driven mixing, variation in phytoplankton biomass and external loading of particulate materials through runoff. The maximum and minimum values of Secchi depth were not directly related to the maximum and minimum value of phytoplankton biomass (See Table 2 and Table 4). The correlation between Secchi depth readings and phytoplankton biomass was negatively correlated (r= -0.36) probably indicating the greater importance of a biogenic turbidity to the underwater light climate of Lake Kuriftu.

Using Secchi depth as a tool one can evaluate the light climate of aquatic ecosystems and can compare the optical conditions of a lake at different times of the year. Vertical coefficients for total underwater light (mean vertical extinction coefficient, K_d) can be estimated from Secchi depths using the widely used equation, which was proposed by Holmes (1970) as a better estimator of the vertical extinction coefficient of total underwater light of turbid waters (See Table 2 for results). The values of $K_{d,}$ calculated according to Holmes (1970, see Appendix 5), ranged from a minimum of 2.4 to a maximum of 4.11 corresponding to euphotic depths (Z_{eu}), approximated as Z_{eu} = 4.6/ K_d

(Kalff, 2002), of 1.12 m and 1.91m. The calculation of euphotic depth using the equation given above assumes that light reduction conforms, approximately, to a single average vertical extiniction coefficient, K_d.

Euphotic depths (the depth at which 1% of the surface irradiance is detected) estimated using vertical extinction coefficients calculated from Secchi depths seem to indicate that the vertical extent of the euphotic zone was always shallower than 2m.

The surface water temperatures at the central station of Lake Kuriftu ranged from a minimum of 22.8 ^{o}C in February, 2006 to a maximum of 33.3 ^{o}C in January, 2006 with most values between 28 ^{o}C and 30 ^{o}C . The maximum surface water temperatures of Lake Kuriftu are closer to those of Lake Chamo (26-30 ^{0}C; Eyasu Shumbulo, 2004) in Ethiopia and Lake George, in Uganda (26-36 ^{0}C; Ganf and Horne (1975) than to those reported for 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).

Appendix 2 presents the vertical distribution of temperature. The vertical distribution of temperature in Lake Kuriftu shows the occurrence of small differences between successive depths of the water column down to 4 m. In this lake there seemed to be no

thermal stratification considering its shallow depth and exposure to wind action although the oxygen-temperature meter used did not allow the determination of temperature at depths deeper than 4 m. The thermal regime of Lake Kuriftu is probably comparable to the shallowest Crater Lake Kilole (Wood *et al*., 1969) and Lake Ziway (Girma Tilahun 1988) which are almost continually stirred to their bottoms.

Water column mixing in the Ethiopian Rift Valley lakes is frequent (Wood *et al*., 1978) for there has been no indication of strongly developed persistent thermal stratification. Studies on the thermal characterstics 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. 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 15-30 m and thermal stratification is largely diurnal, a water column condition documented for a large number of Ethiopian Rift Valley lakes (Elizabeth Kebede, 1994; 1996).

5.1.2. CHEMICAL FEATURES OF LAKE KURIFTU

5.1.2.1. The depth profiles of oxygen

Depth profiles of dissolved oxygen determined at the central station of Lake Kuriftu during the study period are shown in Appendix 2. All depth profiles showed oxygen maximum in the upper layer of the water column, with a minimum of 4 mg $O_2\ l^{-1}$ at the surface in March, 2006 and a maximum of 17.15 mg $O_2\ l^{-1}$ in December, 2005). Dissolved oxygen was usually lower at the surface of the lake compared to the depth of

0.25m. The observed lower oxygen concentration at the surface is attributable to the influence of temperature on the solubility of oxygen. It could also be the result of the effect of high light intensity on the photosynthetic generation of molecular oxygen as almost all depth profiles of photosynthesis determined in the present study exhibited depressed photosynthetic rates at the surface (Fig. 5).

Dissolved oxygen declined with increasing depth, which is 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. During the study period concentration of dissolved oxygen at the 4 m depth also showed temporal variations from a minimum of 2 mg O_2 l^{-1} (August, 2005) to a maximum of 7.6 mg O_2 l^{-1} (December, 2005).The oxygen concentration in the surface water of Lake Kuriftu was generally higher than 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).

Percentage saturation of dissolved oxygen at the surface also showed temporal variations, with values ranging from 55 to 305 % in January and March, 2006 respectively, with the maximum value coinciding with one of the peaks in phytoplankton biomass. The depth distribution of percentage saturation of dissolved oxygen often showed a pattern similar to that of absolute values of oxygen concentration.

Marked temporal and vertical variations in oxygen concentrations were observed over the study period. The fluctuations could be the result of the variations observed in phytoplankton photosynthetic activity, thermal regime and/or changes in the weather conditions of the lake area.

5.1.2.2. pH and alkalinity of Lake Kuriftu

Aggregate chemical parameters of Lake Kuriftu measured over the study period are given in Table 3. The pH of the surface water of Lake Kuriftu at the central station ranged from a minimum of 8.2 in August, 2005 to a maximum of 8.8 in November, 2005. The pH values recorded for this lake in the present study are slightly higher than those reported in an earlier investigation (7.9-8.4; Brook Lemma *et al.,* 2001). The pH values of Lake Kuriftu, which are comparable to those of Lake Awassa (Makin, *et al.*, 1975; Demeke Kifle, 1985) 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).

pH values, which are remarkably different from those observed for Lake Kuriftu were reported only from saline lakes, including Red Rock Tarn in Australia (Hammer, 1981), Mariut in Egypt (Aleem and Samaan, 1969) and Arenguade in Ethiopia (Talling *et al*., 1973), which have pH values between 9.0 and 10.5 that tend to remain at high levels owing to the high buffering capacity of the lake waters (Talling and Lemoalle, 1998).

The relationship between levels of phytoplankton biomass and A_{max} and pH was not apparent although a few of the high pH values were associated with relatively large algal biomass. High rates of primary productivity allow large daytime CO_2 and HCO^-_3 withdrawal leading to an increase in pH (Maberly, 1996). It is such biological removal of inorganic carbon which is responsible for the high pH levels observed in saline lakes of high alkalinity including the hype eurtrophic Lake Arenguade in Ethiopia (Talling, 1965; Talling *et al*., 1973; Talling and Lemoalle, 1998).

Table.3. Collective chemical features: pH, Total Alkalinity (TA) and Phenolphthalein Alkalinity (PA) and calculated free CO_2 of Lake Kuriftu

Sampling Date	pH	Total alkalinity (PA) (meq/l)	Free CO_2 (mg/l)
8-08-05	8.2	2.6(0.2)	0.576
27-08-05	8.7	3(0.8)	0.528
8-10-05	8.5	2.9(0.8)	0.504
15-10-05	8.6	2.5(0.2)	0.552
29-10-05	8.6	3(0.8)	0.528
19-11-05	ND	2.7(0.7)	0.480
15-12-05	8.8	3.1(0.9)	0.528
9-01-06	8.42	2.9(0.6)	0.552
5-02-06	8.72	3(0.8)	0.528
1-03-06	8.45	2.4(0.2)	0.528
25-03-06	ND	2.5(0.4)	0.504
26-04-06	8.3	2.3(0.2)	0 .504

ND-Not detected

The high positive correlation between pH and alkalinity reported for the combined data of Ethiopian lakes (Wood and Talling, 1988) and saline lakes worldwide (Hammer, 1986) was also observed for Lake Kuriftu (r = 0.814; see Appendix 6).

Carbonate-bicarbonate alkalinity (in meq l^{-1}) at the central station showed marked temporal fluctuations, varying from a low value of 2.3 meq/l (April, 2006) to a high value of 3.1 meq/l in December, 2005. The high alkalinity value was observed during the dry period, which was probably associated with evaporative concentration of dissolved ions of this period. 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).

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).

Variations in the amount of rainfall can bring about considerable differences in lake levels and concentration of dissolved chemicals either through input of more ions or dilution. The decline in the water level of this lake is obviously the result of recurrent dry

season and the use of the lake water for irrigation. 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.

The level of free carbon dioxide was calculated from pH-alkalinity relationship (Table 3 and Appendix 5) described in Lind (1979). The level of free carbon dioxide ranged from 0.480 in November, 2005 to 0.576 mg l^{-1} in August, 2005. The maximum value of free carbon dioxide coincided with the minimum value of photosynthetic activity and biomass while the minimum value was observed at the time when photosynthetic activity peaked, indicating greater photosynthetic removal of dissolved inorganic carbon. The calculated concentrations of free carbon dioxide in Lake Kuriftu are lower than most of the values reported for Legedadi Reservoir (0.26 -3.15; Adane Sirage, 2006).

The concentration of carbon dioxide in a water body is a chemical factor playing an important role in determining phytoplankton groups that may grow and flourish. Shapiro (1997) has shown that when blue-green algae dominate in lakes, carbon dioxide is taken much more efficiently than when the phytoplankton community is composed of non-blue greens. Thus, unusually low levels of carbon dioxide give a competitive advantage for blue-green algae over other algal groups owing to their physiological adaptation (Shapiro, 1997).

