ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

Spatio- Temporal Variations of the Biomass and Primary Production of Phytoplankton in Koka Reservoir

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Master of Science in Biology

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1. BACKGROUND AND JUSTIFICATION

There is a need to support the ever-increasing human population with supplementary food source and to alleviate the severly hunger striken people due to the recurring drought in Ethiopia. Therefore, the sustainable utilization of aquatic resources, particularly the fishery resource, as a cheap source of animal protein, has no imperative (Shibru Tedla, 1973; Tesfaye Wudneh, 1998). Although the country is land-locked, there are various freshwater lakes and reservoirs from which a great deal of food for humans could be obtained. Koka Reservoir is one such fresh water body with an estimated high potential fish yield of 2000-2500 tons per year (Feyissa, 1983).

Temporal variability in the structure and function of phytoplankton community is of fundamental importance to the metabolism of an aquatic system (Calijuri *et al.*, 2002). Aquatic environments are subject to high temporal variability, with frequent reorganization of the relative abundance and species composition of phytoplankton as a result of the interactions between physical, chemical and biological variables (Reynolds, 1990). In Reservoirs, there are additional factors owing to the hydrodynamic differences arising from the location, morphometry and the main function of a given system. The hydrological cycle, which determines precipitation, governs dam operation and theoretical water retention times in the system, generating 'pulses' of material and nutrients in suspension, material cycling and biomass losses (Calijuri, 1999).According to Calijuri (2002) study on eutrophic Barra Bonita Reservoir, the main external factors that regulate the reservoir are rainfall,wind,flushing rate and theoretical water retention time. The study of changes in phytoplankton biomass, species composition and primary production in water bodies is, therefore, fundamental to the understanding of both water quality and fisheries. (Taylor *et al.*, 2002). Furthermore, fish yield depends on the primary production of phytoplankton, particularly in such water bodies as Koka Reservoir in which the piscifauna is primarily composed of planktivorous species such as Tilapia (FLDP, 1998).

A large number of studies have been made on the community structure and primary production of phytoplankton in various East African Lakes (Talling and Lemoalle, 1998). In Ethiopia, several reservoirs have been built, the most important ones being those which are used principally for the generation of hydroelectric power. However, very limited attention has been given to Ethiopian reservoirs. The few studies which were conducted on the phytoplankton of Ethiopian reservoirs have not been systematic. The studies made on the species composition of phytoplankton in Ethiopian reservoirs are those of Melaku Mesfin *et al.*, (1988) and Elizabeth Kebede & Willen (1996) on Koka Reservoir, whose investigations involved the analysis of single samples. The only systematic long-term studies made on the phytoplankton of reservoirs in Ethiopia are those of Melaku Mesfin & Amha Belay (1989) and Adane Sirage (2006) on Legedadi Reservoir. Thus, very little has been done in this aspect in Ethiopian reservoirs.

Though not on a long–term basis, primary production of phytoplankton in Rift Valley lakes of Ethiopia was investigated by Amha Belay and Wood (1984) for the first time. The only long–term studies carried out on phytoplankton production on monthly basis are those of Girma Tilahun (1988) in Lake Ziway, Demeke Kifle and Amha Belay (1990) in Lake Awassa, Eyasu Shumbulo (2004) in Lake Chamo, Adane Sirage (2006) in Legdadi Reservoir and Girma Tilahun (2006) in Lakes Awassa, Ziway and Chamo. Taylor and Zinabu Gebre-Mariam (1989) also initiated a more functional approach to the productivity of the planktonic community in Lake Awassa. Despite the importance of its flourishing commercial fisheries, published information on the biomass and photosynthetic production of phytoplankton in Koka Reservoir is not available.

More importantly, the reservoir is undergoing environmental degradation as a result of increased human activities. The shores of Koka Reservoir are being used for watering huge populations of livestock, irrigation and washing clothes. In addition, the tanneries that are established near its shores are damping their wastes including toxic chemicals. Seyoum Letta *et al.*, (2003) observed that pollution parameters along the Modjo River, which eventually flows into Koka Reservoir, were too high to meet the provisional discharge limits set by the Ethiopian Environmental Protection Agency (EEPA) especially for most toxic substances such as chromium, sulphide and ammonia (Seyoum Leta *et al.*, 2003)

