

Temporal Dynamics of the species composition and Size fractionated
Biomass of Phytoplankton In Lake Kuriftu, Ethiopia

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Abstract

*The temporal dynamics of phytoplankton and physic-chemical variables were studied at a central station of Lake Kuriftu from December, 2008 to November, 2009. The lake is shallow and as a result undergone complete mixing throughout the study period. Secchi depth ranged from 0.21 m to 0.6 m. The Lake's transparency (Z_{SD}) was always less than 0.6 m with smaller values coincident with high phytoplankton biomass even though there is weak correlation b/n phytoplankton biomass and Z_{SD} . The chemistry of the lake was basically similar to the dilute East African lake waters, with maximum pH and total alkalinity values of 9.09 and 4.1 meq/l respectively. Nitrate concentration ($\mu\text{g L}^{-1}$) ranged from a minimum of 9.33 in November, 2009 to 65.45 in April, 2009. Soluble reactive phosphate- phosphorus (SRP, in $\mu\text{g L}^{-1}$) varied from a minimum value of 14.65 in January, 2009 and May, 2009 to a maximum of 402.57 in August, 2009. Dissolved silica (Molybdate-reactive silica, SRSi in mg L^{-1}) ranged from 3.051 in December, 2008 to 97.92 in September, 2009. The phytoplankton community which was dominated by Cyanobacteria is 2nd in diversity to chlorophycea which covers 25 species of the 50 species. *Cylindrospermopsis Africana* was the most dominant species throughout the study period. The diversity index was narrow ranging from 1.24 -6.42 bits/individual. Among the three size-group of phytoplankton, the nanoplankton (2-20 μm) was the most important contributor to the total phytoplankton biomass with its biomass and percentage contributions to the total phytoplankton biomass ranging from 15.44 $\mu\text{g L}^{-1}$ and 51.93 % to 19.74 $\mu\text{g L}^{-1}$ and 73.84 % respectively. The Chl a biomass and percentage contribution to total phytoplankton biomass of the Netplankton and Picoplankton varied from 1.94 to 6.73 and 6.53 % to 13.87% and 4.68 to 14.63 and 17.5% to 41.54 % respectively. The factors responsible for the observed spatio-temporal variations in the physical, chemical and biological features of the lake are discussed.*

Key words: Lake Kuriftu, Size fractionated Biomass, Phytoplankton, Temporal Variation.

1. Background and Justification

Volcanic crater lakes are distributed throughout the Tropics. Some of them occur in south East Asia (Ruttner, 1931) and South America (Umana, 2001). The African representatives are found in Ghana (Whyte, 1975), Cameroon (Kling, 1988; Giresse *et al.*, 1991), Uganda (Beadle, 1966; Crisman *et al.*, 2001), Kenya (Melack, 1988), Madagascar (Schabetsberger *et al.*, 2009) and Tanzania (Hecky and Kling, 1981). There are a number of crater lakes in Ethiopia, which may provide tremendous opportunities for comparative limnological studies owing to their different morphometric, physico-chemical and biological features. Among these are the Bishoftu lakes, which form an extensive series of volcanic explosion craters in the vicinity of the town Bishoftu (Debre Zeit).

Like other lakes, crater lakes support various groups of organisms, phytoplankton being among the most prominent ones. They 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 aquatic system. The life of all animals that live in the sea and freshwater ultimately 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, is controlled by the photosynthetic activity of the phytoplankton. Half of the world's oxygen is produced via phytoplankton photosynthesis (Roach, 2004). The distribution, abundance, species diversity and species composition of the phytoplankton are used to assess the biological integrity of a water body. They also reflect the nutrient status of the aquatic environment. They do not have control over their

movements, thus they cannot escape pollution and this makes them a good indicator of pollution in the aquatic environment (Polat, 2002).

Phytoplankton species composition, numerical abundance, spatial distribution and total biomass are in a direct relation with the environmental factors (Lewis, 1996). The physical and chemical characteristics of water bodies affect the species composition, abundance, productivity and physiological conditions of aquatic organisms (Elber and Schanza, 1989). Unlike temperate lakes in which phytoplankton periodicity follows seasonal pattern (Reynolds, 1984) dominated by solar energy cycle (Patterson and Wilson, 1995; Pikaityte, and Razinkovas, 2007), phytoplankton periodicity in tropical waters is controlled mainly by weather and related changes. Underwater light, rainfall, temperature, water clarity, wind-induced mixing/thermal stratification, nutrients, pH, alkalinity, salinity, hardness and dissolved oxygen of water columns are some of the major water quality parameters that bring about the dynamics of phytoplankton (Jones, 1977; Reynolds, 1984). Talling (1986) stated that change in the abundance of algal species occurs due to changes in turbulence, illumination per cell and distribution of nutrients in the water column.

Tropical lakes are thought as permanently stratified lakes due to low seasonal variation in temperature. Kling (1988) calculated the stability of thermal stratification of 31 lakes of West Africa, out of which 17 had distinct thermoclines and well-developed anoxic hypolimnia. In deep equatorial lakes, the temperature coefficient of the density of water is much greater in the range 20-25 °C than 0-10 °C, so that stratification, once established, is more stable in a tropical than in a temperate lake having large difference in temperature between surface and bottom water (Beadle, 1966). Hutchinson and Loffler (1957) had put

forward a model that considered altitude as important factor in tropical lakes, and proposed that high elevation lakes were polymictic but Lewis (1987) has proposed a modification of their model and included Lake morphometry specially depth as another important factor. According to Lewis (1987) lakes less than 10 m deep are polymictic regardless of their altitude.

Stratification can be a barrier to the upward transport of nutrients as well as to the transport of heat, oxygen and algal cells (Baxter, 1980) thereby affecting the structure of phytoplankton in lakes. In stratified lakes, heterogeneous distribution of chemical (Baxter *et al.*, 1956) and biological parameters (Wood *et al.*, 1984) are observed. Dinoflagellates seem to be favoured by stratification. Their success in stratified lakes is related to vertical migration which maximizes nutrient uptake from nutrient-replete hypolimnetic waters (Cullen and Horrigan, 1981) and reduces sinking losses (Levandowsky and Kaneta, 1987). Whereas mixing favours diatoms whose maintenance in suspension is dependent upon turbulence (Reynolds, 1984). Cocquyt and Vyverman (2005) observed the dominance of diatoms during periods of increased vertical mixing that brought low light and high nutrient level due to turbidity and mixing respectively in the tropical Lake Tanganyika.

Mechanical mixing of water has been a successful management tool for scum-forming cyanobacterial species such as *Microcystis aerogenosa* which rely on buoyancy regulation to compete for the available light. *Microcystis aerogenosa* has been found to form blooms during warm and calm conditions in lake Nasser (El-Otify, 2002). However, it has proved less successful for another nuisance cyanobacterium, *Cylindrospermopsis raciborskii*; the use of

mechanical aeration increased, rather than decreased mean abundance (Saker and Griffiths, 2007).

In tropical lakes, nutrient limitation is considered to be the main factor limiting algal growth at light-saturated depths, while light may be limiting in deeper water layers during stratification (Reynolds, 1984). Melack (1979) indicated that in most tropical lakes, seasonal and inter-annual fluctuations of phytoplankton correspond to variations in rainfall and the consequent runoff or vertical mixing within the lake that could increase the nutrient concentration. Phytoplankton studies in some African lakes have shown dynamics that are the results of several years of cultural eutrophication (Hecky and Kling, 1981). Talling (1986) indicated that phytoplankton seasonality in larger and deeper African lakes is influenced by external factors and periodic changes in the hydrographic structure of the water column. The sequence of dominant phytoplankton forms, at least in terms of the taxonomic classes of algae they represent, is often similar in different lakes sharing similar morphometric and chemical properties (Reynolds 1984). These similarities suggest that seasonal succession may be generally subject to overriding interactions of a relatively small number of environmental variables (Reynolds, 1984).

Changes in nutrient availability can lead to variations in phytoplankton diversity and species composition in aquatic systems. Elevated pH, dissolved oxygen, $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$ and silica favored the growth of Cyanophyceae and Chrysophyceae in the tropical ponds of Pindamonhangaba Brazil (Asiyo, 2003). In eutrophic lakes, Cyanophyceae could bloom and cell division occurs rapidly due to the enriched nutrients (Reynolds 1984; Wetzel, 2001). The recurrent toxic algal blooms of *Microcystis aeruginosa* in Koka Reservoir, similar to that

which occurred in Lake Chamo in 1978 (Amha Belay and Wood, 1982), which were responsible for the death of livestock seems to be the result of pollution of Koka Reservoir with algal nutrients originating from nearby agricultural lands on which fertilizers were applied (Demeke Kifle, pers.comm).

A shift from dominance by diatoms to that of blue greens in the open waters of Lake Victoria has been associated with the reduction of silica concentration in the water column due to increased burial of diatoms in the sediments, associated with increased productivity in the lake (Verschuren *et al.*, 2002). When the phytoplankton density is high, the nutrients such as phosphates and nitrates are low, indicating rapid utilization of these compounds by the algae growth and it is also observed that the nutrient concentrations are high just before the phytoplankton peaks (Fatimah *et al.*, 1984). Nutrient enrichment experiments carried out in Lake Malawi water (Guildford *et al.*, 2003) and eutrophication in Lake Victoria, however, suggest that increased nutrient loading (particularly of P) might cause not only an increase in phytoplankton biomass but also a species shift to nitrogen-fixing cyanobacteria, especially in shallow, near shore areas of the lake (Guilford *et al.*, 2007). The growth of the cyanobacteria appears to have been influenced by their ability to maintain their vertical position in deeper waters. These algae are able to regulate their position in relation to the light-gradient through control of the volume occupied by their intracellular gas vacuoles (Reynolds, 1976). High temperature and high irradiance also favour cyanobacteria (Chen, 2003; Davies *et al.*, 2009).

The Ethiopian rift valley lakes have shown two different patterns concerning wet and dry season. Zinabu Gebrmariam (2002) observed Lake Zwai, Abijata, and Awassa responding to rainy season with higher chlorophyll-*a* whereas Lake Chamo, Langano, Abaya and Shalla showed less chlorophyll *a* during the rainy season. He proposed that low chlorophyll-*a* concentrations in dry and wet seasons reflect nutrient and light limitation, respectively. Lakes that responded (Zwai, Abijata, and Awassa) are presumably those that are nutrient-limited during the dry season (Zinabu Gebre-Mariam, 2002). Tanaka *et al.*, 1988 noted that the declining rate of primary production and population densities during the wet season could be attributed to the dilution of planktonic organisms following the increase in the volume of water.

Dussart (1965) divided plankton on a logarithmic size scale: macroplankton (200-2000 μm), microplankton (20-200 μm), nanoplankton (2-20 μm) and Sieburth *et al.* (1978) elaborated this classification scheme and added the terms picoplankton (0.2-2 μm) and femtoplankton (0.02-0.2 μm). The dominance of one of the size fractions of phytoplankton in relation to total biomass will define the principal transfer path of biogenic carbon in the ecosystem. When the small fraction dominates, the main route will be nutrient recycling through the microbial loop in the euphotic zone (Bell and Kalff, 2001). In contrast, when the large fraction dominates, new production will either be exported to the bottom of the lake or consumed by herbivores and eventually exported as faecal pellets (Adame *et al.*, 2007).