5.1.2.3. AMBIENT CONCENTRATION OF INORGANIC NUTRIENTS

The temporal variations in the concentration of inorganic nutrients in relation to phytoplankton biomass at the central and near-shore stations of Lake Kuriftu are shown in Fig.3 and Table 4.

Concentrations of soluble reactive phosphate (PO_4-P) recorded in this study ranged form a minimum value of 8.64 in August, 2005 to a maximum of 41.5 µg/l in March, 2006 at the near-shore station, and from 10 in August, 2005 to 51 µg/l in February, 2006 at the open station. The maximum level of soluble reactive phosphate (SRP) observed in Lake Kuriftu is much lower than those 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), although it is still higher than values recorded for other nearby crater Lakes Babogaya (1-11 µg/l); Yeshiemebet Major, 2006) and Kilole (27; Zinabu Gebre Mariam ,1994).

Table 4. 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) station of Lake Kuriftu.

	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
8-08-05	34.67	33.3	11.926	10.2813	8.1688	7.5946	18.348	17.236
27-08-05	35	36	8.6363	21.796	6.9247	7.0204	23.352	35.028
8-10-05	40	40.6	20.151	34.956	7.1161	7.4145	22.24	31.692
15-10-05	33.3	33.3	10.2813	15.2163	7.3075	7.4032	33.638	41.144
29-10-05	34.6	35	9.9113	13.5713	9.4129	11.039	39.6	55.6
19-11-05	35	37.3	10.2813	13.5713	8.743	8.9344	28.078	46.426
15-12-05	33.3	34	13.5713	14.0648	8.3602	10.465	32.248	46.426
9-01-06	34	35.3	30.02	11.926	9.2215	8.743	34.472	47.816
5-02-06	33.3	36.7	38.2463	51.4063	7.656	8.1345	37.805	39.476
1-03-06	36	34	41.5363	36.6013	6.6376	7.9774	44.13	40.31
25-03-06	34.6	33.3	39.5211	31.66	5.4892	6.6376	39.6	32
26-04-06	46.7	43.3	39.891	34.956	6.829	7.2118	45.175	43.09

The concentration of SRP recorded in the present study showed greater temporal variations than spatial variations as can be expected from the small size of the lake and the frequent occurrence of mixing. Most of the time phosphate concentrations were low on days of high phytoplankton biomass and higher at the central station than at the near-shore station. Low concentrations of phosphate were also detected in Lake Ziway during periods of high phytoplankton biomass (Girma Tilahun, 1988). The slightly higher concentrations of phosphate at the central station 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 closer to the central station than the near-shore station.

Animals are important in nutrient cycling in freshwater ecosystems (Michael, 2002). Nutrient excretion by animals has not been studied in detail in any African lake ecosystem (Thornton, 1986). Aquatic organisms play a great role either in depletion or enrichment of phosphate. For example, Livingstone and Melack (1984) determined the excretory rate of zooplankton and found a rate of 100 mg m^{-2} d^{-1} for phosphate, and 34 mg m^{-2} d^{-1} for nitrate. Furthermore, daily phosphate release by *Cladoceran* zooplankton was found to be in the range of 35-60 % of their total body phosphorus and for rotifers values 3-4 times higher are expected (Lehman, 1980). Of the zooplankton group found

during the present study (Girum Tamire, 2006), *Rotifers* contributed 70% of the total Zooplankton abundance. The fairly high level of phosphate in this lake is probably partially a consequence of zooplankton excretion.

Nitrate-N (NO_3-N), which showed less temporal and spatial variations than phosphate and silica, varied from 33.3 to 46.7µg/l at the near-shore station and from 33.3 to 43.3 µg/l at the open station with the maximum values in April, 2006 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 (1-31µg/l; Yeshiemebet Major, 2006) and Bishoftu (25 µg/l; Zinabu Gebre Mariam, 1994) Lakes Awassa (7-20; Elizabeth Kebede and Amha Belay, 1994) although they are still considerably lower than those of the rift valley and Ziway (28-136.5 µg/l; Girma Tilahun, 1988).

The high nitrate concentrations at times coincided with relatively low phytoplankton biomass and vice-versa at the open station although the relation between nitrate levels and phytoplankton biomass was not apparent for the near-shore station in Lake Kuriftu.

Molybdate reactive silica (SiO_2) also showed small temporal variations at both the open and near shore stations. The values recorded for the near-shore station ranged from 5.49 to 9.14 mg/l while those for the open station varied from a minimum of 6.64 to a maximum of 11.1 in March, 2006 and October, 2005 respectively. The concentrations of silica were generally higher at the open station than at the near-shore station. The higher concentrations of silica at the open station are probably attributable to the greater input of

the nutrient through runoff from the steep slopes found on the side of the open station. The most plausible explanation seems that internal loading of silica was higher at the open station owing to its position relative to the effect of wind blowing over this small-sized lake. Furthermore, the seasonal peaks in silica concentrations at both stations were observed during the dry season suggesting the greater importance of autochthonous sources of silica.

Although the observed concentrations of silica never approached that regarded as limiting to diatom growth (ca, 0.3 mg l^{-1}; Reynolds, 1984) they are low in view of the high concentrations (> 10 mg l^{-1}) commonly encountered in African lakes (Talling and Talling, 1965; Talling, 1994) including the nearby crater lakes Kilole (32; Prosser *et al*., 1968), Hora (55; Prosser *et al*., 1968) and Babogaya (10-58; Yeshiemebet, 2006) and the Ethiopian Rift Valley lakes Ziway (45), Koka (32) (Wood and Talling, 1988) and Awassa (50-90; Demeke Kifle, 1985). The only lake for which silica concentrations considerably lower than those of Lake Kuriftu were reported is Lake Chamo of the Ethiopian Rift Valley (0-4 mg l^{-1}; Elizabeth Kebde *et al.,* 1994 and Zinabu Gebre-Mariam *et al*., 2002)

Over the last two decades or so the Ethiopian Rift Valley lakes showed a decline in silicate concentrations (Elizabeth Kebede *et al*., 1994; Zinabu Gebre-Mariam *et al*, 2002; Girma Tilahun, 2006) as did the crater lakes (Demeke Kifle, unpublished). The depletion of silica can be related to its removal from solution in diatom-dominated lakes like Shalla (Elizabeth Kebede and Willen, 1998) or its slower rate of regeneration resulting from the accumulation of organic matter as was shown for alkaline lakes in Africa (Hecky and

Kilham, 1988). 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: Lehman and Branstrator, 1994).

