Full Length Research Paper

Photosynthetic productivity and biomass of phytoplankton, in Lake Kuriftu, Ormia Region, Ethiopia

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Photosynthetic productivity of phytoplankton and chemicals of the water column in Lake Kuriftu were studied from August 2005 to April 2006. 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 A_{max}, 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.

Key words: Photosynthetic productivity, phytoplankton, oxygen.

INTRODUCTION

In order to meet the growing food requirements of the world population, great effort is needed in the development and utilization of the biological wealth of the aquatic environment. 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). Phytoplanktons are the major primary producers in many aquatic systems and are an important food for consumers (Reynolds, 1984).

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. 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 to 57 g O_2 m^{-2} d^{-1} (Ca. 16 to 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.*

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 dynamics of phytoplankton standing stock and productivity in African lakes was reported to vary intimately with the fluctuation in water level (Lemoalle,

1975; Melack 1976). Melack (1976) found positive correlation between level of primary productivity and changes in water level. 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.

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. 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. So, the purpose of this research study was, therefore to study the temporal dynamics of photosynthetic primary production of phytoplankton in relation to some physico-chemicals in Lake Kuriftu.

Study area

Lake Kuriftu is one of the lakes found in and around the town of Bishoftu. It is found at an altitude of 1860 m, 47 km southeast of Addis Ababa. The lake is located at 8° 47' N and 39° 00'E. Lake Kuriftu is a shallow (≈6 m) (Brook 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 et al., 2001).

MATERIALS AND METHODS

Sampling protocol

Two stations of samplings were selected 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, 0.50, 1.00, 1.50, 2.00 m) distributed within the euphotic zone. The samples collected from different depths were mixed in equal proportions to produce a composite sample for measurement of biomass, chlorophyll a concentration and photosynthetic primary production.

Measurement of physico-chemical parameters in the field

The parameters measured in situ include the following:

(i) Secchi depth was estimated with a standard Secchi disc of 20 cm diameter.
(ii) pH was measured in situ by a portable digital pH meter (Jenway 3200).
(iii) Depth profiles of oxygen were determined with a digital oxygen

meter (Hanna 9024) within a few hours of sample collection and carbonate-bicarbonate alkalinity was determined by titration with HCl to a pH of 4.5.

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 (used just to have almost uniform samples for the lake in taking samples at different depth of the lake) was produced using water samples collected from selected depths distributed within the euphotic zone which was used in the estimation of photosynthetic production. Duplicate light bottles were attached to a suspension line prepared for incubation purpose, at each of the established depths distributed within the euphotic zones (0.00, 0.25, 0.50, 1.00, 1.50 and 1.75 m).

Statistical analysis

The relationships between the different physico-chemical and biological parameters were tested statistically using Minitab ver.14.

RESULTS AND DISCUSSION

Physical parameters

The physical characteristics of Lake Kuriftu during the study period were measured. Lake's transparency (vertical visibility) varied between 0.35 m in April 2006 of the minor rainy season and 0.6 m in December 2005 of the dry season at the open water station.

The surface water temperatures at the central station of Lake Kuriftu ranged from a minimum of 22.8°C in February 2006 to a maximum of 33.3°C in January 2005 with most values between 28 and 30°C. The maximum surface water temperatures of Lake Kuriftu are closer to those of Lake Chamo (26 to 30°C; Eyasu, 2004) in Ethiopia and Lake George, in Uganda (26 to 36°C; Ganf and Horne, 1975) than to those reported for the Ethiopian Rift Valley Lakes including Lakes Ziway (18.5 to 27.5°C; Girma, 1988), Abijata and Langano (18 to 27°C; Elizabeth and Amha, 1994) and Awassa (23.8 to 28.4°C) (Demeke, 1985) and other lakes of the same region as the present study lake, Lakes Kilole (18.5 to 24°C; Brook, 1994), Babogaya (20.5 to 28.4°C; Yeshiemebet, 2006) and the Legedadi Reservoir (22.2 to 23.9°C; Adane Sirage, 2006).

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 and Lake Ziway (Girma, 1988) which are almost continually stirred to their bottoms.

Table 1. 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.

Chemical features of Lake Kuriftu

Depth profiles of oxygen

Depth profiles of dissolved oxygen determined at the central station of Lake Kuriftu during the study period were observed. 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 0.25 m. 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.