Nutrient concentration, light intensity and vertical water movements are important factors regulating the size composition of phytoplankton. Netplankton tend to predominate in

eutrophic waters (Adame *et al.*, 2007). They are abundant in the surface water of tropical lakes, and play an important role in maintaining the ecology and water quality of freshwater ecosystems (Chattopadhyay and Banerjee 2007). They sometimes develop noxious blooms, creating offensive taste, odour, and toxic conditions that may result in animal death and human illness (Chattopadhyay and Banerjee 2007). The larger fractions dominate when nutrients are abundant (Adame *et al.*, 2007) Shiomoto (1997) pointed out that the necessary nutrient conditions for predominance of large-sized phytoplankton (mainly diatoms) are silicate concentration and atomic ratios of Si/N higher than 20 μM and 1.7 respectively.

Nanoplankton is predominant in oligotrophic waters (Adame *et al.*, 2007). Its predominance in natural waters has been hypothesized to be due to intrinsically higher growth rates, photosynthetic rates and nutrient uptake rates of small algal cells with high surface-to-volume ratios (Cole *et al.*, 1986) as well as lower sinking rate and may be better adapted to stress (Adame *et al.*, 2007).

Studies have shown on average that the biomass of nanoplankton increases with nutrient richness but that their biomass relative to the larger phytoplankton decreases. Two hypotheses were put forwarded to explain this phenomenon. Although nanoplankton don't appear to be competitively disadvantaged at high nutrient level and suffer small sedimentation losses, their biomass increase is constrained by high loss rates that are at least in part the result of predation. Second, the larger microalgae ($\approx > 70\mu\text{m}$) not only compete for nutrient in nutrient-rich water but they are little preyed upon, at least by

freshwater microzooplankton, commonly allowing them to dominate eutropic waters (Bell and Kalff, 2001).

The discovery of picoplankton during the late 1970s led to considerable research. Recent studies made by epifluorescence methods have revealed that picoplankton are ubiquitous and very common and this size-fraction accounts for about 80-90% of the total primary productivity in some waters (Harris, 1986; Ehnert and Peter Mcroy, 2007; Polat and Aka, 2007). Due to its small size, picoplankton has advantage to acquire nutrients in oligotrophic environments. However, under nutrient-rich conditions, phytoplankton communities are dominated by large cells (Polat and Aka, 2007).

Importance of studying phytoplankton cell size has recently been emphasized because cell sizes influence the response of phytoplankton to environmental changes and food chain dynamics (Fogg, 1986). The size classes have been used to divide algal community considering the potential influence of the particle size on the dynamics of the food chain, and also because species within the same class tend to respond similarly to environmental changes (Becker and Marques, 2004). It's also well known that the size of phytoplankton plays an important role in phytoplankton population dynamics and in trophic interactions between phytoplankton and herbivorous zooplankton (Tanaka *et al.*, 1988).

The lakes in Ethiopia 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. Lake Kuriftu is one such lake, which has not received much attention in spite of its potential economic importance. Though the temporal dynamics of phytoplankton in the present study lake has been investigated relatively recently by Zelalem Desalegne (2007), the focus on major phytoplankton taxa and Primary productivity.. Moreover, unlike most other studies that investigated phytoplankton biomass in Bishoftu crater lakes, the present study looked into the size-structure of phytoplankton biomass of Lake Kuriftu. The purpose of this study was, therefore to study the temporal dynamics of the species composition and size-fractionated biomass of phytoplankton in relation to some physico-chemical factors in Lake Kuriftu.

2. Objectives

2.1. General Objective

- To investigate the temporal dynamics of the species composition, abundance and size-fractionated biomass 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 determine the species composition of phytoplankton
- To determine the relative contribution of different size classes of phytoplankton to total chlorophyll *a*
- To identify factors which bring about the temporal changes in Phytoplankton species composition, abundance and biomass.

- To generate water quality and biological data, which may be of some use in developing management and conservation strategies of our aquatic resources.

3. Description of the study area

Lake Kuriftu (Fig 1) is one of the lakes found in Bishoftu (Debreziet), a town located 47 Km South East of Addis Ababa, at an altitude of 1860m. The lake is located at 8° 47' N and 39° 00'E. It is a shallow (maximum depth \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 morphometric and physico-chemical features of the lake are given in Table 1.

The lake's region is characterized by moderate rainfall, varying around about 850 mm per annum, which is the major source of water (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 and Koriftu resort, plantation of trees, construction of utilities and establishment of livestock and agricultural farms were made around the southern and eastern shore of the lake.

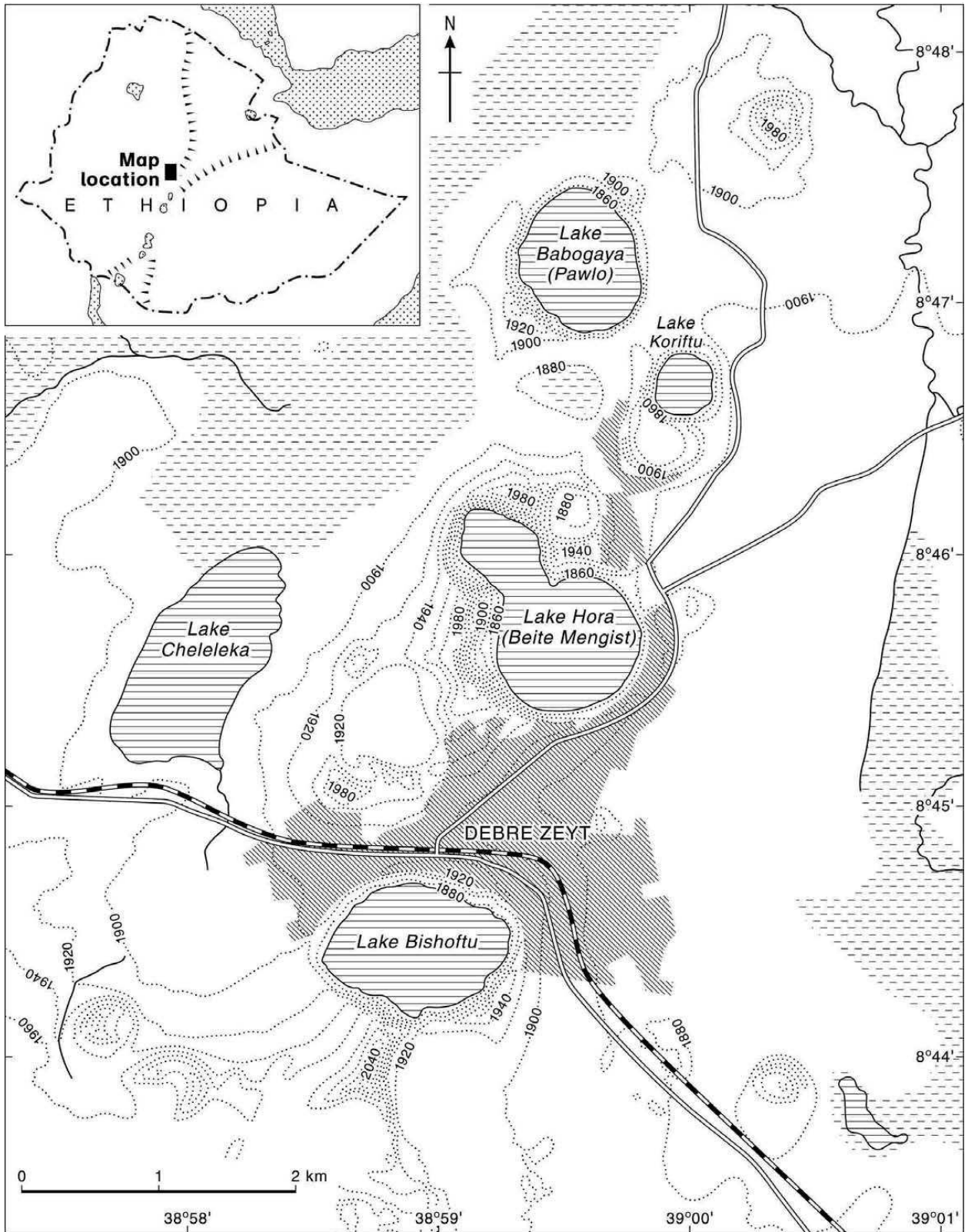


Fig. 1. Map showing the location of the study lake. Lake Kuriftu, in relation to other Bishoftu Crater lakes. (After Lamb, 2001).

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 also observed.

Table 1. Physico-chemical features of Lake Koriftu (After Brook Lemma *et al.*, 2001 and Zinabu Gebremariam *et al.*, 2002)

Area (Km ²)	0.4
Max. depth (m)	6
Mean depth (m)	2
pH	7.9-8.4
Volume (m ³)	3 x 10 ⁶
Secchi depth (m)	0.15-0.20
Conductivity (mS cm ⁻¹)	319
Salinity (g/l)	0.260
Cations (meq/l)	3.187
Anions (meq/l)	3.461
Na ¹⁺ (meq/l)	1.000
Ka ¹⁺ (meq/l)	0.154
Ca ²⁺ (meq/l)	1.250
Mg ²⁺ (meq/l)	0.783
Alkalinity (meq/l)	2.890
Cl ⁻ (meq/l)	0.571
SO ₄ ²⁻ (meq/l)	0.000

Phytoplankton composition of Lake Kuriftu was reported by Zelalem Desalegne (2007). Blue- green algae, green algae and diatoms were reported as the major algal (taxonomic) groups in terms of species richness and abundance. *Microcystis aeruginosa* was usually the most important in terms of abundance and formed the most conspicuous populations (Zelalem Desalgne, 2007). Zooplankton species composition of Lake Koriftu was reported by Brook Lemma *et al.* (2001) (Table 2). The fish and phytoplankton species found in the lake have not been reported in sufficient detail; however, *Oreochromis niloticus*, *Cyprinius carpio* and *Barbus* species are known to occur in the lake.

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

Copepods	Cladocera	Rotifera
<i>Mesocyclops</i>	<i>Ceriodaphnia sp.</i>	<i>Asplanchna sp.^a</i>
<i>aequatorialis^a</i>	<i>Diaphanosoma</i>	<i>Brachionus</i>
<i>Thermocyclops consimilis</i>	<i>excisum</i>	<i>bidentata</i>
++	<i>Moina micrura</i>	<i>B. calycyflorus</i>
		<i>B. caudatus</i>
		<i>B. falcatus⁺⁺</i>
		<i>Filinia sp.^a</i>
		<i>Karatella sp.^a</i>

++

Dominant species; ^a Rare occurrence

3.1. 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 7.8 °C in November, 2008 to 13.8 °C in August, 2009 while the mean monthly maximum air temperature ranged from 24.5 °C in August, 2009 to 30.2° C in May, 2009. Mean maximum air temperature of the study period increased consistently from its lowest level of November, 2008 to one of its seasonal peaks in March, 2009 before it declined to a lower value in April, 2009 and increased again to peaks of similar magnitude in May and June, 2009. Thereafter, it declined consistently to another low value in August, 2009 which was comparable to that of November, 2008. Peaks of mean maximum air temperature occurred during the minor (March-May) and major (June-September) rainy periods. Although the pattern of temporal variation in the mean minimum air temperature was broadly similar to that of the mean maximum air temperature, the former peaked in April and July while the latter showed declining trends during the same months.