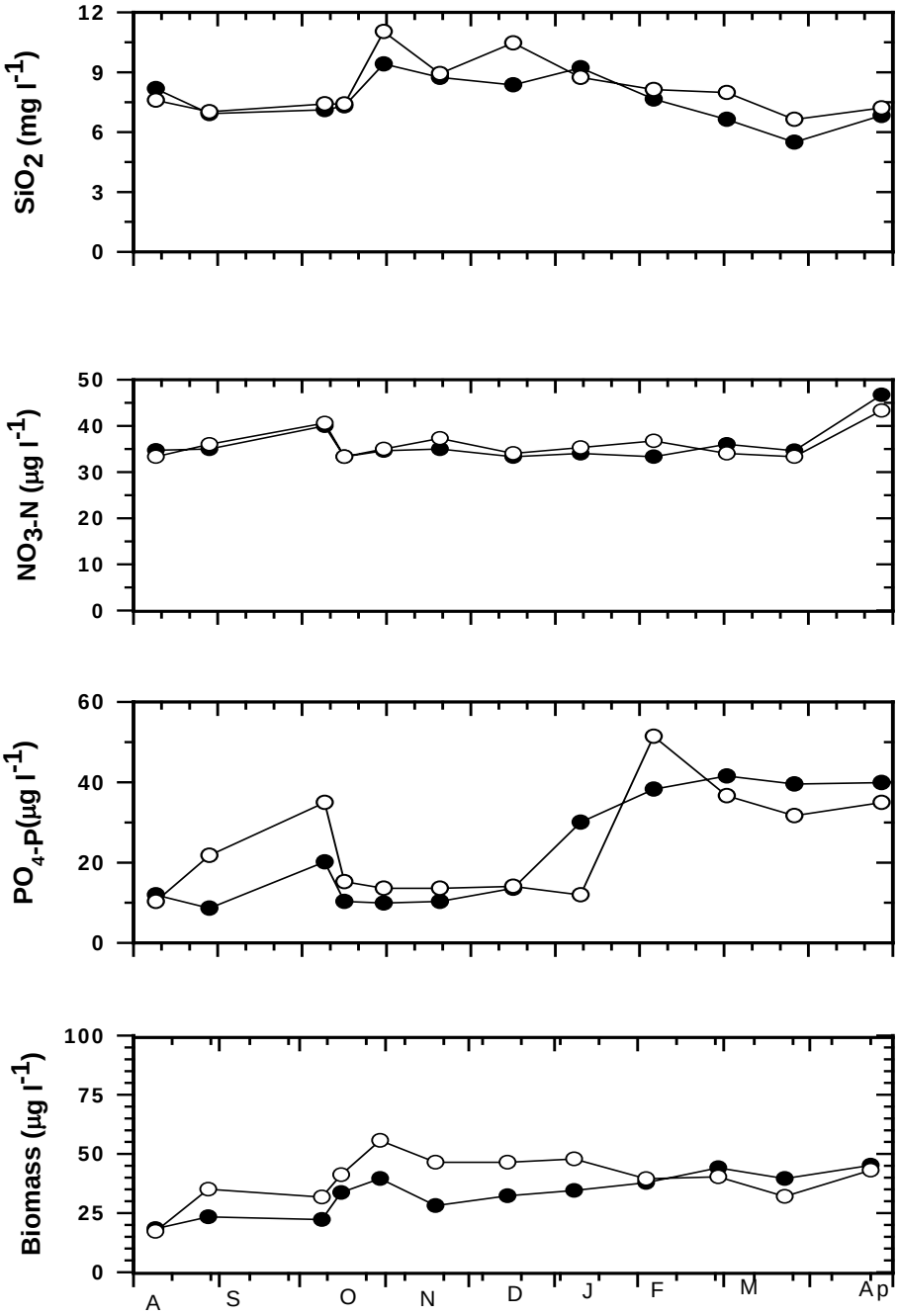

Fig.3. Tempoiral variations in the concentrations of inorganic nutrients in relation to phytoplankton biomass at the near-shore(closed circle) and central (open circle) stations of Lake Kuriftu.

5.2. BIOLOGICAL FEATURES

5.2.1 SPECIES COMPOSITION AND ABUNDANCE OF PHYTOPLANKTON

Net samples are not recommended for quantitative assessment of phytoplankton since nets do not capture phytoplankton of all sizes and the determination of the volume of water that passes through the net is difficult. Net samples can, however, be used to estimate the relative abundance of phytoplankton as all phytoplankton whose size is greater than that of the mesh size of the net used have equal probability of being retained.

Table 5 and Fig.4 present a list of the major phytoplankton species identified in samples collected during the study period and the relative abundance of groups of phytoplankton respectively.

A total of 25 species of phytoplankton belonging to 6 classes were identified. The species composition and diversity of phytoplankton of Lake Kuriftu are similar to those of Lake Babogaya (32; Yeshiemebet Major, 2006). Phytoplankton diversity in Lake Kuriftu (25 spp) is low when compared to those of the Ethiopian Rift Valley Lakes Ziway (67), Awassa(70) and Chamo 44) (Elizabeth Kebede and Willen, 1998). Girma Tilahun (2006) has also recently reported similarly high species diversity for Lakes Ziway, Awassa and Chamo in which the cyanobacteria were qualitatively and quantitatively important.

Blue green algae, green algae and diatoms were the major algal (taxonomic) groups in terms of species richness and abundance. The other taxonomic groups- dinoflagellates; cryptomonads and euglenoids -were poorly presented. *Microcystis aeruginosa* was usually the most important in terms of abundance and formed the most conspicuous populations.

The temporal changes in the percentage contributions of the different algal groups to the total abundance of the phytoplankton community are shown in Fig.4. Temporal changes

in the relative importance of the different taxonomic groups to the abundance of the phytoplankton assemblage in the Lake Kuriftu were observed.

Table. 5. 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 *Planktolyngebya tallingii* Kom. and Kaling *Planktolyngebya contorta* (Lemm.)Anagn. and Kom. *Microcystis aeruginosa* Rab. *Anabaena circinalis* Rab. *Anabaena nygaerdinom.* *Psuedoanabaena sp*. *Raphidiopsis sp*.
Chlorophyceae (Green algae)	*Pediastrum simplex* Meyen *P. duplex* Meyen *Scenedesmus armatus* Chod. *Scenedesmus dimorphus* (Turp.)Kutz. *Scenedesmus quadricauda* (Turp).Breb. *Chlamydomonas reticula* *Phacotus lenticularis* (Ehr.) Stein
Bacillariophyceae (Diatoms)	*Thalassiosira sp*. *Navicula cryptocephala* Kutz. *Nitzschia vermicularis*(Kutz.)Grun. *N. rostellate*. *Rhopahodia sp*.
Dinophyceae (Dinoflagellates)	*Peridinium sp*.
Cryptophyceae (Cryptomonads)	*Cryptomonas obovata* Skuja
Euglenophyceae (Euglenoids)	*Phacus longicauda* (Ehr.) Duj. *Lepocincilis sp.*

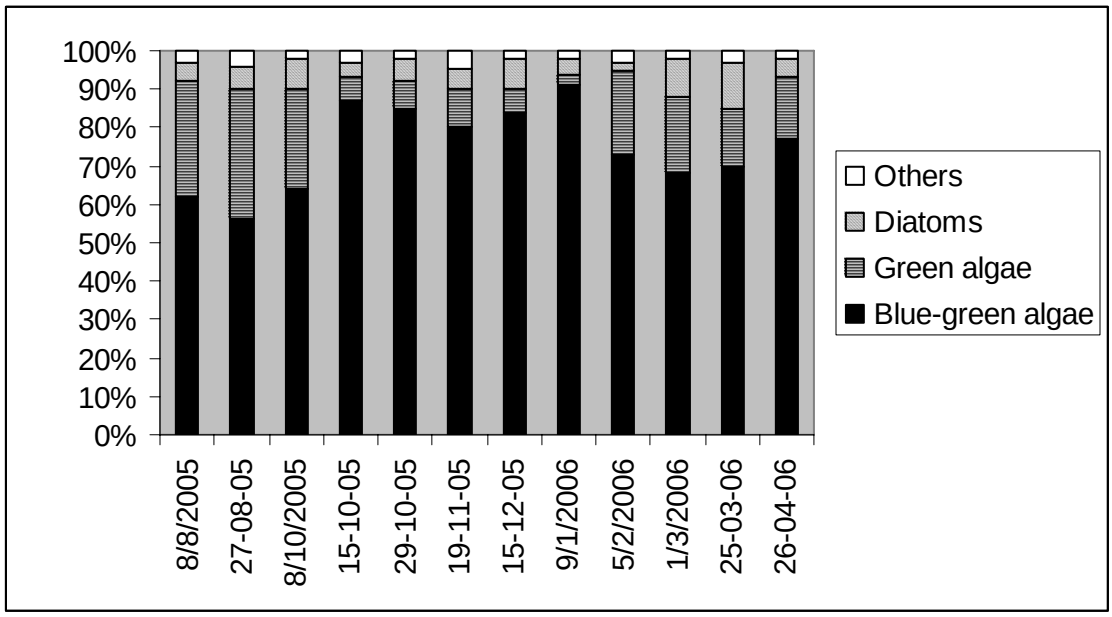

Fig.4.Temporal variations in the percentage contribution of different taxonomic groups to the abundance of total phytoplankton in Lake Kuriftu.

The Blue-green algae, with 9 species, were the most diverse and dominant taxonomic group with contributions to the abundance of the phytoplankton assemblage in Lake Kuriftu ranging from a minimum of 56% in August, 2005 to a maximum of 91% in January, 2006. Among the blue green algae *Microcystis aeruginosa* and *Cylindrospermopsis africana* were the most important in terms of abundance.

Green algae, which were of secondary importance to the total abundance of the phytoplankton assemblage, had contributions that ranged from 3 to 34% and which were primarily constituted by *Pediastrum duplex* and *p. simplex* from the 7 component species. Diatoms were the third important taxonomic group with contributions much lower than those of the green algae (2 to 12 %).

Several studies have addressed phytoplankton composition and dynamics in large East African lakes and have provided a basis for understanding the ecology of algal communities (Descy *et al*., 2005). The existence of different taxa is initiated and enhanced by one or several environmental factors such as light, temperature, water column mixing or stratification and availability of nutrients in the water column (Salmaso, 2000) although the relative importance of these factors vary considerably among different phytoplankton species (Reynolds, 1984). Each species of algae possesses a range of tolerance to these factors and its population growth proceeds most rapidly at some optimal conditions of the factors (Buskey and Stockwell, 1993).

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 (22.8 to 33.3 ^{o}C). 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 this probably explains why the abundance of cyanobacteria in Lake Kuriftu peaked in the middle of the dry period (December) with 91 % contribution to the abundance of the phytoplankton community in the lake.

Cyanobacterial dominance is a common phenomenon in Lakes and Reservoirs in Ethiopia (Adane Sirage, 2006; Ayalew Wondie, 2006; Girma tilahun, 2006, Hadgembes, unpublished) and South Africa (Thornton, 1987), Kenya (Pacinin, 1994) .

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.3 d (See also Table 4).

The Phytoplankton biomass of Lake Kuriftu exhibited temporal and spatial variations over the study period. The values recorded ranged 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 open station. The lowest phytoplankton biomass measured as Chl a was observed in August, 2005 at both stations. This seasonal minimum of Chl a coincided with a period of 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). The peak in phytoplankton biomass (45.18 mg Chl a m^{-3}), which was observed in April, 2006 for the near –shore station, coincided with an increase in NO_3-N and PO_4-P levels while that of the open station (55.6 mg Chl a m^{-3}) occurred in October, 2005 concomitant with a relatively low level of phosphorus and a slight increase in NO_3-N.