Phytoplankton studies on some of Africa's large and better studied lakes have shown some qualitative changes that are the result of several years of cultural eutrophication (e.g. Ochumba, 1987, Hecky, 1993, Mugidde, 1993). The Changes in species composition, standing crop and photosynthetic production of phytoplankton are brought about by several biotic and abiotic factors including water column mixing/stratification, underwater light, temperature, nutrients, toxic substances, heterotrophic microorganisms, pathogenic agents, parasites and herbivores (Reynolds, 1987). The recurrent toxic algal blooms of *Microcystis aeruginosa* in Koka Reservior, similar to that which occurred in Lake Chamo in 1978 (Amha Belay and Wood, 1982), which were responsible for the death of livestock seem to be the result of pollution of Koka Reservoir with algal nutrients originating from nearby agricultural lands on which fertilizers were applied. These activities obviously lead to the deterioration of environmental conditions in the reservoir, with consequent direct impacts on the species composition and production of phytoplankton and indirectly determining the pelagic food web structure and fish production in the Reservoir. Therefore, data generated through close monitoring of phytoplankton changes in man-made lakes can serve as an advance warning of potential problems and assist in the development of appropriate strategies of conservation.

The purpose of the present study was, therefore, to investigate the spatio-temporal dynamics of photosynthetic production and biomass of phytoplankton in relation to the physico-chemical conditions of the water column in the reservoir. The project also seeks to generate information on the physico-chemical water quality and composition of major species of phytoplankton in Koka Reservoir.

2. OBJECTIVES

2.1 General Objective

To investigate the spatio-temporal dynamics of phytoplankton photosynthetic production and biomass in relation to physico-chemical conditions of the water column in Koka Reservior.

2.2. Specific Objectives

-To determine the species composition of major phytoplankton taxa and their temporal dynamics.

-To generate information on the physico-chemical features and water quality of Koka Reservoir.

-To investigate primary production and biomass of phytoplankton in Koka Reservoir.

-To identify factors of overriding importance in determining the temporal and spatial variations in the biomass and primary production of phytoplankton.

3. DESCRIPTION OF THE STUDY AREA

Koka Reservoir is situated about 90 km south of Addis Ababa (Fig 1) at an altitude of 1590m (Van den Bossche and Bernacsek, 1990). It was constructed in the course of Awash River to produce hydroelectricity. The dam, which has a height of 42 m was erected in 1960 E.C. The reservoir has a maximum and mean depth of 14 and 9m, respectively and covers an area of 20 Km^2. There are two inflowing rivers: Awash (major) and Modjo (minor), which flow into the Reservoir in its western part. The Reservoir has an outflow called Awash River (Melaku Mesfin *et al.*, 1988). The region around Koka Reservoir had a total annual rainfall of about 630 mm, which was averaged for the period between 1943 and 1995 (Data from National Meteorological Services Agency).

Limnological studies carried out on this reservoir are very few. Some physico - chemical features of the Reservoir are presented in Table 1. The conductivity of the reservoir water is low as compared to those of most Ethiopian Rift Valley lakes (about 200μS/cm, Melaku Mesfin *et al.*, 1988). Koka Reservoir has a surface water temperature of 19°c and its water column does not show any marked thermal stratification (Melaku Mesfin *et al.*, 1988).

Microscopic analysis of phytoplankton samples collected from Koka Reservoir resulted in the identification of 72 taxa with the dominant phytoplankton species being the diatom *Aulacoseira granulata* (Elizabeth kebede and Willen, 1998). According to Melaku Mesfin *et al.,* (1988), although *Microcystis* spp dominated the phytoplankton community of Koka Reservoir, species of *Anabaena, Merismopedia, Chlamydomonas, Coelastrum, Mougeotia, Oedogonium, Scenedesmus, Staurastrum, Chromulina, Cyclotella* and *Navicula* were also important.

The dominante zooplankton groups that occur in the reservoir are Rotifers (*Keratella tropica*), Cladocerans (*Daphnia barbata* and *Moina micrura*) and Copepoda (*Tropodiaptomus processifer*, *Metadiaptomus colonialis* and *Mesocyclops aequatorialis*) (Melaku Mesfin *et al.*, 1988). Koka Reservoir supports commercially important fish species such as *Oreochromis niloticus*, *Cyprinus carpio*, *Clarias gariepinus* and *Barbus intermedius* (FLDP, 1998). The average annual production over the period 1994 to 1998 was 249 tons of tilapia, 235 tons of catfish, 101 tons of common carp and 10 tons of *Barbus* (FLDP, 1998). Koka Reservoir harbours submergent and floating macrophytes like water hyacinth (*Eichhornia crassipes*) especially along the shores.