Total monthly rainfall ranged from 0.6 mm in Nov, 2009 to 243.9 mm in Aug, 2009 with the major rainy period broadly similar with Zelalem Desalgne (2007) although there was rainfall in March, 2009. Wind also has impact on variation of nutrients directly, but due to there is no data it is impossible to describe it.

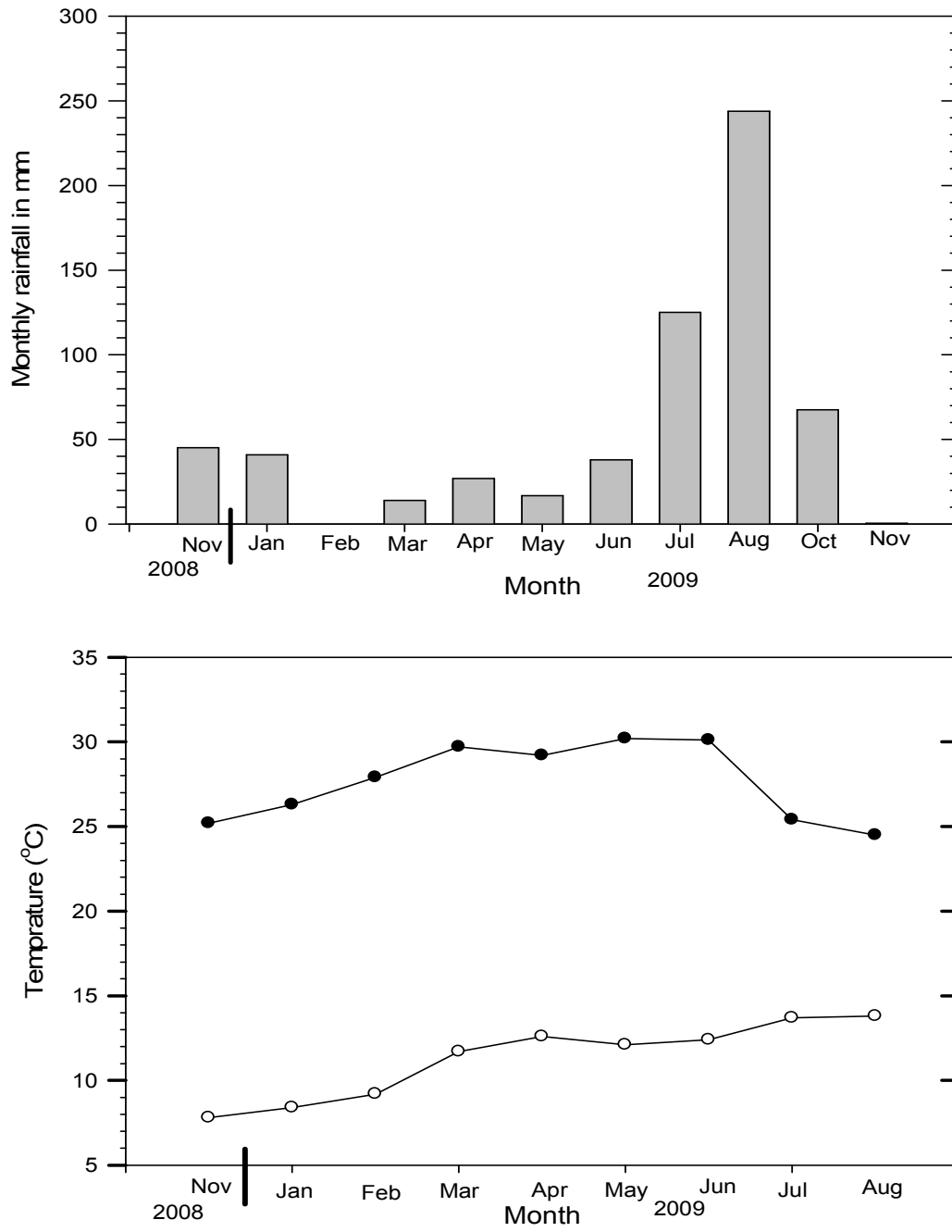


Fig.2. Meteorological data of Lake Koriftu: monthly rainfall and mean maximum (closed circle) and minimum (open circle) air temperature. (Source: Ethiopian Meteorological Service Agency)

4. Materials and Methods

4.1 Sampling protocol

Water samples were collected once a month from an offshore sampling station (about 5 meters in depth) with a bottle sampler (Kemerer). The water samples were collected from selected depths (0.00, 1.0 and 2.0) 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, which were used for chemical analyses, measurement of biomass as chlorophyll a concentration and determination of species composition and abundance.

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 biomass of phytoplankton, were measured *in situ* and *ex situ* in field.

The parameters measured include the following:

- Vertical distribution of (depth profile) of temperature by thermometer.
- 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).

Total and phenolphthalein alkalinity were determined by titration of the sample with 0.01NHCl to a pH of 4.5 using phenolphthalein and bromocresol green-methyl red indicator solutions with in few a hours after sample collection according to Wetzel and Lichens (2000) and expressed in meq L⁻¹.

4.3 Determination of depth profiles of Dissolved Oxygen

Vertical distributions (depth profiles) of oxygen were determined by the Winkler method using samples collected from the depths of 0, 1, 2, 3, 4 and 5 meters.

4.4 Analysis of inorganic nutrients

Composite water samples filtered through Glass Fiber Filters (GF/F) were used for the analyses of Soluble Reactive Phosphate ($\text{PO}_4\text{-P}$), Silica (SiO_2) and Nitrate ($\text{NO}_3\text{-N}$). Nitrate-N was determined by the Salicylic method (Robarge and Edward, 1983), while phosphate and silica were measured colorimetrically by the Ascorbic Acid and Molybdsilicate methods (APHA *et al.*, 1999) respectively.

4.5. Measurement of biological parameters

4.5.1 Species composition and abundance of phytoplankton

Monthly sampling was carried out from December, 2008 to November, 2009. Aliquots of composite samples collected from the euphotic zone were placed in glass bottles and fixed immediately with Lugol's iodine solution. These were transported to the laboratory and transferred to a measuring cylinder of 50 ml capacity and stored in darkness for sedimentation. After a period of 48 hours, the upper 45 ml of the sample was siphoned off and the remaining 5 ml was mixed to make it homogenous. 1 ml of the concentrated sample was siphoned into a Sedgwick-Rafter cell and algal units (unicels, filaments and colonies) within 28-33 grids were counted diagonally under an inverted microscope (Nikon) at a magnification of 400X. To facilitate comparison of total abundance of phytoplankton

observed at different times of the year, number of cells in 20 to 30 filaments and colonies were counted and mean cell number per colony or filament of a taxon was determined and employed to estimate the total number of cells of a filamentous or colonial alga encountered in the phytoplankton samples (i.e. no. of filaments or colonies X No. of cells per colony or filament). The cell number (cells ml⁻¹) of phytoplankton in the lake water was calculated according to Hotzel and Croome (1999). The diversity index of phytoplankton was also calculated by Shannon weaver diversity index (see Appendix 3)

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; Jeji-Bai *et al.*, 2002; Komarek and Anagnostidis, 2005).

4.5.2 Biomass estimation

The composite samples were also used for the estimation of total phytoplankton biomass and biomasses of the different size-groups. Total Phytoplankton biomass was estimated as chl a concentration spectrophotometrically from water samples filtered through glass fiber filters (GF/F). *Chl a* was extracted from the phytoplankton concentrate with aqueous acetone (90%). The filters were let to stand for overnight for the extraction of pigments (Khan *et al.*, 2010). The concentration of *Chl a* was calculated according to Talling and Driver (1963) using absorbance measurements made at 665 and 750 nm.

4.5.2.1. Size fractionated phytoplankton biomass estimation

Water samples were also sequentially filtered through 20, 2 and 0.2 μm pore size polycarbonate filters (47 mm diameter) to estimate the Chl *a* concentration of the three phytoplankton size-groups: > 20 μm (Netphytoplankton), 2-20 μm (nanophytoplankton) and < 2 μm (picophytoplankton). The filtration process was aided by electrically-operated suction pump (Model SPEEDIVAC 2). The filters were let to stand for overnight (Khan *et al.*, 2010) in darkness under cool condition for the extraction of pigments in acetone and then centrifuged at 3000 rpm for 10 min in a parafilm-covered centrifuge tubes. The extract was then decanted into a 10 ml volumetric flask. The optical density of the sample extract (Absorbance) was then measured against a blank at 665 nm and 750 nm with a spectrophotometer (model PYE UNICAM SP6-350 visible spectrophotometer). The concentration of Chlorophyll *a* was calculated according to Talling and Driver (1963) using absorbance measurements made at 665 and 750 nm.

Phytoplankton biomass as Chl *a* concentration was estimated from the absorbance readings using the following abbreviated formula of Talling and Driver (1963):

$$\text{Chl } a \text{ (}\mu\text{g l}^{-1}\text{)} = 13.9 (E_{665} - E_{750}) \cdot V_e / (V_s \cdot Z)$$

Where E_{665} = absorbance at 665nm

V_s = Volume of sample filtered in liter

E_{750} = absorbance at 750nm

Z = path length of the cuvette in cm

V_e = Volume of extract in ml

Chl *a* = chlorophyll *a*

4.6 Statistical Analyses

The correlation and regression between the different physico-chemical and biological parameters and the contributions of the different size classes to total chlorophyll *a* were tested statistically using Sigmaplot 10.0.

5. Results and Discussion

5.1. Physico-chemical Features

5.1.1. Optical characteristics

Lake transparency (vertical visibility) varied (mean=0.46 m) between 0.21 m of May, 2009 of the minor rainy season and 0.6 m of January, 2009 of the dry season. The Secchi depth of Lake Kuriftu increased from a value close to its annual mean (of December, 2008) to one of its seasonal peaks in February, 2010 before it consistently decreased and dropped to its seasonal minimum in June, 2010. Thereafter, it increased to another seasonal peak in August, 2010, which was followed by a decline to a lower value in September and a steady decline to a value comparable to the seasonal minimum in December, 2010 after a slightly higher value in October, 2010. The Secchi depths (Z_{SD}) of Lake Kuriftu recorded in this study are broadly similar to those of the previous study (0.35- 0.6m; Zelalem Desalgne, 2007).

The lakes found in close proximity to kuriftu such, Lake Hora-kilole ($Z_{SD}= 0.15- 0.78$ m) (Rediat Abate, 2008), Babogaya ($Z_{SD}=1.48-4.46$ m, Yeshiemebet Major, 2006), Hora- Arsedii ($Z_{SD}=0.60- 0.93$ m, Ageze Abza, 2009) and Bishoftu ($Z_{SD}=0.50- 1.05$ m, Tadesse Ogato, 2007) exhibited higher transparency than Lake Kuriftu owing probably to differences among the lakes in the extent of plant cover found in their catchment areas, human activities including agricultural practices and resort and shelter from wind.