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, 1994), and Babogaya (2.75 to 15.8 mg O_2 l^{-1}; Yeshiemebet, 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.

pH and alkalinity of Lake Kuriftu

Aggregate chemical parameters of Lake Kuriftu measured over the study period are given in Table 1. The pH of the surface water of Lake Kuriftu at the central station ranged from a minimum of 8.20 in August 2005 to a maximum of 8.80 in November 2005. The pH values recorded for this lake in the present study are slightly higher than those reported in an earlier investigation (7.90 to 8.40; Brook et al., 2001). The pH values of Lake Kuriftu, which are comparable to those of Lake Awassa (Makin et al., 1975; Demeke, 1985) were generally lower than those recorded in the nearby crater lakes, Lake Bishoftu (9.20; Zinabu, 1994) and Babogaya (8.84 to 9.09; Yeshiemebet, 2006) and the Rift Valley Lake Chamo (8.53 to 9.44; Eyasu, 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 9.00 and 10.50 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^- withdrawal leading to an increase in pH (Maberly, 1996).

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). Carbonate-bicarbonate alkalinity (in meq/L) 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, 1994).

The alkalinity of Lake Kuriftu, which is close to that of Koka Reservoir (Elizabeth, 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 to 12.1; Yeshiemebet, 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 level of free carbon dioxide was calculated from pH-alkalinity relationship (Table 1) 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 to 3.15; Adane, 2006).

Photosynthetic primary productivity

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 Figure 2. The vertical distribution of photosynthetic activity per unit volume of water in Lake Kuriftu was of a typical pattern for phytoplankton (Talling, 1965; Ganf, 1974; 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 subsurface 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. The depth profiles of photosynthetic activity observed for Lake Kuriftu (Figure 1) 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 and Wood, 1984; Girma, 1988; Demeke and Amha, 1990), Chad (Lemoalle, 1983), Kenya (Talling, 1965; Melack, 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 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 16.70%.

As a function of irradiance, the extent of inhibition of photosynthetic productivity was variable. An irradiance (PAR) of 11.78 E m^{-2} h^{-1} in March 2006 produced 16.60% 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 were reported from other water bodies of the tropical (Demeke and Amha, 1990) and temperate regions (Jones, 1978). 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
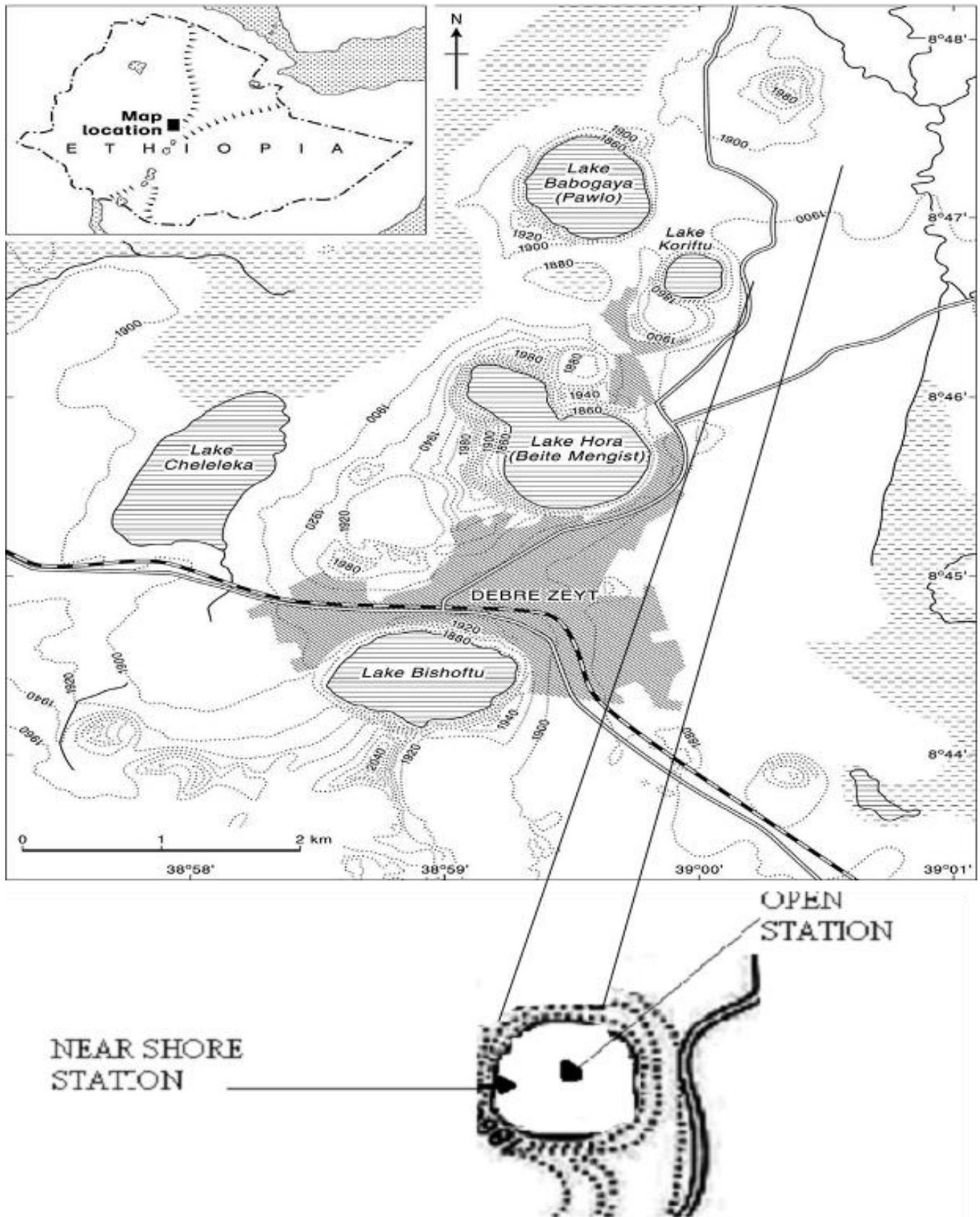
Figure 1. Map of the Lakes in and around Bishoftu town including Lake Kuriftu.