The maximum phytoplankton biomass value of Lake Kuriftu is closer to those reported for Lakes Bishoftu (Zinabu Gebre-Mariam and Taylor, 1997 and Ziway (Girma tilahun, 2006) and Legedadi Reservoir (Adane Sirage, 2006) higher than those observed for the nearby crater lakes Babogaya (Yeshiemebet Major, 2006) and Hora (Zinabu G.Mariam and Taylor (1997) and the Ethiopian Rift Valley lake Awassa (Girma tilahun, 2006) and Koka Reservoir (Eizabeth Kebede, 2006). Much higher phytoplankton biomass values are known from a number of shallow East African lakes including Kilole and Arenguade in

Ethiopia (Talling *et* al., 1973) and Lakes Nakuru (Melack, 1976) , Elmenteita (Kalff, 1983 and Simbi (Melack, 1979c) in Kenya and Lake George in Uganda (Ganf and Horne, 1975).

Most of the time the biomass in Lake Kuriftu was higher at the open station (mean=39.69 mg Chl a m^{-3}) than at the near-shore (mean=31.52 mg Chl a m^{-3}) station. This seems to be associated with the generally higher concentration of nutrients and transparency (less turbidity) at the open station than at the near-shore station. Similar 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). Howard-Williams and Lenton (1975) during their study in Lake Chiliwa, Malawi also reported lower phytoplankton biomass in the littoral than in the open water.

Table 6. Phytoplankton biomass measured as chlorophyll a concentration in different lakes.

Lake	**B(mg Chl a m^{-3})**	**Data Source**
Koka	16	Elizabeth and Willen(1998)
Babogaya	4-20	Yeshiemebet Major(2006)
Awassa	20 - 46	Demeke Kifle (1985)
	10.43-25.21	Tadesse Fetahi (2004)
	13 - 26	Girma tilahun (2006)
Hora	29	Zinabu G.Mariam and Taylor (1997)
Abaya	0-33	Zinabu G.Mariam(2002)
Kuriftu	***17.24-55.6***	***This study***
Legedadi	2.61-57.33	Adane Sirage (2006)
Bishoftu	60	Zinabu G.Mariam and Taylor(1997)
Chamo	47-108	Eyasu Shumbulo(2004)
Ziway	149.5-212	Girma Tilahun(1988)
	22.9 – 57.5	Girma Tilahun (2006)
Simbi	200	Melack(1979c)
George	100-400	Ganf and Horne(1975)
Kilole	382-412	Talling *et al*.(1973)
Arenguade	195-880	Demeke Kifle *et al* (Unpublished)
Nakuru	1160	Vareschi(1982)
Chitu	2600	Wood and Talling(1988)

Although both phytoplankton biomass and all inorganic nutrients showed spatial variations, the differences between the two stations in the concentrations of nitrate and phosphate (T-value =0.25 for nitrate, 0.48 for phosphate) were not statistically significant while those of Chl a and silica were as the T- test values (2.34 for silica and 2.57 for chl a) indicate significancy.

In tropical lakes, irradiance and temperature are probably not as frequently limiting as they are in temperate lakes (Lund, 1964; Talling , 1986; Talling and Lemoalle, 1998) but nutrient availability as a function of hydrographic and hydrological conditions of the water body plays a major role in controlling the seasonal pattern of algal growth (Moss, 1969a; Talling, 1986). In Lake Kuriftu, the correlations between biomass and the macronutrients nitrate-nitrogen (r=0.109) and phosphate (SRP) (r=0.14) were positive but weak while that between silica and biomass was relatively strong (r=0.691) although diatoms were not as important as the other algal groups in Lake Kuriftu**.** Schindler and Fee (1974) found a good correlation between annual phytoplankton productivity and nutrient levels. Moreover, the importance of nutrient supply to the productivity and abundance of phytoplankton has been shown by enrichment experiments on natural populations (Melack, 1984).

Temporal dynamics of phytoplankton biomass are known to be controlled by loss processes including grazing by zooplankton and fish. The Cyclopoid copepod, *Thermocyclops consimilis* dominates the zooplankton community in Lake Kuriftu, followed by rotifers and lower abundance of cladocerans (Girum Tamire,2006). The feeding habit of *Termocyclops is,* however, is less defined (Seyoum Mengistou,1989). The Research conducted by Girum Tamire (2006) has shown the dominance of copepods throughout the study period except in September and October, 2005 when rotifers became more important. In October, 2005 there was a decline in phytoplankton biomass, which was probably associated with the peak abundance of rotifers. Rotifers particularly *Brachionus* species can have a considerable effect on phytoplankton as they are known to

resist the toxicity of blue greens although they mainly ingest particulate material (Ganzalez, 2000).

The size-fractionation experiments conducted by Girum Tamire (2006) in this lake also seemed to indicate that the grazers probably have lower contribution to the removal of phytoplankton (Girum Tamire, 2006). Carney and Elser (1990) also confirmed the weak effect of grazers on large–sized, cyanobacteria-dominated algal assemblages in eutrophic lakes, which supports the view that grazers' impact is weaker in eutrophic and hypertrophic systems. In such systems colonial and other algae can dominate and weaken the ability of crustacean zooplankton to graze them efficiently. In light of this it is tempting to draw the conclusion that grazers' have low impact on the phytoplankton biomass of Lake Kuriftu.

The rare occurrence of cladocerans and common occurrence of large phytoplankton, primarily blue-greens which are less edible and sometimes toxic to cladocerans (De Bernardi and Guissani,1990), can be the reason for not having higher impacts of zooplankton on natural phytoplankton assemblages in Lake Kuriftu (Girum Tamire,2006) since grazing impact depends mainly on the size structure and taxonomic composition of grazers and phytoplankton (Cyr and Pace,1992)

Carlson's Trophic Index which relates Secchi depth and concentrations of chlorophyll a, and phosphorus, is a common means of characterizing the trophic state of a lake. According to Carlson(1977), lakes with trophic status index (TSI) ranging from 60 to 70 are eutrophic with dominance of blue-green algae. Lake Kuriftu whose TSI for chlorophyll a and Secchi depth are 66.59 and 69.7 respectively is, therefore classified under the category Eutrophic one in which blue-green algae are the dominant algal groups (Carlson,1977).

5.2.3 Photosynthetic Primary productivity

5.2.3.1 Depth profiles of gross photosynthesis

The depth profiles of gross photosynthetic rate per unit water volume (A, mg O_2 m^{-3} h^{-1}) are shown in Fig.5 (See also Appendix 3). The vertical distribution of photosynthetic activity per unit volume of water in Lake Kuriftu was of a typical pattern for phytoplankton (Talling, 1965; Ganf, 1974a; Talling and Lemoalle, 1998). Since composite samples were used for all incubations, the observed depth –profiles were not expressions of varying photosynthetic biomass, but were rather differing responses of uniform algal biomass to different irradiances. The depth profiles included three main regions on all sampling days except in April, 2006. The regions were a near-surface region of light-inhibition, a sub-surface region of light-saturation and a lower region of light-limitation.

The depth profiles of photosynthesis of Lake Kuriftu showed variations in the maximum rates attained and the extent of surface depression of photosynthetic activity. During the study period, the depth-profiles of gross photosynthesis exhibited a sub –surface maximum rate of gross phtotosynthesis at 0.25 m in all sampling months except April, 2006 when the maximum was observed at the near-surface of the water column owing to the cloudy condition of the day of production measurement

It is well established that considerable variations occur in day-to-day productivity in lakes. The depth profiles of photosynthetic activity observed for Lake Kuriftu (Fig. 5) exhibited depressed rates of photosynthesis at the near-surface of the water columns during most of the sampling months. Profiles with reduced photosynthetic activity at the near-surface have been reported from many East African lakes including those in Ethiopia (Talling *et al*., 1973; Amha Belay and Wood, 1984; Girma Tilahun, 1988;; Demeke Kifle and Amha Belay, 1990), Chad (Lemoalle, 1983), Kenya (Talling, 1965; Melack, 1979, 1981; Vareschi, 1982) and Tanzania (Melack and Kilham, 1974). Basically, lower photosynthetic rates of phytoplankton at a lake's surface are linked to photo-inhibition, which is believed to occur when light exceeds physiological saturation

and results in excess of photons that do not become dissipated by photosynthetic carbon fixation (Long *et al.*, 1994; Falkowski and Raven, 1997). The decrease in photosynthetic rates is associated with photo-oxidative disruption of pigment systems (Amha Belay and Fogg, 1978; Falkowski and Raven, 1997), inactivation of photosynthetic enzymes (Steemann-Nielsen, 1962; Steemann-Nielsen and Jørgensen, 1962) and increased photorespiration (Harris and Lott, 1973; Osmond, 1981).

Considering the significance of inhibition of photosynthesis at a lake's surface for water column productivity, the extent of percentage reduction in gross photosynthesis from A_{max} due to photo-inhibition was estimated by calculating the difference between maximum gross photosynthetic rate and gross photosynthetic rate at the near-surface and expressing it as a percentage of the latter. The reduction in photosynthetic rates due to photo-inhibition varied from 0 to 16.7%.