The mean Secchi depth values of Lake Kuriftu are, however, greater than those recorded for Legedadi (0.082-0.11m; Adane Sirage, 2006) and Koka (0.28m, Elizabeth Kebede, 1996) reservoirs and Lakes Ziway (0.35m), Abaya (0.43m) (Elizabeth Kebede *et al.*, 1994) and Chamo (0.21-0.375m, Eyasu Shumbulo, 2004), in which attenuation of underwater light is

primarily due to silt and clay, which are known to form a stable colloidal suspension in Lake Langanu (Wood *et al.*,1978; Amha Belay and Wood, 1984; Elizabeth Kebede, 1996).

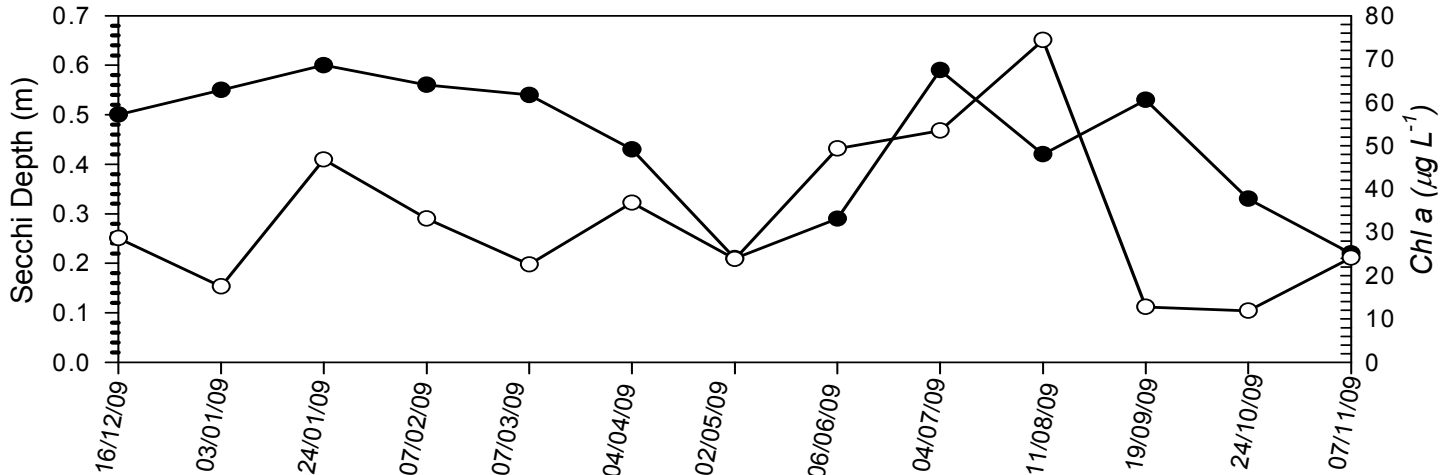


Fig. 3. Temporal changes in Secchi depth (m, closed circle) in relation to algal biomass ($\mu\text{g chl a L}^{-1}$, open circle) in Lake Koriftu.

The temporal variations seen in the transparency of Lake Koriftu 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 correlation between secchi depth and phytoplankton biomass was poor ($r= 0.0476$) indicating the greater importance of abiogenic turbidity. Though data on dry weight of organic and inorganic particulate matter have not been generated, it can be speculated that there was significant amount of abiogenic turbidity, which was probably greater than biogenic turbidity. Eventhough phytoplankton biomass and secchi depth

showed weak correlation on yearly basis, secchi depth showed a sharp decline from April, 2009 to July, 2009 which coincided with the decline in soluble reactive phosphate concentration after one of its peak in April, 2009 and with the increase in total *chl a* concentration suggesting that biogenic turbidity was the major factor for the attenuation of light during these months (April to July) of the year 2009.

5.1.2. Temperature and Dissolved oxygen

The surface water temperatures of Lake Kuriftu ranged from a minimum of 20.3 °C in January, 2009 to a maximum of 26.5 °C in October, 2009. These values are low compared to the previous study by Zelalem Desalgne (2007) (22.8- 33.3 °C). The surface water temperatures of Lake Koriftu are broadly similar to those reported for Legedadi Reservoir (22.2-23.9°C; Adane Sirage, 2006) Babogaya (20.5-28.4°C; Yeshiemebet Major, 2006) Lakes Ziway (18.5-27.5°C; Girma Tilahun, 1988), Abijata and Langano (18-27°C ; Elizabeth Kebede *et al.*, 1994) and Awassa (23.8-28°C ; Demeke Kifle, 1985).

Top-Bottom temperature differences were small ranging from 0.17 °C to 2.73 °C The water temperature at the bottom of the lake ranged from 20.73 °C to 24 ° C. Of March and April, 2009 the bottom water temperature was higher than that of the surface by 0.17 °C and 0.03 °C respectively. This could be attributed to the fact that surface water of the lake is exposed to evaporation and relatively cooler wind, which can bring cooling of the surface water. Protection of bottom water from wind and evaporation by the overlying column of water may have caused bottom water temperature to be slightly higher than surface water

temperature. Thermal stratification was not observed as the lake was continuously mixing owing to its shallowness and exposure to wind action.

Baxter *et al.* (1965) concluded that in lakes with maximum depth less than about 15 to 30 m, complete mixing is normally frequent (polymictic condition) and stratification is largely diurnal in tropical African lakes. Wood *et al.* (1978) also noted that the extent of stratification in crater lakes is dependent on the degree of protection provided by their crater walls. Therefore, frequent and complete mixing is expected in Lake Koriftu as was observed in this study due to its smallness (surface area= 0.4 Km²) and shallowness (5m) and the largely low-elevation and gentle-sloped terrain surrounding the lake which exposes the lake to strong wind action.

Dissolved oxygen (DO) concentration (in mg L⁻¹) showed both spatial and temporal variations. DO in the surface water of the study lake varied from 2.45 of May, 2009 to 14.3 of August, 2009. The seasonal maximum concentration of DO (16.53 mg L⁻¹) was observed at 1 m in November, 2009, while the minimum (2.04 mg L⁻¹) was observed in December, 2008 at 2 and 3 m. The maximum concentration of DO recorded for surface water of the present study was closer to that reported in Zelalem Desalgne (2007) (15 mg O₂ l⁻¹ of December, 2005). It coincided with the highest phytoplankton biomass suggesting photosynthetic liberation of O₂ was higher at this time of the study period. The oxygen concentration in the surface water of Lake Koriftu was generally higher than those recorded for the nearby lakes, Lake Kilole (3.4 to 10.6 mg O₂ L⁻¹; Brook Lemma, 1994), and Babogaya (2.75-15.8 mg O₂ L⁻¹; Yeshiemebet Major, 2006). The lower oxygen concentrations at the

surface observed on some sampling dates seem to be associated with the effect of high temperature on the solubility of gases and photoinhibition. The depth profiles of oxygen seem to corroborate the absence of marked thermal stratification which the present temperature data suggested.

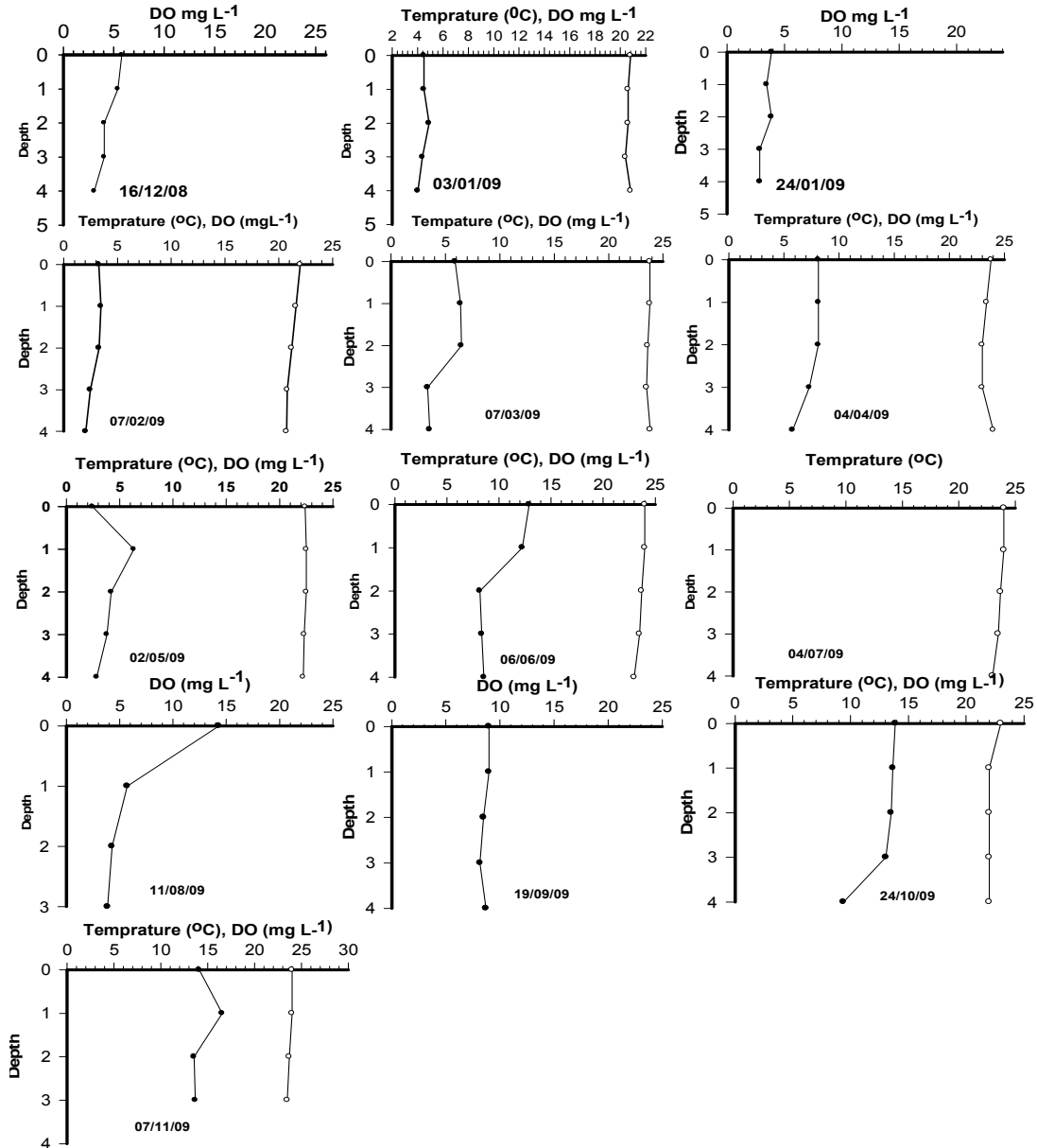


Fig. 4. Depth profiles of temperature (open circle) and dissolved oxygen (closed circle) during the study period in Lake Koriftu.

Relatively lower concentrations of DO were recorded in January and February, 2009 despite the relatively high biomasses of phytoplankton. This could be due to rapid consumption of O₂ combined with surface warming. Mukankomeje *et al.* (1993) noted that even when complete mixing occurs, the combination of surface warming and rapid O₂ consumption by decomposers establishes O₂ decrement in Shallow tropical Lake Mukahi though the temperature never exceeded above 24 °C.