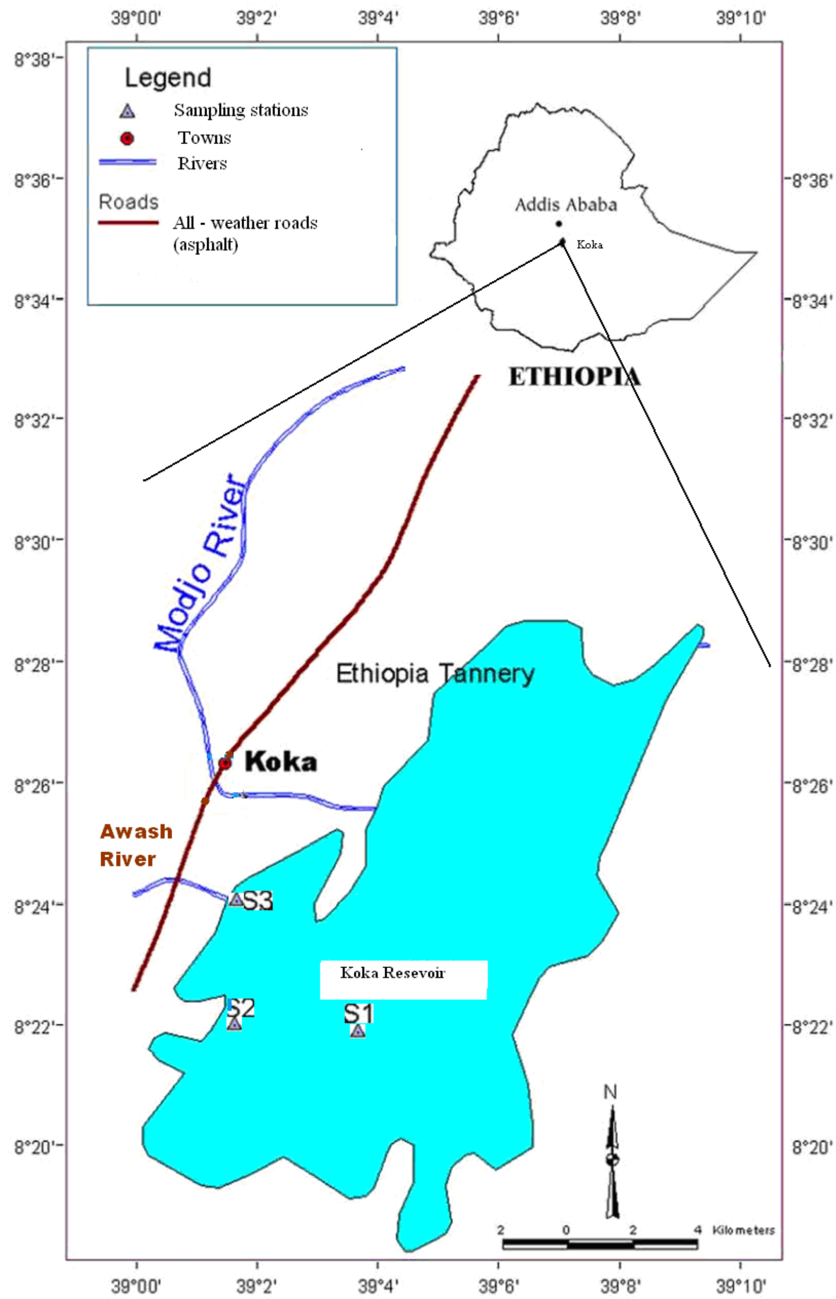

Fig.1 Map of Koka Reservoir showing sampling stations

Table 1: Some Physical,Chemical and biological Characteristics of Koka Reservoir

Parameters		**Sources**
Location	8° 23'N; 39° 5'E	Welcomme (1972)
Secchi depth (cm)	28	Wood and Talling (1988)
pH	8.3	Elizabeth Kebede *et al.*(1994
Conductivity ($\mu S\ cm^{-1}$)	200	Melaku Mesfin *et al.* (1988) and FLDP (1998)
Salinity ($g\ l^{-1}$)	0.319 0.2	Wood and Talling (1988) Elizabeth Kebede *et al.*,(1994)
Total Alkalinity ($meq\ l^{-1}$)	2.6 3.22	Elizabeth Kebede *et al.*,(1994) Wood and Talling (1988)
Na ($meq\ l^{-1}$)	1.35	“
K ($meql^{-1}$)	0.14	“
Ca ($meq\ l^{-1}$)	1.16	“
M ($meq\ l^{-1}$)	0.43	“
Cl ($meq\ l^{-1}$)	0.22	“
SO_4 ($meq\ l^{-1}$)	12.5	“
Total P(µg)	224	“
SiO_2($mg\ l^{-1}$)	2.5	“
Chlorophyll a($\mu g\ l^{-1}$)	22.4 16	Melaku Mesfin *et al.*, (1988) Ellizabeth Kebede *et al.*,(1994)

4. MATERIALS AND METHODS

4.1. Sampling Protocol

To study the temporal and spatial changes in the biomass and photosynthetic production of the phytoplankton community in Koka Reservoir, samples were collected monthly from August, 2005 to April, 2006 from three stations: Offshore station, in the offshore zone at a depth of 6 m; Littoral station, in the littoral zone of the reservoir, at a depth 2m and Awash River mouth station, at the mouth of Awash River at a depth of 2 m. The three sampling stations were selected because of the differences to the extent to which they were impacted (intensity of human impact), their accessibility and also general difference of reservoir from lakes such as flow rate, TSS and turbidity was taken into consideration.

From each station water samples were collected with bottle (Ruttner) sampler. Samples were taken from 0, 2 and 4m depths at station I and from 0m depth (surface) at other stations. Samples were used for the estimation of biomass (as chlorophyll-a concentration), identification of species of phytoplankton and for the analyses of inorganic nutrients. Composite samples were prepared by mixing samples collected from 0, 2, and 4m depths and used for the estimation of photosynthetic production and biomass of phytoplankton at offshore station.

4.2. Measurement of Physico-Chemical Parameters in the Field