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 mg Chl a m^{-3} while the lowest gross photosynthetic rate (571 mg O_2 m^{-3} h^{-1}) was observed in August 2005 to be associated with a biomass of 17.236 mg 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 0.25 m 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.

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}), daily integral rates of gross photosynthesis ($\sum\sum A$, g O_2 m^{-2} d^{-1}) and photosynthetically active radiation (PhAR) are given in Figure 2.

The maximum rates of phytoplanktonic photosynthesis (A_{max}) ranged from 571 to 1136 mg O_2 m^{-3} h^{-1}. The highest values of these light-saturated rates of gross photosynthesis are higher than those reported for Lake Babogaya (106 to 407; Yeshiemebet, 2006), Awassa (217 to 425; Demeke and Amha, 1990) and Abijata (960; Amha and Wood, 1984); all in Ethiopia and Lakes Naivasha and Cresent Island Crater (150 to 240 mg O_2 m^{-3} h^{-1}; Melack, 1979a). Much higher values of A_{max} have been reported for the Ethiopian crater Lakes Kilole and Arenguade (10,000 to 30,000; Talling et al., 1973), the shallow rift valley Lake Ziway (1640 to 4670; Girma, 1988); Lake George in Uganda (1900 to 6,000 mg O_2 m^{-3} h^{-1}; Ganf and Horne, 1975) and Lake Simbi in Kenya (950 to 12,900 mg O_2 m^{-3} h^{-1}; Melack, 1970).

Higher rates of light-saturated photosynthesis were observed at times of high phytoplankton biomass in Lake Kuriftu. 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% of the variation in the former. Pentecost and Happey-Wood (1978) have also found similar 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, 1988) and Lake Chamo (r=0.3; Eyasu, 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 and Amha, 1990).