5.1.3. pH and Alkalinity of Lake Koriftu

Carbonate-bicarbonate alkalinity (in meq l⁻¹) showed marked temporal changes varying from a low value of 1.3 in September and October, 2009 to a high value of 4.1 in July, 2009. The high total alkalinity observed in this study was considerably higher than that recorded in a previous study (3.1 meq l⁻¹; Zelalem Desalegne, 2007). Total alkalinity of Lake Koriftu increased from February, 2009 to its highest value in July, 2009. The high alkalinity value observed during the unusually extended dry period was probably associated with evaporative concentration of dissolved ions of this period. It declined to its minimum in September and October, 2009 probably due to dilution by rain fall.

The pH of lake Koriftu varied from a minimum of 7.76 in August, 2009 to a maximum of 8.65, in March, 2009. The P^H values recorded for this lake in the present study were slightly lower than those reported in an earlier investigation for the same lake (8.2- 8.8; Zelalem Desalgne, 2007). The pH values of this lake were generally lower than those reported for Lake Awassa (8.1- 9.09; Girma Tilahun, 2006), Lake Chamo (8.51- 9.22; Girma Tilahun, 2006), Lake Bishoftu (9.17- 9.14; Tadesse Ogato, 2007).

A moderate positive correlation between alkalinity and pH reported for the combined data of Ethiopian lakes (Wood and Talling, 1988) and saline lakes worldwide (Hammer, 1986) was observed in the present study for Lake Kuriftu although it was moderate ($r= 0.6462$, $r^2=0.4176$ at $P<0.05$).

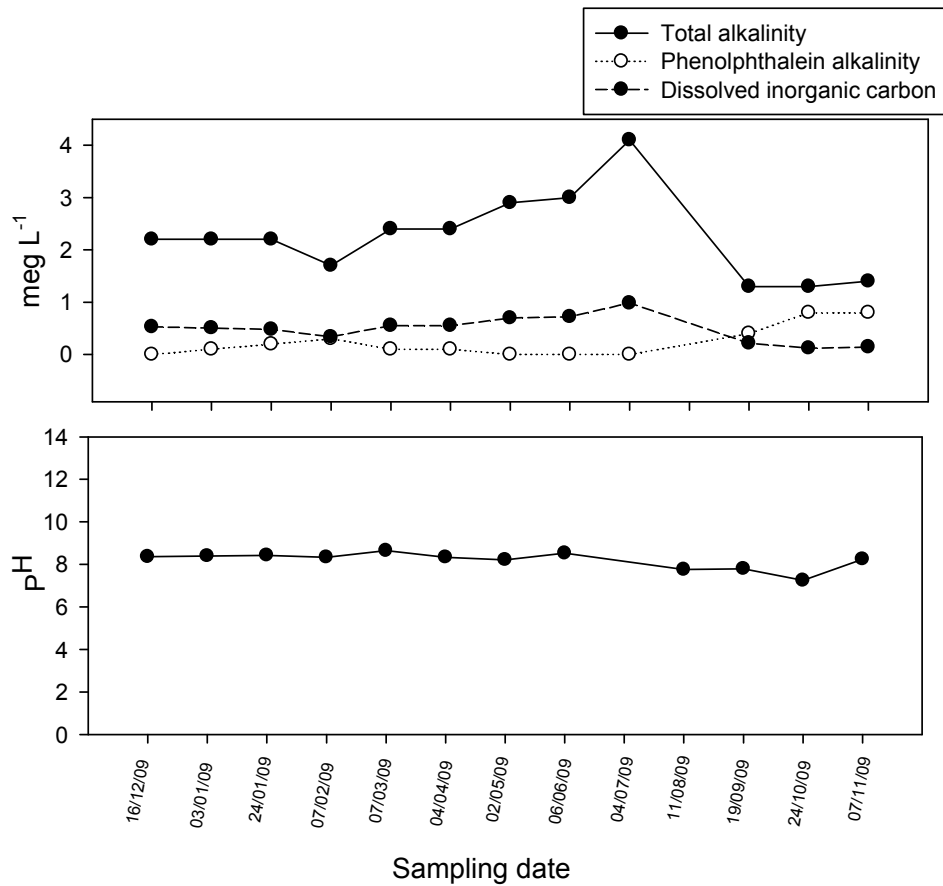


Fig 5. Temporal variation in collective chemical parameters:pH, Total alkalinity (TA), Phenolphthalein alkalinity and calculated free CO₂

The level of free carbon dioxide was calculated from pH-alkalinity relationship described in Saunders *et al.* (1962). It ranged from 0.12 in October, 2009 to 0.984 mg L⁻¹ in July, 2009.

This

Level of free CO₂ was low compared to the values reported for Legedadi Reservoir (0.21 – 3.2 mg L⁻¹; Adane Sirage, 2006). The high level of free CO₂ observed in this study was considerably higher than that observed in a previous studies (0.480-0.576 mg L⁻¹).

The structure and composition of phytoplankton is determined by the level of CO₂ in a body of water because of the differential response of phytoplankton to changes in CO₂ concentration (Shapiro, 1997). 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, the unusually low levels of carbon dioxide may give a competitive advantage to the blue-green algae over other algal groups owing to their physiological adaptation (Shapiro, 1997). Correlations between low CO₂ concentration in lakes and dominance of blue green algae, similar to the situation observed in Lake Koriftu, has well been documented for the nearby Bishoftu Lake (Taddese Ogato, 2007). Talling *et al.* (1973) noted that dense phytoplankton biomass and vigorous photosynthesis can shift pH upwards through more than one pH units.

5.1.4. Inorganic nutrients

The temporal variations in algal macronutrients in Lake Kuriftu are shown in Fig. 7. Nitrate concentration (µg L⁻¹) ranged from a minimum of 9.33 in November, 2009 to 65.45 in April, 2009. The maximum value recorded in this study was higher than that previously reported by Zelalem Desalgne (2007). The levels of nitrate determined in the present study in Lake Kuriftu are higher than the values recorded for other crater lakes including Babogaya (1-31 µg L⁻¹; Yeshiemebet Major, 2006) and Lake Hora (0.97-22.5 µg L⁻¹) but are lower than those

of Lake Bishoftu ($6-110 \mu\text{g L}^{-1}$; Tadesse Ogato, 2007) and Lake Hora-Kilole ($17-303 \mu\text{g L}^{-1}$; Rediat Abate, 2008).

The concentration of NO_3 increased continuously from December, 2008 reaching its peak in April, 2009 during the minor rainy season. This could be attributed to the moderate precipitation, which occurred during the period extending from November, 2008 to January, 2009 leading to increased concentration due to external nutrient loading and internal nutrient loading which was associated with the frequent and strong wind-induced mixing. It then decreased continuously reaching its minimum in August, 2009. This coincided with the highest phytoplankton biomass indicating the decline in nitrate level was due to phytoplankton uptake. Thereafter, it increased until the end of the sampling period, November, 2009, probably due to internal nutrient -loading since the rain fall declined from August, 2009 to November, 2009.

The high nitrate concentrations at times coincided with relatively low phytoplankton biomass and vice-versa although the relation between nitrate levels and phytoplankton biomass was not apparent ($r=0.0051$). Similar observation were made in a previous study by Zelalem Desalgne (2007). The present levels of NO_3 are higher than those reported by Zelalem Desalgne (2007) probably reflecting the human-induced environmental changes to which the lake is subjected to.

Soluble reactive phosphate- phosphorus (SRP, in $\mu\text{g L}^{-1}$) varied from a minimum value of 14.65 in January, 2009 and May, 2009 to a maximum of 402.57 in August, 2009. The seasonal maximum value of SRP coincided with the maximum monthly rainfall suggesting the external loading of SRP through runoff from the surrounding areas. The seasonal

maximum value of SRP corresponded to the largest peak of phytoplankton biomass. SRP concentration in Lake Koriftu was positively and strongly correlated with phytoplankton biomass ($r=0.7168$, $r^2= 0.5138$ at $p<0.01$) probably suggesting the greater importance of phosphorus in determining phytoplankton biomass in Lake Kuriftu.

The maximum level of soluble reactive phosphate (SRP) observed in Lake Koriftu is much higher than those reported for other crater lakes of the same region including Lakes Bishoftu ($280 \mu\text{g L}^{-1}$; Zinabu Gebre -Mariam, 1994), Babogaya ($1-11 \mu\text{g L}^{-1}$; Yeshiemebet Major, 2006) and Hora-Kilole ($0.33- 3.5 \mu\text{g L}^{-1}$; Rediat Abate, 2008). But it's lower than that recorded for Arenguade ($3200 \mu\text{g L}^{-1}$, Elizabeth Kebede, *et al.*, 1994).

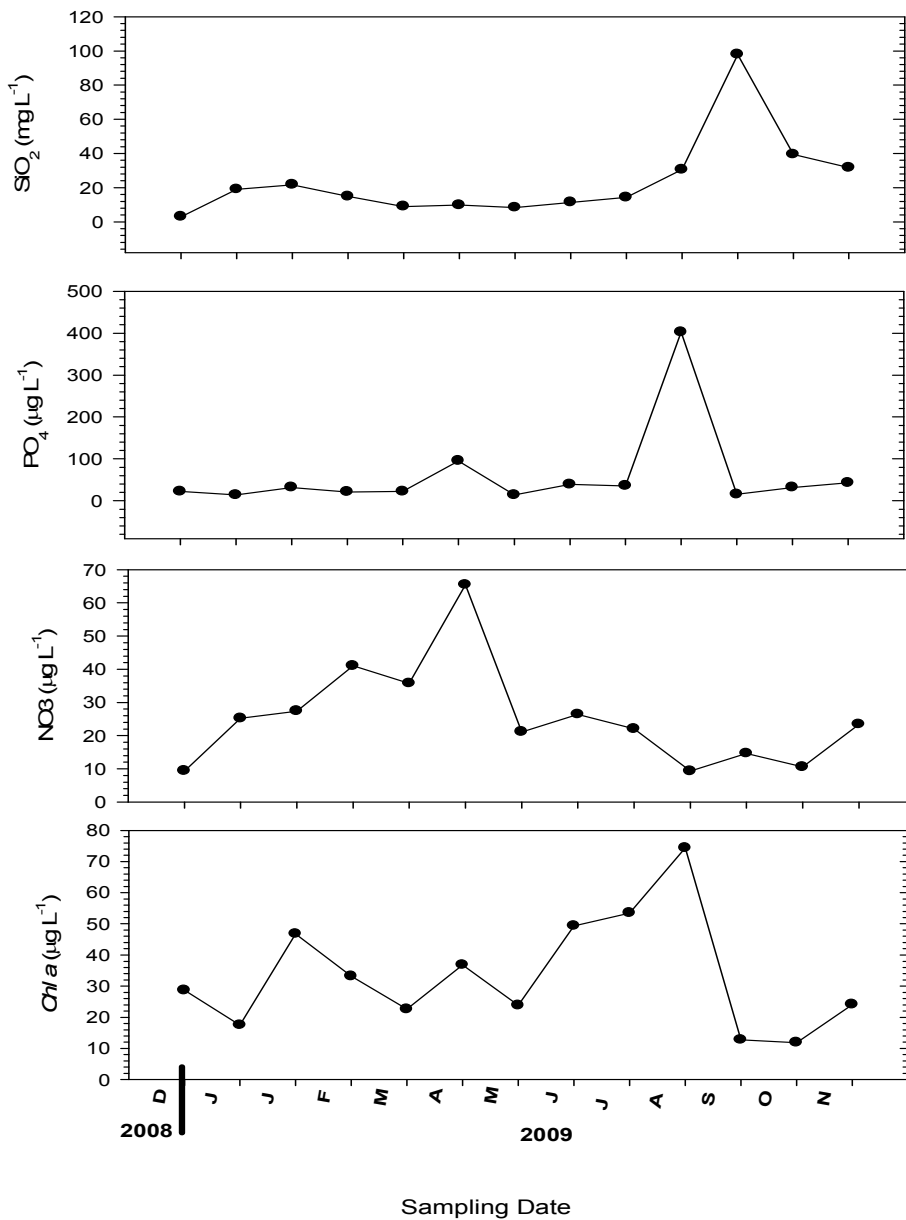


Fig. 6. Temporal variations in the concentrations of inorganic nutrients in relation to phytoplankton biomass in Lake Koriftu.