As a function of irradiance the extent of inhibition of photosynthetic productivity was variable. An irradiance of (PAR) 11.78 E m^{-2} h^{-1} in March, 2006 produced 16.6%)reduction from the light –saturated rate (A_{max}) while a lower irradiance of 5.849 E $m^{-2}h^{-1}$ in August, 2005 caused only 5.07% reduction from A_{max}. Similar results where reported from other water bodies of the tropical (Demeke Kifle and Amha Belay, 1990) and temperate (Jones, 1978; Demeke Kifle, 1992) regions. It seems that the extent of surface depression of photosynthetic rates is not a function of only the intensity of incident irradiance. Experimental studies have shown that the extent of photoinhibition varies with photo-acclimatization state (Kok, 1956; Talling and Lemoalle, 1998) and species-specific differences in photo-acclimatization strategies (Jorgensen, 1964; Behrenfield *et al*., 1998). The difference in the extent of photo-inhibition between different days of incubation in Lake Kuriftu might be related to differences in the relative importance of different species of phytoplankton at different times of the study period.

The maximum (1136 mg O_2 m^{-3} h^{-1}) gross photosynthetic rate at light -saturation was observed in November, 2005 coinciding with a photosynthetic biomass of 46.426 Chl a m^{-3} while the lowest gross photosynthetic rate (571 mg O_2 m^{-3} h^{-1}) was observed in

August, 2005 associated with a biomass of 17.236 Chl a m^{-3}. The low gross photosynthetic rates at light-saturation were associated with a period of the main rainy season during which runoff brings particulate materials that reduce light penetration. Net photosynthetic rates showed a depth–distribution pattern, which was similar to that of gross photosynthesis with maximum volumetric rates at a depth of 0.25m and ranged from a minimum of 429 in August, 2005 to a maximum of 1000 mg O_2 m^{-3} h^{-1} in October, 2005 (See Appendix 3).

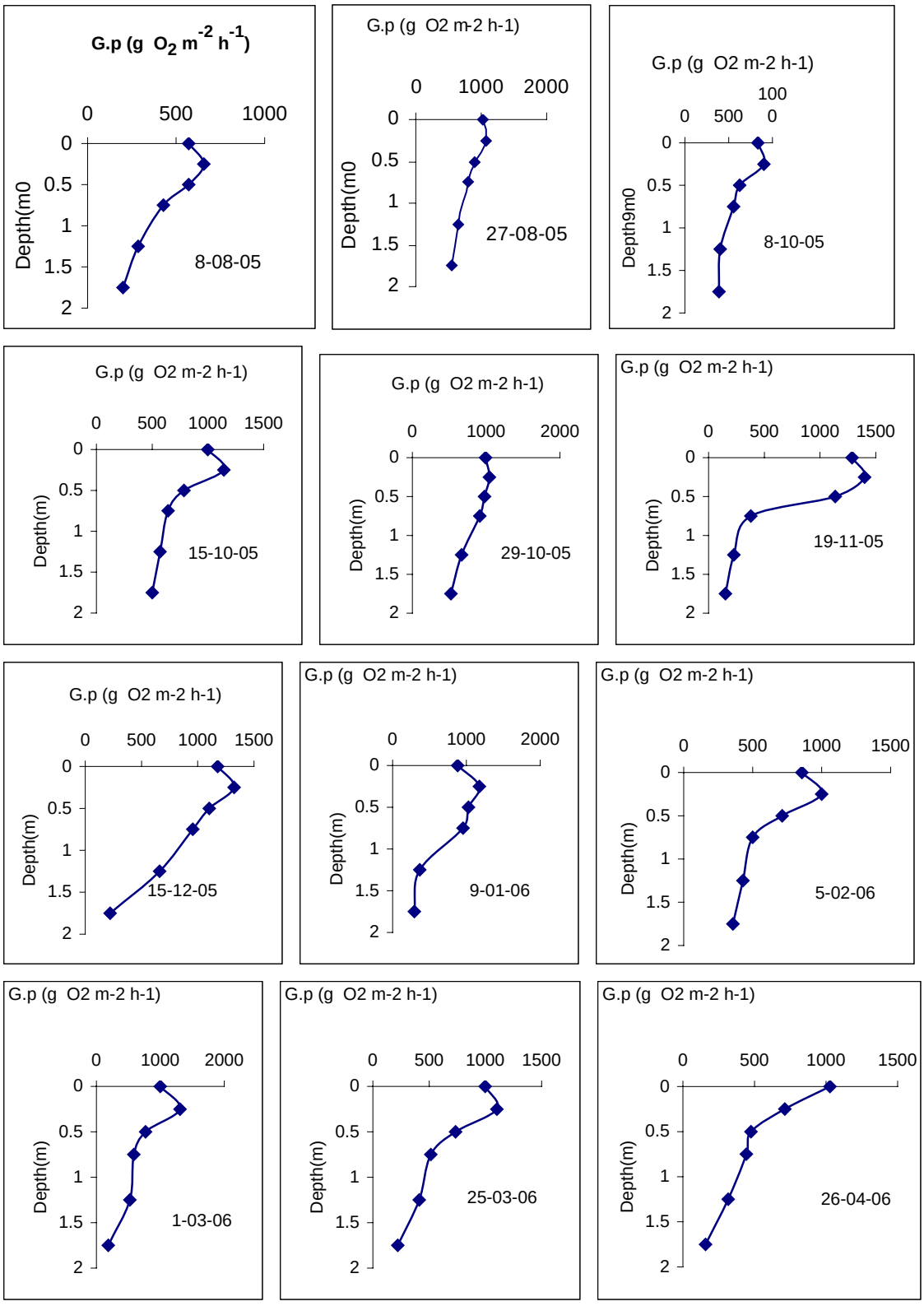

Fig 5. Depth profile of gross Photosynthesis per unit volume at open station.

5.2.3.2. Photosynthetic characteristics

The light-saturated rate of gross photosynthesis (A_{max}), specific-rate of gross photosynthesis at light-saturation (P_{max}, mg O_2 (mg Chl a)$^{-1}$ h$^{-1)}$, Percentage reduction from A_{max} due to photo-inhibition, Hourly integral ($\sum$A, g O_2 m^{-2} h^{-1}) and daily integral rates of gross photosynthesis ($\sum\sum$A, g O_2 m^{-2} d^{-1}) and photosynthetically Active radiation (PhAR) are given in Appendix 4 and their temporal variations shown in Fig 6.

The maximum rates of phytoplanktonic photosynthesis (A_{max}) ranged from 571 to 1136 mg O_2 m^{-3} h^{-1} (see Table 7 for comparison with values reported for different lakes). The highest values of these light-saturated rates of gross photosynthesis are higher than those reported for Lake Babogaya (Yeshiemebet Major, 2006), Awassa (Demeke Kifle and Amha Belay, 1990) and Abijata (Amha Belay and Wood, 1984), all in Ethopia and Lakes Naivasha and Cresent Island Crater (Melack, 1979a) and Sonachi, in Kenya (Melack, 1976) and several perennial irrigation reservoirs in Sir Lanka (Silva *et al*.,2002). Much higher values of A_{max} have been reported for the Ethiopian crater Lakes Kilole and Arenguade (Talling *et al.*, 1973), the shallow rift valley Lake Ziway (Girma Tilahun, 1988) and Lake George in Uganda (Ganf, 1975) and Lake Simbi in Kenya (Melack, 1970).

Higher rates of light-saturated photosynthesis were observed at times of high phytoplankton biomass in Lake Kuriftu. Melack (1979a) also recorded higher photosynthetic rates in Kenyan freshwaters when chlorophyll a concentrations were also high. The correlation between A_{max} and phytoplankton biomass in Lake Kuriftu was positive and strong (r=0.67) with the latter accounting for about 45 per cent of the variation in the former. Pentecost and Happey-Wood (1978) have also found similarly high correlation (r=0.671) between maximum (light-saturated) rates of photosynthesis and chlorophyll a concentration for Welsh lakes. Positive but weak correlation was reported between A_{max} and phytoplankton biomass in previous studies in the Ethiopian

lakes Ziway (r= 0.36; Girma Tilahun, 1988) and Lake Chamo (r=0.3, Eyasu Shumbulo, 2004).

It is interesting to note that the highest biomass (~55) of Lake Kuriftu was associated with an A_{max} value of 1044 mg O_2 m^{-3} h^{-1}, while the lower phytoplankton biomass (46.426) yielded the highest A_{max} (1136). Similarly, Talling *et al*. (1973) found relatively low light- saturated rate of photosynthesis with a high algal crop and the relatively low algal crop was found to yield the highest maximum rate (A_{max}) in Lake Arenguade. The lack of correspondence between biomass and A_{max} was also reported for phytoplankton of several reservoirs in Sri Lanka (Silva *et al*., 2002) and in Lake Awassa (Demeke Kifle and Amha Belay, 1990).

Table.7.Comparison of light-saturated rate of gross photosynthesis (A_{max}) and specific-rate of gross photosynthesis at light-saturation (P_{max}, mg O_2 (mg Chl a)$^{-1}$ h^{-1}).