In the field, some physical and chemical parameters were measured on each sampling day. Photosynthetically Available Radiation (PhAR) incident on a horizontal surface near the shore of the Reservoir during the incubation period of productivity measurements was recorded at 15 minute interval with LI–COR quantum sensor (LI–190SB) connected to LI–510B integrator. The values obtained for the different exposure periods were calculated and converted to E m^{-2} h^{-1} using appropriate factors (Talling and Lemoalle, 1998; Wetzeel and Likens, 2000) and used to estimate photosynthetic light utilization efficiency of phytoplankton. Water transparency was determined using a standard Secchi disc of ca. 25cm diameter quartered alternately black and white.

Depth profiles of oxygen and temperature were determined up to a depth of 3.5m with a digital Oxygen meter (Hanna 9024). pH was measured *in-situ* by a portable digital pH meter (Jenway 3200). Within a few hours after sample collection, carbonate-bicarbonate alkalinity was determined by titration with 0.01N HCl to a pH of 4.5 using Phenolphthalein and Bromocresol green-Methyl Red indicators.

4.3. Analysis of Inorganic Nutrients

Nutrients were analyzed following the standard methods described in Wetzel and Likens (2000) using samples previously filtered through Whatman GF/C glass fibre filters. Orthophosphate (PO_4 - P) was determined by the Ascorbic Acid method while soluble reactive silica (SiO_2) was determined by the Molybdosilicate method. The determination of Nitrate (NO_3-N) was carried out with HACH-portable spectrophotometer (DR/2010).

4.4. Measurement of Biological Parameters

4.4.1. Species composition and abundance of phytoplankton

Aliquots of samples taken from the surface of the offshore station by bottle sampler were used to identify species of phytoplankton dominant on each sampling date. Subsamples for phytoplankton counting and identification were also preserved with Lugol's iodine. The major phytoplankton species were enumerated on a Sedgewick- Rafter cell with an inverted microscope (WILD M 40), at a magnification of x40 in random fields after sedimentation of 50 ml of the sample in a graduated cylinder overnight. The supernatant water was removed by a syringe leaving 5ml of the sample in the graduated cylinder. From the concentrated sample, 1 ml subsample was taken with a pipette to enumerate phytoplankton on the Sedgewick- Rafter cell. The phytoplankton samples were examined with an inverted microscope and their identification to genus or species level was made using concentrated samples on the basis of various taxonomic literatures available on phytoplankton (Whitford and Schumacher, 1973; Jeeji-Bai *et al.*, 1977; Durand and Leveque, 1980; Gasse, 1986; John *et al.*, 2002).