Dissolved silica (Molybdate-reactive silica, SRSi, in mg L⁻¹) ranged from 3.051 in December, 2008 to 97.92 in September, 2009. The concentration of SRSi showed positive but weak correlation with phytoplankton biomass ($r = 0.2948$, $r^2 = 0.0869$ at $p = 0.3522$). This is to be expected considering the fact that diatoms were less important in their contribution to

phytoplankton abundance of Lake Kuriftu. Silica was at its very low concentrations during the period of short rains (March-May). Coincident with this period of low levels of SRSi, the seasonal maximum concentration of NO₃-N and a small peak of PO₄ occurred in March and April, 2009 respectively. This may be attributable to the fact that loading of nitrate and phosphate depletes silicate (Wetzel, 2010). Due to inputs of N and P, Si:N and Si:P ratios have decreased in many water systems (Turner *et al.* 2003; Billen and Garnier 2007). When Si:N and Si:P ratio's are low, diatom production becomes limited by Si and total consumption of Si increases (Conley *et al.* 1993). Diatoms convert dissolved Si to biogenic Si or opal, which has a low remineralisation rate and easily accumulates in sediments. Therefore, Si consumption in aquatic system by diatoms may result in an increased retention of Si and a reduced export of Si to upper water column (Muylaert *et al.*, 2009). A similar situation was also observed by Zinabu Gebermaiam (2002) in Lakes Chamo and Shalla. 5.3.

5.2. Biological features

5.2.1 Species composition and abundance of phytoplankton

A total of 50 species of phytoplankton belonging to 6 classes were identified (see Table 3). The previous study by Zelalem Desalegne (2005) reported a total of 25 species in Lake Koriftu. The difference could be due to the difference in the focus of the study and methods used. Zelalem Desalgne (2007) used net sampling which is not recommended for quantitative assessment of phytoplankton since nets do not capture phytoplankton of all sizes. Chlorophytes followed by cyanophytes contributed the most to the total number of species in Lake Koriftu. A similar observation was made by Girma Tilahun (2006) in Lakes Ziway, Awassa and Chamo. Among the chlorophytes, *Scenedesmus* was the most species-

rich genus. The species-richness could be due to their resistance to grazing caused by *Daphnia* in which their presence in Lake Koriftu was recorded by Brook Lemma *et al.* (2001). Unicell to colony transformation in green algal *genus Scenedesmus* is triggered by chemicals released by well fed *Daphnia* making them less susceptible to predation because of their increased size (Lurling *et al.*, 1997).

Table 3. List of the species of phytoplankton identified in samples from Lake Kuriftu during the study period

Cyanophyceae	Chlorophyceae	Bacillariophyceae
<i>Anabaena circinalis</i> G.S.West	<i>Arthroocystis ellipsoidae</i> West & West	<i>Cymbella minuta</i> Hilse
<i>A. crotonesis</i> G.S.West	<i>Ankistrodesmus bibraianus</i> (Reinsch) Korsch	<i>C. naviuliformis</i> (Auersw.) Cleve.
<i>Anabaenopsis tanganyikae</i> G.S. West	<i>A. falactus</i> Ralfs.	<i>Nitzschia lanceolata</i> W. Smith.
<i>Cylindrospermopsis africana</i> Kom. & Kling	<i>Chlamydomonas reinhardii</i> Dang	<i>Synedra ulna</i> (Nitsch.)Ehrenberg.
<i>C. cf. catemoca</i> Kom. & Kling	<i>C. debaryana</i> Gorosch	<i>Rhoicosphenia abbreviate</i> (Agadrh) Lange-Berl.
<i>C. Curvispora</i> M. Watanbe	<i>Chlorella c.f.vulgaris</i> Beijerinck	Chryptophyceae
<i>C. raciborski</i> Wolosz	<i>Closterium acutum</i> (Lemm.) Krieg.	<i>Cryptomonas ovata</i> Ehr.
<i>Coelosphaerium</i> sp.	<i>Cosmarium bicuneatum</i> (Rac.) Schmidle	<i>C. borealis</i> Skuja.
<i>Microcystis aeruginosa</i> (Kutz.) Kutz	<i>C. humile</i> (Gay) Nordst	<i>C. marssoni</i> Skuja.
<i>Planktolyngbya microspora</i> komarek et Kling	<i>Monoraphidium contractum</i> (Lemm.) Skv	<i>C. obovata</i> Skuja.
<i>Pseudoanabaena limnetic</i> (Lemm.) Kom.	<i>M. mirabile</i> (Lemm.) Skv	Euglenophyceae
<i>P. moniform</i> Komarek et Kling	<i>Pediastrum tetras</i> Ralfs.	<i>Phacus tortus</i> (Lemm.) Skv.
<i>Raphidiopsis mediterranea</i> Skuja	<i>P. simplex</i> Clathratum.	Dinophyceae
	<i>Phacotus lenticularis</i> (Ehr.) Stein	<i>Peridinium cinctum</i> (O.F. Mull.) Ehr.
	<i>Scenedesmus acuminatus</i> Lagerh	<i>P. bipes</i> Stein
	<i>S. armatus</i> (Chod.) G.M. Smith	
	<i>S. bicaudatus</i> G.M. Smith	
	<i>S. denticularis</i> Lagerh	
	<i>S. quadricauda</i> W. &G.S. West	
	<i>Staustrium curvatum</i> W. West	
	<i>S. muticum</i> W. West	
	<i>Treubaria triappendicularis</i> Ehrenberg	

Tetraedron minimum (A. Br.) Hansg

T. muticum Korsch

T. triangulare Korsch

The other taxonomic groups- dinoflagellates and euglenoids -were poorly represented.

Fig. 7 shows changes in the percentage contributions of different algal groups to the total abundance of phytoplankton in Lake Koriftu. Blue green algae (Cyanophytes) were the most important contributors to the total abundance of phytoplankton with contributions of 94.77 to 99.64 % to the total abundance of phytoplankton. Species of the blue-green algal genera *Cylindrospermopsis* and *Microcystis* were the most quantitatively important phytoplankton taxa. The dominance of these colonial and filamentous cyanobacteria may be attributed to the relative inedibility of filamentous and colonial cyanophytes even to large herbivorous zooplankton (Gliwicz and Lampert, 1990) coupled with their competitive superiority under conditions of low light (higher turbidity) (Scheffer *et al.*, 1997).

Nutrient loading has been considered as an important environmental factor that influences cyanobacterial dominance. Thus, the high concentrations of phosphates ($14.65 - 402.57 \mu\text{g L}^{-1}$) may have resulted in the blooming of *Microcystis* in Lake Manchar (cf. Mahar *et al.*, 2009). The persistence and dominance of cyanobacteria in the present lake could also be due to the high temperature ($22 - 25^\circ\text{C}$) (Davies *et al.*, 2009) as the physiology and growth rates of bloom-forming cyanobacteria, including the potentially toxigenic members, grow optimally around 25°C or higher (Wood, 1978; Ballot *et al.*, 2004).

In general, tropical lakes show cyanobacterial dominance during the dry and falling water level period (Harris and Baxter, 1996) and this probably explains why the abundance of

cyanobacteria in Lake Koriftu peaked in the middle of the dry period (January) with 99.64 % contribution to the total abundance of the phytoplankton community in the lake as the maximum depth recorded in this study was only 5m.

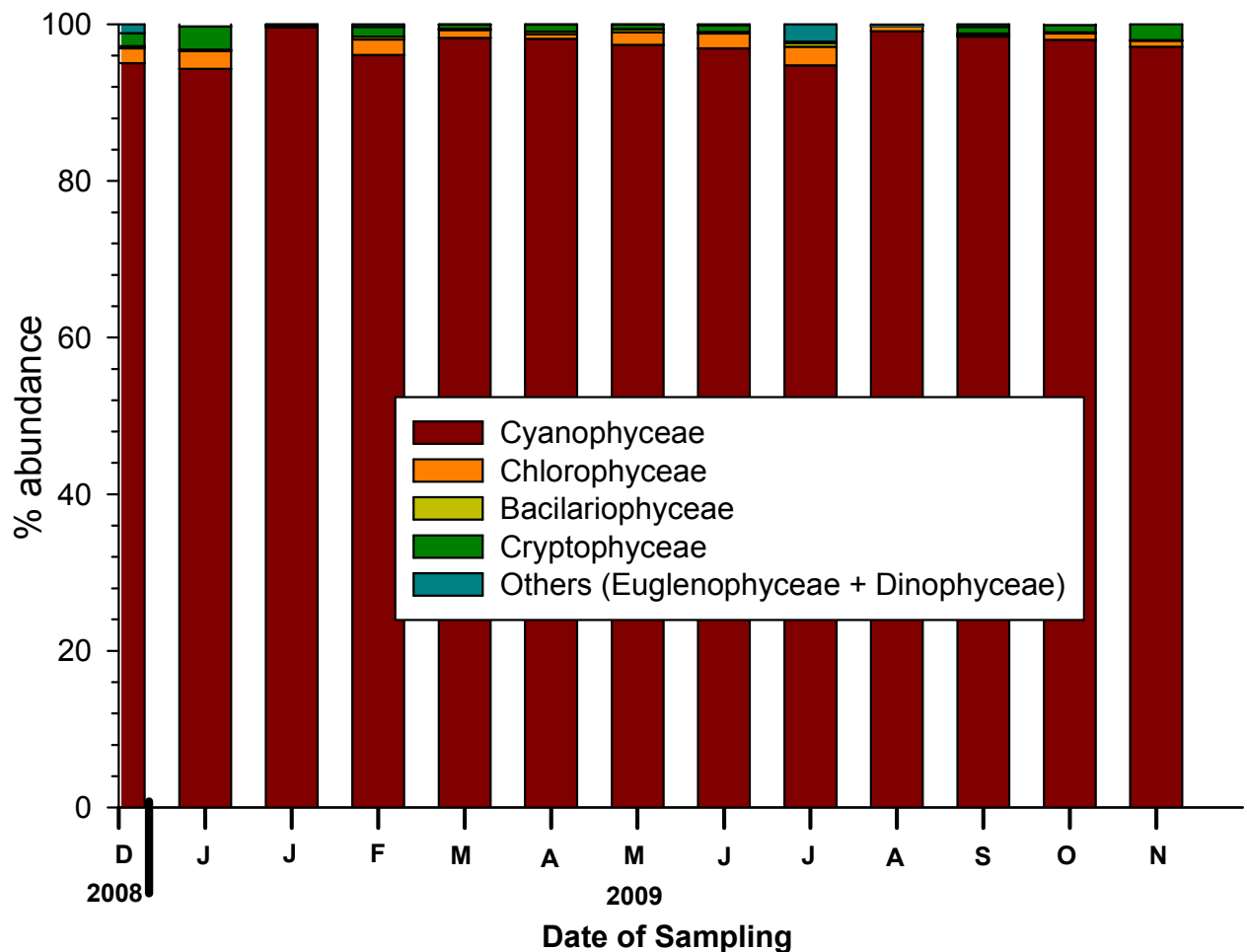


Fig. 7. Temporal changes in the percentage contributions of taxonomic groups to the total abundance of phytoplankton in Lake Koriftu.