Lake	A_{max}	P_{max}	Data Source
Awassa	217-425	4-19	Demeke Kifle and Amha Belay(1990)
Babogaya	106-407	19-29	Yeshiemebet Major(2006)
Kuriftu	**571-1136**	**20.2-33**	**This study**
Abijata	960	14.8	Amha Belay and Wood(1984)
Chamo	716-1789	10-34	Eyasu Shumbulo(2004)
Ziway	1640-4670	9.6-22.5	Girma Tilahun(1988)
Kilole	4000-10000	16.3-33.7	Talling *et al*, (1973)
Arenguade	10000-30000	11-18	Talling *et al*, (1973)
Naivasha	150-240	-	Melack(1979b)
Simbi	950-12900	15-17	Melack(1979c)
Nakuru	1100-2300	-	Melack and Kilham(1974)
George	1900-6000	-	Ganf(1975)

According to Talling (1965) and Hammer (1981), high maximum rates associated with low algal biomass are the result of high specific activity [$P_{max,,}$ mg O_2 (mg Chl a)$^{-1}$ h^{-1}].

It seems that there is a general stimulation of growth and photosynthetic activity of phytoplankton by nitrate alone or in combination with phosphorus (Reynolds, 1984; Tilman, 1982; Harris, 1986; Smayda, 1990)). Algal communities may respond to a decreased supply of a limiting nutrient either by decreasing the optimum photosynthetic rate or by producing less efficiently at suboptimal irradiances (Schindler and Fee, 1975). Studies on algal nutrients emphasize the importance of nitrogen and phosphorus (Boney, 1975). In the study the relationship between light-saturated photosynthetic rates and levels of nutrient was not evident.

The correlation between A_{max} and photosynthetically active radiation (PAR) falling on a horizontal surface in the lake's area was positive but modest (r =0.526) although the relation between rates of photosynthesis, magnitude of photoinhibtion and PAR is regarded as being controversial because of their dependence on the previous life-history of the cells (Talling and Lemoalle, 1998).

It is necessary to consider the magnitude of the light-saturated rate of photosynthesis per unit of chlorophyll a [Photosyntheic capacity or Assimilation number (P_{max})$_,$ mg O_2 (mg Chl a)$^{-1}$ h^{-1}] when comparing the photosynthetic capacity of phytoplankton communities. Biomass-specific rates at light-saturation ranged from 18.78 to 33 mg O_2 (mg Chl a)$^{-1}$ h^{-1} with most values between 23 and 30 mg O_2 (mg Chl a)$^{-1}$ h^{-1}. P_{max} of Lake Kuriftu is higher than those of Lakes Ziway (9.6-22.5) (Girma Tilahun, 1988), Awassa (4-19) (Demeke Kifle and Amha Belay, 1990) and Arenguade (11-18) (Talling *et al*., 1973) in Ethiopia and Lakes Simbi and Sonachi in Kenya (15-17 and 8-14 respectively; Melack, 1981) and Lake George in Uganda (17-19; Ganf and Horne, 1975). The maximum P_{max} value of Kuriftu is closer to those of Lakes Babogaya (19-29) (Yeshiemebet Major,

2006), Chamo (10-34; Eyasu Shumbulo, 2004) and Lake Kilole (16.3 - 33.7; Talling *et al.*, 1973). In lakes of temperate regions, values rarely exceed 20 mg O_2 (mg Chl a)$^{-1}$ h^{-1} (Bundles, 1974).

The correlation between P_{max} and A_{max} is negative and low (r =-0.34) which may provide an explanation for the association of high light-saturated rates with low algal biomass observed for Lake Kuriftu. In the present study, the higher P_{max} value was recorded at the time of minimum phytoplankton biomass during the rainy season while the minimum value was observed when the phytoplankton biomass was at maximum. P_{max} is inversely proportional to the biomass of phytoplankton as the strong and negative correlation (r = -0.90) between the two seem to suggest. This is often encountered worldwide and the trend is represented in tropical lakes including Lake George, in Uganda (Ganf, 1972), Lake Maciiwaine, in Rhodesia (Robarts, 1979).

There are a number of factors that determine the photosynthetic capacity of phytoplankton. It has been shown that temperature (Eppley, 1972), light (Beardall and Morris, 1976; Falkowski, 1981), nutrient regimes (Falkowski and Stone, 1975) and cell size (Malone, 1971) directly affect photosynthetic capacity. As temperature and light are generally high in the tropics, algal type including cell size, nutrients and CO_2 supply may be considered to be of greater importance in determining the magnitude of photosynthetic capacity of phytoplankton.

Comparison of mean photosynthetic productivity in the trophogenic zone of tropical and temperate lakes led Lemoalle (1981) to the conclusion that higher tropical rates originate from high photosynthetic capacity, which may be the result of the usual higher temperature in the tropics. The studies made on Lakes MacIlwaine, Rhodesia (Robarts, 1979) and Chad (Lemoalle, 1983), which showed a drop in photosynthetic capacity during the markedly cooler season supported the same view. As it has been shown by Talling *et al.*, (1973) for Lake Arenguade, Melack (1979) for Lake Simbi, Kenya and Lemoalle (1973) for Lake Chad in Chad, tropical soda lakes can show a combination of high phytoplankton standing crop and above-average biomass-specific rates, partly due to

the large reserve of CO_2 for localized photosynthetic activity in condensed photosynthetic zones (Talling *et al*., 1973).

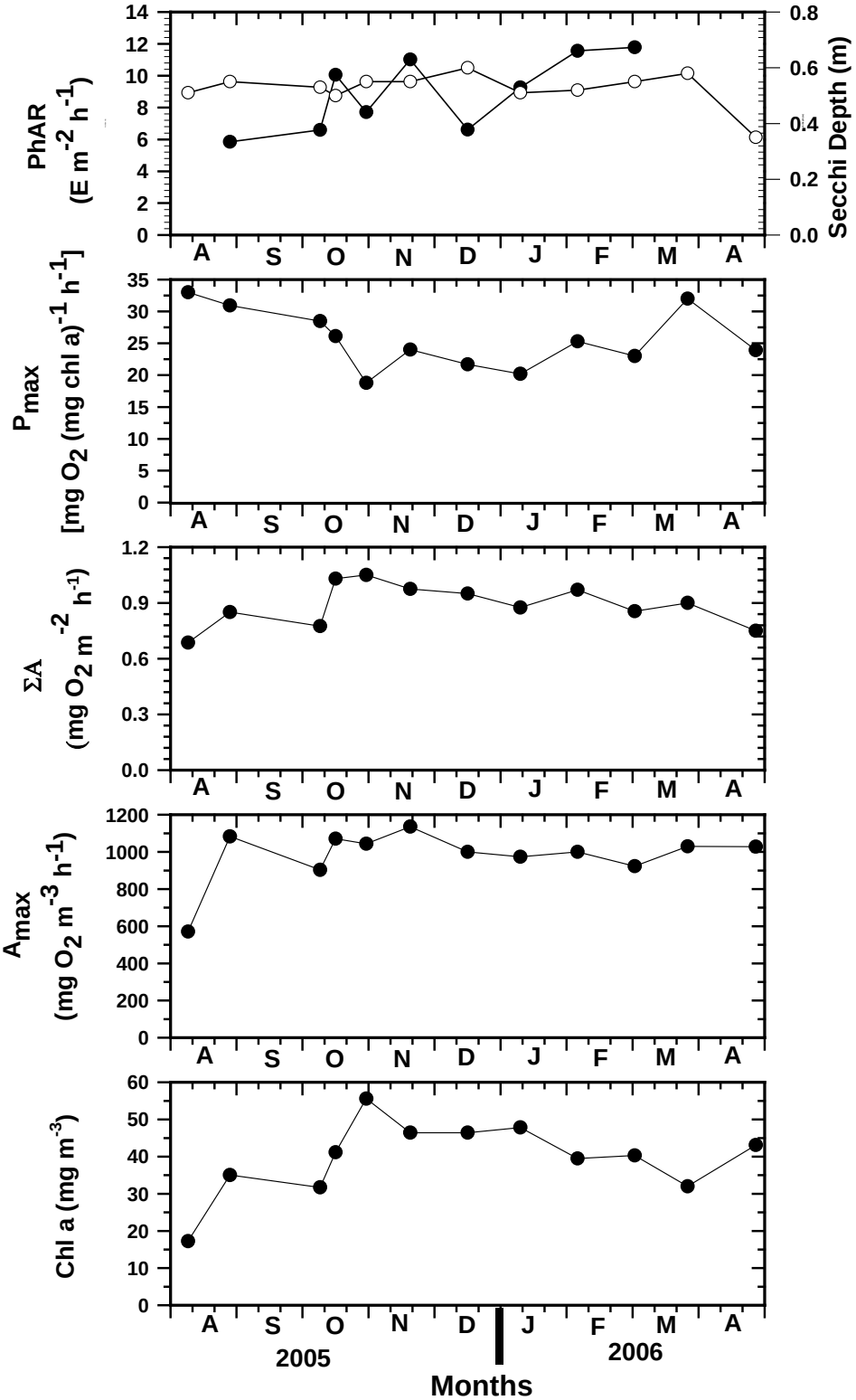

Fig. 6. Temporal variations in phytoplankton photosynthetic parametes in relation to biomass and integral irradiance (closed circle) of the incubation period and Secchi depth (open circle) in Lake Kuriftu.