According to Talling (1965) and Hammer (1981), high maximum rates associated with low algal biomass are the results 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 (Uku and Mavuti, 1994)). 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 to 22.5; Girma, 1988), Awassa (4 to 19; Demeke and Amha, 1990), Arenguade (11 to 18; Talling et al., 1973) in Ethiopia, Lakes Simbi and Sonachi in Kenya (15 to 17 and 8 to 14 respectively; Melack, 1981) and Lake George in Uganda (17 to 19; Ganf and Horne, 1975). The maximum P_{max} value of Kuriftu is closer to those of Lakes Babogaya (19 to 29) (Yeshiemebet, 2006), Chamo [10 to 34 mg O_2 (mg Chl a)$^{-1}$ h^{-1}]; Eyasu, 2004] and Lake Kilole [16.3 to 33.7 mg O_2 (mg Chl a)$^{-1}$ h^{-1}; Talling et al., 1973].
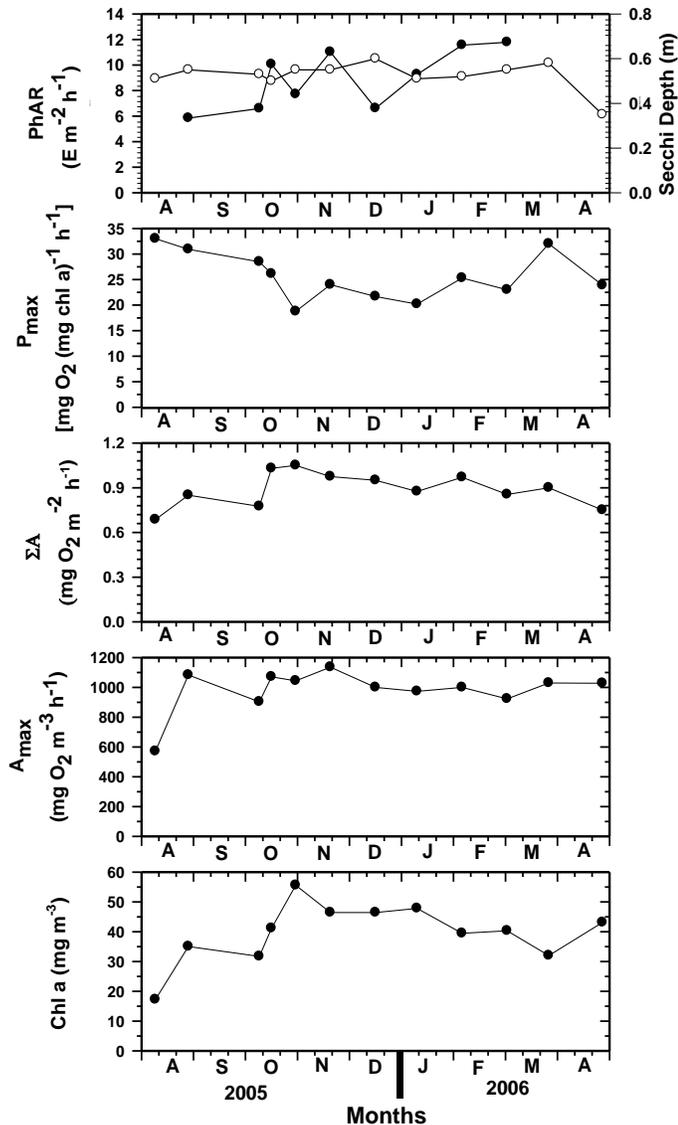
The correlation between P_{max} and A_{max} is negative and low (r =-0.34) which may provide an explanation for the association of high light-saturated rates with low algal biomass observed for Lake Kuriftu. In the present study,
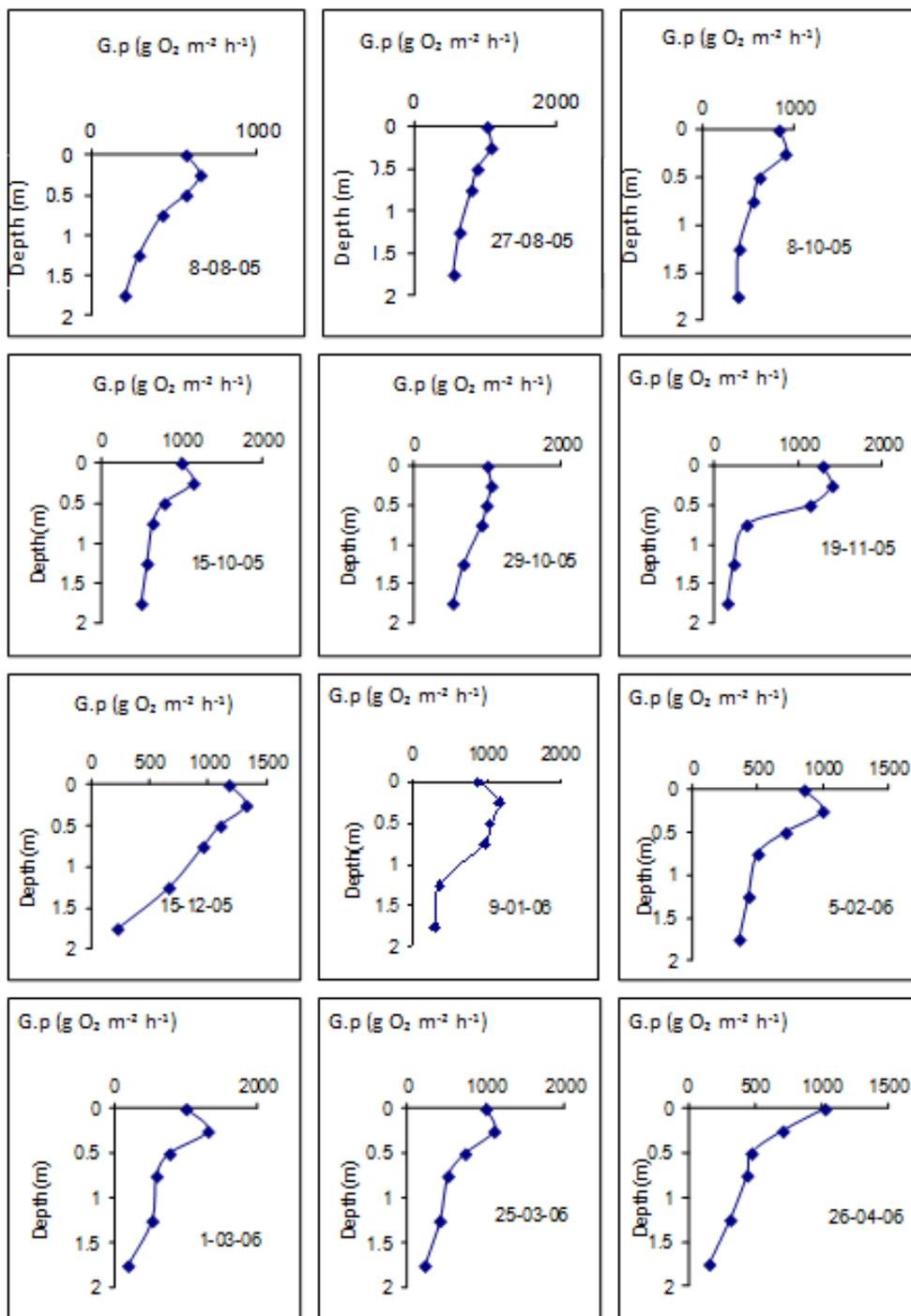
Figure 2. Depth profile of gross photosynthesis per unit volume at open station.