Temporal dynamics of the major species of phytoplankton in relation to Chl a biomass and total abundance of phytoplankton are illustrated in Fig. 8. Among the blue-green algae, *Cylindrospermopsis curvispora*, *C. africana* and *Microcystis aeruginosa* were usually the most important in terms of abundance and formed the most conspicuous populations.

Cylindrospermopsis curvispora was the most dominant followed by *Microcystis aeruginosa* and then by *Cylindrospermopsis africana*. The dominance of these two genera has also been reported for other tropical lakes such as the Great African lakes (Hecky and Kling, 1987), Kenyan fresh water Lakes, Naivasha and Oloidien, (Kalff and Watson, 1986), Lake Kariba (Ramberg, 1987), Lake Valencia (Lewis and Reihl, 1982) and Lake Lano (Lewis, 1987).

Cylindrospermopsis curvispora was persistent throughout the study period reaching its peak in late January, 2009. It declined and then maintained almost a constant population until it reached its second peak in August, 2009. The *Cylindrospermopsis curvispora* peaks coincided with the peaks of phytoplankton biomass indicating that *C. curvispora* was the major contributor to total phytoplankton biomass in those months of the year, 2009 although the correlation between the abundance of *C. curvispora* and Chl *a* was poor ($r = 0.42$).

Microcystis aeruginosa was the second most abundant species in Lake Kuriftu. It was common in the dry season and attained its peak in March, 2009. According to Reynolds (1986) daily alteration in thermal stratification and mixing represents an environmental stability level which may favour *Microcystis* dominance in tropical waters. The crucial factor for the dominance of *Microcystis aeruginosa* is its ability to regulate its buoyancy to accommodate severe changes in mixing intensity (Reynolds, 1999). In light of this, the dominance of *Microcystis aeruginosa* in Lake Kuriftu could be attributed to its ability to reposition itself after wind-driven complete mixing which is favoured by its shallowness. In turbid aquatic environments, algal species with gas vesicles, such as *Microcystis*, can either move down to avoid the high light intensity at the water surface, or float up when underwater light conditions are poor (Chen *et al.*, 2003). The low Secchi depth of Lake

Koriftu probably explains the dominance of *Microcystis aeruginosa*. A similar observation was reported for *Microcystis aeruginosa* in Legedadi Reservoir by Adane Sirage (2006).

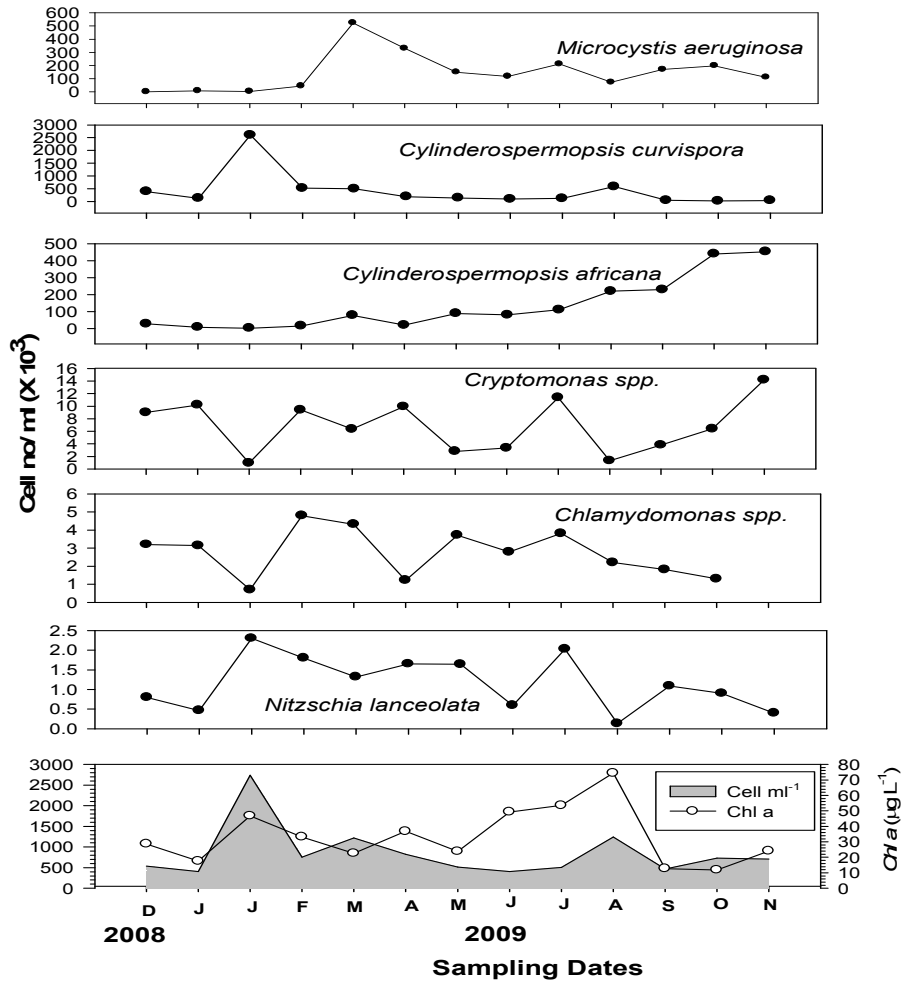


Fig..8. Temporal variation in percentage contribution of different taxonomic groups to the abundance of total phytoplankton abundance in relation to phytoplankton biomass in Lake Koriftu

The third dominant phytoplankton taxon was *Cylindrospermopsis africana* which continuously built up its population until it reached its maximum in November, 2009. It seems unlikely that the nitrogen-fixation capability of *cylindrospermopsis* was the reason for

the dominance, given the relatively high concentration of nitrate (9.33- 65.45 $\mu\text{g L}^{-1}$). The ability to compete for light could be the reason for the predominance of this genus as observed in a subtropical Pine reservoir (Antenucci *et al.*, 2005).

Dinoflagellates contributed very low, with percentage abundance which was in the range of 0 to 2.24%. This could be explained by the inhibition of their growth and cell division by turbulence (Pollinger, 1988) which was the apparent condition in Lake Kuriftu. Similar results were reported for dinoflagellates of Lake Hora-Kilole was observed by Rediat Abate (2008) during periods of increased wind-induced turbulence.

5.2.2. Species Diversity of phytoplankton

Appendix 3 shows seasonal changes in the species diversity of phytoplankton in Lake Koriftu estimated by the Shannon-Weaver diversity index. The highest diversity was recorded in December 2008 (6.42 bits/individual) while the lowest (1.24 bit/individual) was recorded in late January, 2009. During the major rainy season, August-October, 2009, the cyanobacterium *Cylindrospermopsis* rapidly built up and attained its 2nd maximum population peak during which the diversity was about 2.6 bits/individual.

The diversity index for Lake Koriftu varied within a narrow range (1.24 -6.42 bits/individual; mean= 3.43) and was generally higher than 1. The cyanobacterium *Cylindrospermopsis curvispora* accounted for about 95% of the total phytoplankton abundance when the diversity index was 1.24. On the other hand, diversity indices were high (6.42 and 5.11

bits/individual) in December, 2008 and July, 2009 and were associated with relatively large number of taxa (21 and 28 genera respectively).

Many researchers have found eutrophic lakes to have low diversity and oligotrophic lakes to have high diversity (Wetzel, 1983). It has been suggested that eutrophic systems are highly disturbed, and that this results in an inhospitable environment for many species. It has also been suggested that severe light limitation in eutrophic systems can result in lowered diversity (Striebel *et al.*, 2009). It is equally possible that the slower growth rates in oligotrophic lakes permit a larger number of species with similar requirements to coexist resulting in high species diversity of phytoplankton (Wetzel, 2001).

Periodic disturbance has often been shown in both laboratory and field assessments to increase diversity and species richness in phytoplankton communities (Interlandi and Kilham, 2001). Senthilkumar and Sivakumar (2008) observed the maximum phytoplankton diversity during post monsoon season that had created turbulence of the Indian Lake Veeranam Lake. Higher values of species diversity index of phytoplankton in Lake Tamil Nadu, India were reported during monsoon season, which were associated with the heavy rainfall (Regini Balasingh *et al.*, 2008).

5.2.3. Total and size-fractionated phytoplankton biomass

The phytoplankton biomass of Lake Kuriftu exhibited temporal variations over the study period. The values recorded ranged from 11.87 to 74.36 ($\mu\text{g Chl } a \text{ L}^{-1}$). The lowest phytoplankton biomass measured as *Chl a* was observed in October, 2009. The maximum phytoplankton biomass value of Lake Koriftu is higher than those recorded for other lakes in

the same region including Lake Bishoftu (Tadesse Ogato, 2007), Lake Hora (Ageze Abza, 2009) and such similarly shallow water bodies of the rift valley area as Koka reservoir (Hadgembes Tesfaye, 2007), Lake Ziway (Girma Tilahun and Ahlgren, 2009), Lake Awassa (Demeke Kifle, 1985).

Phytoplankton biomass was positively and strongly correlated with SRP ($r= 0.7168$, $r^2=0.5138$ at $p=0.0087$) while its correlation with SRSi ($r=0.2948$, $r^2=0.0869$ at $p=0.3522$) and nitrate-nitrogen ($r=.0051$) was poor probably indicating the importance of SRP in determining the abundance of phytoplankton in Lake Kuriftu. The weak correlation of total phytoplankton biomass with SRSi is consistent with the low abundance of diatoms in Lake Kuriftu which is an indication of the low contribution of diatoms to total phytoplankton biomass.