5.2.3.3 Production rates per unit area

Hourly ($\sum$A, g O_2 m^{-2} h^{-1}) and Daily integral rates of gross photosynthesis ($\sum\sum$A, g O_2 m^{-2} d^{-1}) are given in Appendix 4. The hourly photosynthetic rates per unit area were determined by the Gird Enumeration Analysis (Olson, 1960).

Hourly integral photosynthesis ranged from 0.686 (August, 2005) to 1.05 O_2 m^{-2} h^{-1} (October, 2005). The highest hourly integral rate of gross photosynthesis ($\sum$A, g O_2 m^{-2} h^{-1}) of Lake Kuriftu is greater than those reported for Lakes Ziway (0.0574 to 0.726; Getachew Beneberu, 2004), Babogaya (0.47 to 0.86; Yeshiemebet Major,2006) and Awassa(0.3 to0.725; Demeke Kifle and Amha Belay,1990) although it is much smaller than those observed in the crater lakes Arenguade (1.43 to 2.56; Demeke Kifle *et al.*, unpublished) and Simbi (0.62 to 5.22; Melack, 1979c).

The seasonal peaks of hourly integral rates were associated with peaks of chlorophyll a concentration and light-saturated rate of gross photosynthesis (A_{max}). The correlation between hourly integral rates and chlorophyll a concentration and A_{max} was positive and strong (r =0.71 and 0.69 respectively) while its correlation with PAR was positive but weak (r=0.28).

Values of light utilization efficiency of phytoplankton in Lake Kuriftu are given in Appendix 4. The values ranged from a minimum of 1 % in October, 2005 to a maximum of 5% in August, 2005 during the study time. In Lake Kuriftu efficiency of light utilization was high during the rainy season when low Ph.A.R was recorded. Similar findings were reported for Lakes Ziway, Awassa, and Chamo (Girma Tilahun, 2006) Keifer and Mitchell(1983) suggested that efficiency of light utilization varies as an inverse function of irradiance with maximum values occurring at low irradiance. The light utilization efficiency values of the phytoplankton is Lake Kuriftu are much higher than those obtained for phytoplankton of Legedadi reservoir (0.16 -0.98%; Adane Sirage, 2006)

The daily integral rates of photosynthesis ($\sum\sum$A g O_2 m^{-2} d^{-1}, of the Lake were also determined from the hourly-integrated rates by multiplying with the factor of 0.9 used by Talling (1965) for other East African Lakes. The products were then multiplied by the number of hours of sunshine often considered for tropical lakes (i.e. 10). The calculated values ranged from 6.174 to 9.45 g O_2 m^{-2} d^{-1} (See Appendix 4) during the sampling period. The highest daily integral value of Lake Kuriftu is considerably lower than those recorded for Lake Ziway (3.1 to17.6 Grima Tilahun ,1988), Arenguade (11.25-44.83 g O_2 m^{-2} $d^{-}1$, Demeke Kifle *et al.*, unpublished) although it is close to those of Lake Chamo in Ethiopia (3.8-10.86; Eyasu Shumbulo, 2004) and Lake Muzahi in Uganda (6 to 9.5; Mukankomeje *et al*., 1993). African Lakes with smaller maximum daily integrals include Babogaya (1.01-5.98; Yeshiemebet Major, 2006) and Kilole (1.49-2.4; Talling *et al*., 1973) in Ethiopia and Baringo in Kenya (3.8; Patterson and Wilson, 1995).

6. GENERAL DISCUSSION AND RECOMMENDATIONS

Lake Kuriftu is a shallow, frequently mixing, moderately turbid and productive lake. The lake exhibits temporal variations in photosynthetic biomass and production of phytoplankton. These variations seem to be related to hydrological and hydrographic conditions of the lake, which in their turn determine the levels of nutrients and their spatial variations as Talling (1992) has pointed that the temporal changes in biological parameters of lakes are related to input-output relationships of energy and matter, which are dictated by hydrographic (water column structure and circulation) and/or hydrological (water input-output) conditions. Vincent *et al*., (1986) have also singled out that flood-related changes in nutrient supply and abiotic turbidity are the over–riding factors in shallow well mixed lakes such as Lake Chilwa.

Temporal variations in species composition and relative abundance of different taxonomic groups of phytoplankton were observed. It was the blue-green algae of the genera *Microcystis* and *Cylindrospermopsis*, which persistently dominated the phytoplankton community of the lake. The persistence of fairly high levels of nutrients, particularly phosphate in a generally turbid and mixing water column favors the dominance of blue-greens owing to their structural and physiological adaptation for buoyancy regulation.

Although the calculation of nutrient ratios was not attempted owing to the lack of data on ammonia + ammonium- nitrogen, the N:P ratios seem to be low considering the consistently low concentrations of nitrate relative to phosphate. Talling and Talling (1965) and Talling and Lemoalle (1998) also argued that nitrogen, not phosphorus, is the nutrient which is generally limiting to algal growth in tropical African lakes since nitrate levels were frequently very low and undetectable.

On the basis of the results obtained in this study, the following recommendations are made:

In order to have a better picture of the primary producers and water chemistry of this aquatic ecosystem, future studies should involve a look into the significance of nitrogen-fixation and internal loading of nutrients.

It is well known that physical and chemical and biological variables exhibit short-term variations. Thus, future studies need to have more frequent sampling, at least at biweekly intervals, in order to get a better picture of the temporal trends in all aspects of the lakes.

The present biological condition of the lake is at least partly the result of human activities carried out in the proximity of the lake. If these activities go unchecked, nuisance and toxic cyanobacterial blooms will occur leading to the loss of the biological integrity and aesthetic value of the lake in whose proximity hotels and other recreation facilities are being built. Management strategies should, therefore, be developed at the earliest time possible with a review to avoid the occurrence of irreversible changes in the lake.

7. REFERENCES

APPENDICES

APPENDIX.1. Metorological data-mean maximum and minimum air temperature, total monthly rainfall (source: national meterological agency: Addis Ababa)

DATE	MEAN MONTHLY MINIMUM TEMPE (^{o}C)	MEAN MONTHLY MAXIMUM TEMPE (^{o}C)	MONTHLY TOTAL RAIN FALL (mm)
JAN, 2005	8.1	26.2	_
FEB, 2005	8	29	_
MAR, 2005	12.1	28.6	_
APR, 2005	12.3	28.7	_
MAY, 2005	13.1	27.1	_
JUNE, 2005	12.2	27.2	_
JUL, 2005	13	24	168.0
AUG, 2005	13.6	24.8	186.7
SEP, 2005	12.6	25.6	153.3
OCT, 2005	8.2	26.9	0.0
NOV, 2005	7.4	25.9	2.9
DEC, 2005	3.5	25.9	0.0
JAN, 2OO6	7.8	27.1	5.0
FEB, 2006	10.3	28.3	108.8
MAR, 2006	10.5	27.8	0.0

APPENDIX 2. depth profiles of water temperature, dissolved oxygen and percentage oxygen saturatio the study period.

Date	Depth (m)	0	0.25	0.5	0.75	1.25	1.75	2	2.5	
8-08-05	Temperature ($^{o}_{C}$)	29.9	29.7	29.5	29.3	28.7	28.3	27.9	27.1	2
	Oxygen (mg/l)	15	15.4	15.28	15.18	14.36	12.6	6.64	3.29	3
	Oxygen (%)	173.7	202	201	201	188.2	159.2	96.9	30.6	
27-08-05	Temperature ($^{o}_{C}$)	31.5	29.9	29.6	29.2	28.8	28.5	28.2	27.8	2
	Oxygen (mg/l)	10.30	10.50	9.54	9.47	8.85	8.35	6.24	4	
	Oxygen (%)	142.2	132	128.2	120	116	106	90.9	41	2
8-10-05	Temperature ($^{o}_{C}$)	31.1	30.6	28.5	28.4	28.4	28.2	28	28	2
	Oxygen (mg/l)	8.6	8.8	7.10	7.1	6.8	6.8	6.6	5.6	
	Oxygen (%)	115	120	91.4	88.8	88.4	85.3	80.2	54.5	4
15-10-05	Temperature ($^{o}_{C}$)	31	30.5	30	29.7	29	28	27.3	26	2
	Oxygen (mg/l)	4.7	4.98	4.8	4.46	4.44	4.41	4.3	4.29	4
	Oxygen (%)	56.7	60.6	54	53.7	53.2	53	51.7	51.3	5
29-10-05	Temperature ($^{o}_{C}$)	28.5	26.5	25.8	25.3	24.6	24.1	23.3	23.1	2
	Oxygen (mg/l)	5.08	5.98	5.00	4.95	4.58	4.55	4.29	4.11	3
	Oxygen (%)	67.7	69.5	63	60.5	60	52.3	60.6	46	4
15-12-05	Temperature ($^{o}_{C}$)	26.4	24.4	24	23.1	22.9	22.8	22.8	22.7	2
	Oxygen (mg/l)	17.15	17.6	13.9	12.86	11.3	11	10.5	9.01	
	Oxygen (%)	230	240.4	232	123	128	117	116	115	1
9-01-06	Temperature ($^{o}_{C}$)	27.3	26.6	24.1	22	20.8	20.7	20.5	20.4	2
	Oxygen (mg/l)	13	14	10.78	10.14	10	9.66	9.45	9.25	9
	Oxygen (%)	305	275	175	122	118	116	114	112	
5-02-06	Temperature ($^{o}_{C}$)	22.8	21.9	21.7	21.5	21.4	21.2	21	20.4	2
	Oxygen (mg/l)	11.39	11.5	9.73	9.00	8.9	8.7	6.27	6.08	3
	Oxygen (%)	162	110	105	100	140	89.3	82	56	4
1-03-06	Temperature ($^{o}_{C}$)	30.1	29.5	28.7	28.1	27.9	27.6	27.4	27.2	2
	Oxygen (mg/l)	4	4.2	4.1	3.95	3.34	3.18	3.27	3.04	2
	Oxygen (%)	55	56	58.6	47.4	47.3	38	43	37.3	3
26-04-06	Temperature ($^{o}_{C}$)	24.2	24	23.8	23.5	23.2	23	22.6	22.5	2
	Oxygen (mg/l)	11	10.76	10.32	10.2	10.11	10	9	8	
	Oxygen (%)	108.3	137.6	148.6	138.5	165	151	115	101.5	