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

Figure 3. Temporal variations in phytoplankton photosynthetic parameters in relation to biomass and integral irradiance (closed circle) of the incubation period and Secchi depth (open circle) in Lake Kuriftu.

which showed a drop in photosynthetic capacity during the markedly cooler season supported the same view. As 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 the large reserve of CO_2 for localized photosynthetic activity in condensed photosynthetic zones (Talling et al., 1973).

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 Figure 3. 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, 2004), Babogaya (0.47 to 0.86; Yeshiemebet, 2006) and Awassa (0.3 to 0.725; Demeke and Amha, 1990) although it is much smaller than those observed in the crater lakes Arenguade (1.43 to 2.56; and Simbi (0.62 to 5.22; Melack, 1979b). 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 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, 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 in Lake Kuriftu, are much higher than those obtained for phytoplankton of Legedadi reservoir (0.16 to 0.98%; Adane, 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 (that is, 10). The calculated values ranged from 6.174 to 9.45 g O_2 m^{-2} d^{-1} during the sampling period. The highest daily integral value of Lake Kuriftu is considerably lower than those

Stone, 1983) 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),

recorded for Lake Ziway (3.1 to 17.6; Grima, 1988), Arenguade (11.25 to 44.83 g O$_2$ m^{-2} d^{-1}; although it is close to those of Lake Chamo in Ethiopia (3.8 to 10.86; Eyasu, 2004). African Lakes with smaller maximum daily integrals include Babogaya (1.01 to 5.98; Yeshiemebet, 2006) and Kilole (1.49 to 2.4; Talling et al., 1973) in Ethiopia.

Conflict of Interest

The authors have not declared any conflict of interests.

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