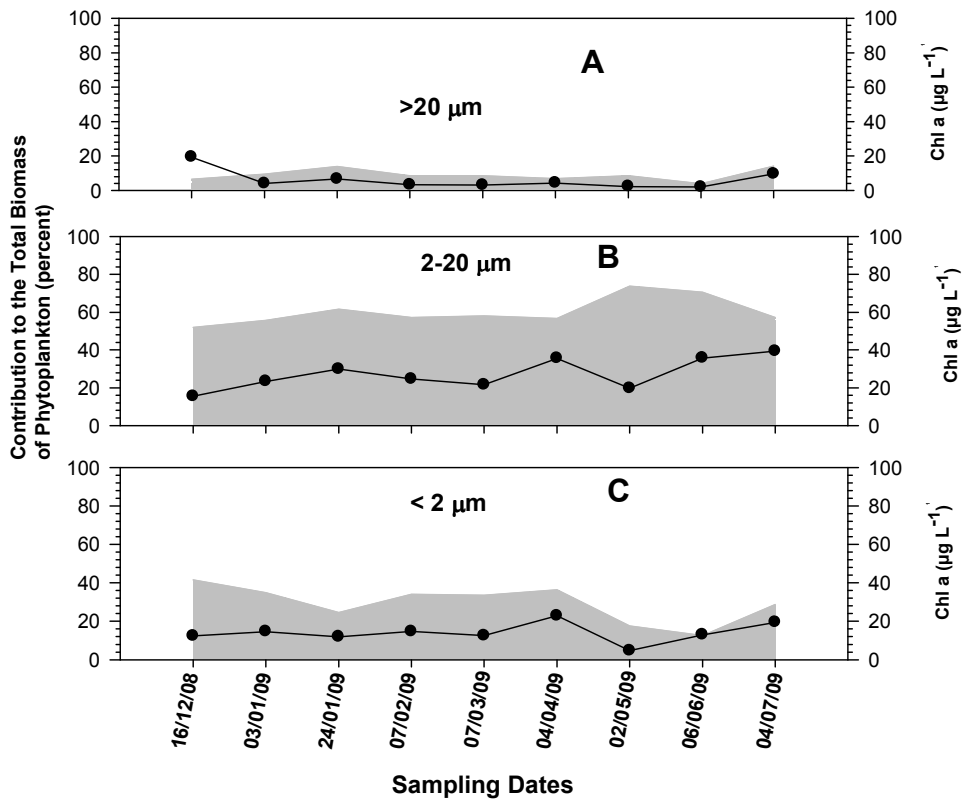


Fig.9. Temporal variations in the biomass (line plot) and percentage contributions to total phytoplankton biomass (area plot) of different size groups.

The contributions of the three size-groups to total Chl a biomass varied temporally (see Fig. 9). The *Chl a* values of the 2- 20 μm (nanoplankton) and < 2μm (picoplankton) fractions were higher than those of > 20 μm (netplankton) fraction. Among the three size-groups, the nanoplankton was the most important contributor to the total phytoplankton biomass with its biomass and percentage contributions to total phytoplankton biomass ranging from 15.44 μg L⁻¹ and 51.93 % to 19.74 μg L⁻¹ and 73.84 % respectively. Similar results were reported by Girma Tilahun (2006) for Lakes Ziway and Awassa. The *Chl a* biomass and percentage contributions to total phytoplankton biomass of the netplankton and picoplankton varied from 1.94 to 6.73 and 6.53 % to 13.87% and 4.68 to 14.63 and 17.5% to

41.54 % respectively. Peak of nanoplankton biomass coincided with relatively low biomass values of the netplankton. The correlation between picoplankton biomass and total phytoplankton biomass was positive and strong ($r=0.8421$, $r^2=0.7091$ at $p < 0.01$). The lowest picoplankton biomass coincided with the highest of the nanoplankton and the lowest of total phytoplankton biomass. This probably indicates that the temporal variations in phytoplankton biomass in Lake Koriftu are largely due to changes in factors that determine the biomass accumulations of the picoplankton.

The highest biomass of picoplankton coincided with relatively low secchi depth. This could be explained by the ability of picoplankton to attain maximum growth at low irradiance (Fogg, 1986). Picoplanktons studied in the laboratory have all been found to show maximum growth at relatively low irradiances, the eukaryotic forms being more efficient than the cyanobacteria in utilizing the blue light which predominates at the bottom of the euphotic zone in clear oceanic waters (Fogg, 1986). Picoplankton has been found to be dominant in oligotrophic oceanic waters around the world as well as in temperate oligotrophic lakes (Bell and Kalff, 2001; Fogg, 1986; Hernandez-Aviles *et al.*, 2010; Winder, 2009; Yamaquachi and Imai, 1996). Although few, there are studies on tropical lakes (Stockner, 1988; Girma Tilahun, 2006; Rediat Abate, 2008). The high contribution to phytoplankton biomass of nanoplankton and picoplankton in Lake Koriftu may be attributed to low light condition and shallow depth that would tend to favour smaller cells with faster growth rates, greater photosynthetic efficiency, and lower sedimentation rates (Chételat, 2006). It could also be attributed to wind-driven turbulence in Lake Kuriftu. Barros and Barbosa (2006) attributed the high biomass contribution of the smaller fraction ($< 20 \mu\text{m}$) to

turbulence which re-suspended these organisms and increased their permanence within the euphotic zone in Dom Helvécio Lake, Brazil.

Results of an artificial lake fertilization experiment demonstrated that phytoplankton abundance was often limited by the concentration of nitrogen rather than by the concentration of phosphorus (Chattopadhyay and Banerjee, 2007). Talling and Talling (1965) suggested that nitrogen limitation is more likely to occur in tropical African lakes because nitrate levels are often very low where as phosphate levels are relatively high. In the tropical man-made shallow Lake, Lake Krishnasayer, the seasonal change in the concentration of $\text{NO}_3\text{-N}$ and overall netphytoplankton abundance demonstrated that $\text{NO}_3\text{-N}$ was the nutrient for growth and also the limiting one for overall netphytoplankton abundance (Chattopadhyay and Banerjee, 2007). It seems unlikely the nitrate-nitrogen limitation was the reason for the least biomass contribution of netplankton to the total biomass given the concentration of Nitrate ($9.33\text{-}65.45 \mu \text{L}^{-1}$).

In some studies, although the net plankton are frequently the most conspicuous component of phytoplankton communities, they are known to be particularly inefficient primary producers, most likely as the result of smaller surface to volume ratio than the picoplankton and nanoplankton (Rodhe *et al.*, 1958; Findcnegg, 1965; Kalff, 1972) where as the predominance of nanoplankton in natural waters has been hypothesized to be due to intrinsically higher growth rates, photosynthetic rates, and nutrient uptake rates of small algal cells with high surface-to-volume ratios. These factors could be the reason for the higher contribution of nanoplankton in Lake Kuriftu.

6. General Discussion

The eutrophic Lake Koriftu supports a phytoplankton community which exhibits temporal variation in its biomass, abundance and to some degree in its species composition in relation to changes in the physico-chemical conditions of its water column. The phytoplankton community in this lake was largely dominated by cyanophyceae whose dominance was favoured by high temperature and elevated nutrients which are regarded as factors of over-riding importance in determining the seasonal dominance of algal groups in Lake Koriftu. Human activities are responsible for the changes in the physico-chemical and biological conditions of the lake. The predominance of toxic and nuisance cyanobacterial genera like *Microcystis* and *Cylindrospermopsis*, whose persistence is favoured by the nutrient rich and turbid water column, are directly connected with human activities around the lake specially resort and agriculture.

Large-sized cyanobacterial assemblage is less affected by grazers in eutrophic Lakes since they can weaken the ability of crustaceans to graze them effectively by interference and also by clogging their feeding apparatus (Carney and Elser, 1990). They are also less edible and sometimes toxic to cladocerans (De Bernardi and Guissani, 1990). The size-fractionation experiments conducted by Girum Tamire (2006) in this lake also seem to indicate that the grazers probably have lower contribution to the removal of phytoplankton. He suggested that the rare occurrence of cladocerans and common occurrence of filamentous and colonial phytoplankton can be the reason for the zooplankton not having high impacts on natural phytoplankton assemblages in Lake Kuriftu. If the activities around

the lake continue, environmental degradation of the ecosystem and the recreational value of the lake will likely to be lost in the near future.

The situation in Lake Kuriftu in which the smaller phytoplankton fractions contributed more than the netplankton does not seem to conform to the generalization that netplanktons dominate eutrophic lakes and picoplanktons in oligotrophic lakes of temperate lakes.

7. Conclusions and Recommendations

The results of the present study show that Lake Koriftu is a very shallow, frequently mixing turbid and eutrophic lake whose phytoplankton community exhibits variation in abundance and biomass. Human activities around the lake coupled with meteorological changes specially rain fall have resulted in seasonal changes in the physic-chemical and biological features of the lake. The phytoplankton community in this lake was largely dominated by cyanophyceae reaching up to 99% in contribution to the total abundance of phytoplankton. Cyanophyceae dominated the phytoplankton community of Lake Kuriftu owing to the adaptive features they evolved for turbid water column conditions.

On the basis of the results of the present study, the following recommendations are made:

- A detailed study on the impact of recreational and agricultural activities talking place around the lake is mandatory to generate information which may be of some use in the development of strategies for the protection of the lake.
- Since the standing crop, species composition and production of phytoplankton are the results of phsico-chemical and biological factors, future investigations should given due consideration to biological controls of phytoplankton.
- Future investigation should also focus on picoplanktonic species composition and abundance.

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9. Appendices

Appendix 1. Formulae used for the estimation of physical, chemical and biological parameters

I. 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

II. From Talling and Driver (1963)

Chl a $\mu\text{g/L} = \underline{13.9 \times (E_{665} - E_{750}) \times V_e}$

$V_{sf} \times PL$

Where E_{665} = extinction at 665 nm

E_{750} = extinction at 750 nm

V_e = Volume of extract

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

PL = path length of the cuvette (1cm)

III. Shannon and Weaver Index

$$H' = -\sum p_i \ln(p_i) \quad \text{Where } H' = \text{The Shannon-Weaver Diversity Index}$$

p_i = the relative abundance of each group of organisms

Appendix 2. Statistical relations between different parameters measured in Lake Koriftu in this study.

X(independent Variable)	Dependant Variable(Y)	r	r ²	P	Regression equation
Biomass	Z _{SD}	0.046	0.002	0.7062	Y=0.174x + 35.2
Alkalinity	P ^H	0.6462	0.4176	0.0273	Y=1.012X - 6.247
NO ₃ -N (µg L ⁻¹)	Total Biomass	r=0.0051	2.601 x 10 ⁻³	0.0327	Y=0.006X+33.3
PO4-P (µg L ⁻¹)	Total Biomass	0.7168	0.513	0.0087	Y=4.115X- 77.06
SiO ₂ (mg L ⁻¹)	Total Biomass	0.2948	0.087	0.3522	Y=-0.0225X + 38.88
Total abundance	Total Biomass	0.3391	0.115	0.2556	Y= 0.009X + 25.12
Abundance of <i>Cylindrospermopsis africana</i>	Total Biomass	0.420	0.177	0.2627	Y= -74.12X + 935
Picoplankton biomass	Total biomass	0.8422	0.7091	0.004	Y= 2.306X + 13.164

Appendix 3. Phytoplankton species Diversity in Lake Koriftu

Sampling date	Diversity index
16/12/08	6.4
03/01/09	3.9
24/01/09	1.2
07/02/09	2.2
07/03/09	2.83
04/04/09	3.6

02/05/09	4.16
06/06/09	4.5
04/07/09	5.11
11/08/09	2.6
19/09/09	3.09
24/10/09	2.4
07/11/09	