Appendix.3. Depth profiles of gross photosynthesis (A, mg O_2 m^{-3} h^{-1}), Net Photosynthesis (NP, mg O_2 m^{-3} h^{-1}) and Secchi Depth in meters.

Date	Depth (m)	A, (mg O_2 m^{-3} h^{-1}	Net(mg O_2 m^{-3} h^{-1}	Secchi Depth (m)
8-08-05	0	571	371	0.51
	0.25	657	429	
	0.5	571	371	
	0.75	428	286	
	1.25	285	143	
	1.75	200	57	
27-08-05	0	1028	543	0.55
	0.25	1083	600	
	0.5	889	400	
	0.75	806	314	
	1.25	639	143	
	1.75	556	57	
8-10-05	0	833	492	0.53
	0.25	903	569	
	0.5	625	262	
	0.75	556	18	
	1.25	403	15	
	1.75	389	0	
15-10-05	0	1000	928	0.56
	0.25	1071	1000	
	0.5	786	500	
	0.75	643	357	
	1.25	571	285	
	1.75	500	214	
29-10-05	0	992	605	0.60
	0.25	1044	658	
	0.5	979	526	
	0.75	914	460	
	1.25	666	211	
	1.75	522	66	
19-11-05	0	985	758	0.55
	0.25	1153	909	
	0.5	530	303	
	0.75	379	152	
	1.25	227	0	
	1.75	151	-76	
15-12-05	0	857	286	0.51
	0.25	1000	428	

	0.5	785	214	
	0.75	714	143	
	1.25	662	71.4	
	1.75	511	0	
9-01-06	0	810	645	0.51
	0.25	973	806	
	0.5	648	484	
	0.75	487	323	
	1.25	368	161	
	1.75	294	81	
5-02-06	0	857	429	0.50
	0.25	1000	571	
	0.5	714	286	
	0.75	500	214	
	1.25	429	0	
	1.75	357	-71	
1-03-06	0	769	692	0.55
	0.25	923	846	
	0.5	615	538	
	0.75	585	200	
	1.25	523	154	
	1.75	153	77	
25-03-06	0	999	588	
	0.25	1029	662	0.58
	0.5	955	515	
	0.75	515	294	
	1.25	412	191	
	1.75	294	-73	
26-04-06	0	1028	473	0.35
	0.25	712	789	
	0.5	475	237	
	0.75	443	205	
	1.25	316	79	
	1.75	158	-79	

Appendix 4. Phytoplankton biomass as chlorophyll per unit water volume (**B, mg Chl a m^{-3}),** Light-saturated rate of photosynthesis **(A_{max}, mg O_2 m^{-3} h^{-1}),** Percentage reduction of gross photosynthesis from A_{max} due to photo-inhibition, Specific rate of photosynthesis at light-saturation (**P_{max}, mg O_2 (mg Chl a)$^{-1}$ h^{-1})** , Hourly **(g O_2 m^{-2} h^{-1})** and daily **(ΣΣA, g O_2 m^{-2} d^{-1})** integral rates of photosynthesis, photosynthetically Active Radiation **(PhAR, E m^{-2} h^{-1}),** Net photosynthesis **(NP, mg O_2 m^{-3} h^{-1})** and photosynthetic efficiency of light utilization **(%)** in Lake Kuriftu at open (op) Station.

Sampling Date	**B**	**A_{max}**	**% Reduction from A_{max} due to photo inhibition**	**P_{max}**	**ΣA**	**ΣΣA**	**PhAR**	**NP at light saturation**	**Photosynthetic efficiency (Eff.%)**
8-08-05	17.236	571	9.9	33	0.686	6.174	-	429	-
27-08-05	35.028	1083	5.07	30.93	0.85	7.65	5.849	600	5
8-10-05	31.692	903	7.75	28.49	0.775	6.975	6.59	569	4
15-10-05	41.144	1071	6.6	26.12	1.03	9.27	10.06	1000	3
29-10-05	55.6	1044	4.98	18.78	1.05	9.45	7.716	658	1
19-11-05	46.426	1136	13.9	24	0.975	8.775	11.02	909	2
15-12-05	46.426	1000	14.3	21.7	0.95	8.55	6.614	428	5
9-01-06	47.816	973	16.7	20.2	0.875	7.875	9.26	806	3
5-02-06	39.476	1000	14.3	25.3	0.97	8.73	11.56	571	2
1-03-06	40.31	923	16.6	23	0.855	7.695	11.78	846	2
25-03-06	32	1029	2.9	32	0.9	8.1	-	662	
26-04-06	43.09	1028	0	23.9	0.75	6.75	-	789	

Appendix.5. Formulae used for the estimation of physical, chemical and biological parameters

1. From Holmes (1970)

$$K_d = \frac{1.44}{Z_{SD}}$$

Where Z_{SD} -Secchi depth (m)

2. From Kalff (2002)

$$Z_{eu} = \frac{4.6}{K_d}$$

3. From Saunders *et al*., 1962

mg DIC= (TA-PA) X0.240 where

DIC is the total free carbon dioxide (dissolved inorganic carbon) in mg/l.

TA-Total Alkalinity

PA-phenolphthalein alkalinity

4. From Talling and Driver (1963)

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

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)

5. From Lind (1979)

$$\textbf{Photosynthetic Efficiency (\%)} = \frac{\textbf{g/C/m}^2\textbf{/dayx2x5500}}{\textbf{PhAR}} \times 100$$

Where 5,500=Approximate caloric equivalent per gram, dry algal tissue
2=Approximate conversion of carbon to dry algal tissue
PhAR is photosynthetically active radiation in $\mathbf{E\ m^{-2}h^{-1}}$

Appendix .6. Statistical relationships among physico-chemical and biological parameters measured in Lake Kuriftu in this study.

Independent variable(x)	**Dependent Variable(y)**	**R^2**	**(r)**	**p**	**Regression equation**
Chl a	Secchi depth	0.1296	-0.36	0.863	Y=35.2-8.5x
Total Alkalinity	pH	0.662	0.8136	0.004	Y=6.39+0.748x
Nitrate	Chl a	0.012	0.109	0.731	Y=27.1+0.350x
Phosphate	Chl a	0.02	0.14	0.663	Y=42.2-0.105x
Silica	Chl a	0.478	0.691	0.013	Y=-1.4+5x
Chl a	$\mathbf{A_{max}}$	0.444	0.666	0.018	Y=552+13.8x
P.A.R	$\mathbf{A_{max}}$	0.277	0.526	0.079	Y=708+31.4x
$\mathbf{P_{max}}$	$\mathbf{A_{max}}$	0.021	0.34	0.654	Y=32.8-0.00371x
P.A.R	∑A	0.081	0.284	0.457	Y=7.41+0.103X
$\mathbf{A_{max}}$	∑A	0.473	0.6877	0.013	Y=3.25+0.00484X
Chl a	∑A	0.504	0.709	0.010	Y=0.567+0.00811x
Chl a	$\mathbf{P_{max}}$	0.822	-0.906	0.000	Y=42.5-0.430x

Results of T-test conducted to determine if the differences in Biomass, NO_3-N, PO_4-P and SiO_2 between the two stations were significant.

Paired T	T-value	P-value	T-test from Table(p=0.05,df=11)
Biomass	2.57	0.026	
NO_3-N	0.25	0.808	
PO_4-P	0.48	0.642	
SiO_2	2.34	0.039	

R^2-Regression coefficient
r- Correlation coefficient

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