4.4.2. Biomass as Chlorophyll-a concentration

Samples from offshore station were collected with a bottle sampler from different depths and mixed in equal proportions to produce composite samples. Samples were also collected from the surface at all sampling stations. Chlorophyll *a* (Chl *a*) concentration was estimated spectrophotometrically from samples (100-200ml) previously filtered using Whatman Glass Fiber filter (GF/C, 47 mm). Filters containing seston were manually ground in a small volume of 90% acetone with a glass rod to enhance the extraction of chlorophyll a. The extracts were transferred into a centrifuge tube and centrifuged at 3000 rpm for 10 minutes. The absorbance of pigment extracts were measured against a blank at 665 and 750 nm and the concentration of chlorophyll a was calculated according to Talling and Driver (1963).

4..4.3. Primary Production

Primary productivity of phytoplankton was determined by the Light and Dark Bottle Technique and the Winkler method of oxygen determination (Mackereth *et al.*, 1978) at the offshore station. Composite water samples were siphoned into light (clear) and dark (covered with black cloth) bottles. Duplicate light bottles were incubated at 0.00, 0.25, 0.5 and 1m depths distributed within the euphotic zone for a period of 2-4 hours around mid-day (10.00 am-2.00 pm). Dark bottles were also incubated at 0.00 and 1.25 m depths. The bottles were attached to a suspension line prepared for this purpose. Samples in a pair of bottles were fixed with Winkler reagents immediately after incubating the light and dark bottles and used as initial bottles. At the end of the incubation period, the bottles were rapidly withdrawn along the shaded part of the boat and dissolved oxygen fixed immediately with the Winkler reagents. Treatment of bottles before and after incubation was made under a cover of dark cloth. On returning to the laboratory, samples were titrated with a standard solution of sodium thiosulphate using starch as an indicator. The concentration of dissolved oxygen in the incubation bottles was calculated according to Mackereth *et al.*, (1978).

4.5. Statistical Analyses

The different sets of data were analyzed statistically using Microsoft excel and Sigma plot version 11 software and the results are presented in Appendix 11.

4.6 Description of symbols

Descriptions of Symbols and their units used throughout this thesis are given below:

Z_{SD} ……………………….Secchi depth (m)

Z_{eu} ………………………..Depth of euphotic zone (m)

K_d …………………….. Mean vertical extinction coefficient of downwelling irradiance (ln unit m^{-1})

Chl a …………………… Chlorophyll a (mg m^{-3} or µg L^{-1} or µg L^{-1})

B ………………………...Phytoplankton biomass (mg Chl a m^{-3})

GP ………………………. Gross photosynthesis (mg O_2 m^{-3} h^{-1})

NP ………………………..Net photosynthesis per unit water volume, (mg O_2 m^{-3} h^{-1})

A ………………………….Gross photosynthesis per unit water volume, (mg O_2 m^{-3} h^{-1})

A_{max} ……………………..Light- saturated rate of gross photosynthesis per unit volume, (mg O_2 m^{-3} h^{-1})

P………………………….(A/B) Specific rate of gross photosynthesis per unit biomass, mg O_2 (mg Chl a)$^{-1}$ h^{-1}

P_{max}(A_{max}/B) …………….Specific rate of gross photosynthesis per unit biomass at light-saturation, mg O_2 (mg Chl a)$^{-1}$ h^{-1}

Φ …………………………Photosynthetic efficiency of light utilization of phytoplankton (%)

∑A…………………………Hourly areal rate of gross photosynthesis, mg O_2 m^{-2} h^{-1}

∑∑A …………………….. Daily areal rate of gross photosynthesis, mg O_2 m^{-2} d^{-1}

PAR …………………… Photosynthetically Active Radiation (E m^{-2} h^{-1})

5. METEOROLOGICAL DATA

Photosynthetically Active Radiation (Ph.A.R.) received by a unit of horizontal surface during the incubation period varied from 7.69 (April, 2005) to 13.7 E m^{-2} h^{-1} (February, 2006) (See Appendix 3). Most of the values were closer to the mean value of 11.04 E m^{-2} h^{-1}. The low integral irradiance recorded in this study was associated with a day of heavy cloud, indicating the importance of meteorological factors in determining the amount of light energy reaching the surface of water bodies.

The mean minimum air temperature varied between about 4.7 ^{o}C and 16.1 ^{o}C while the maximum air temperature ranged from 29 ^{o}C of December 2005 to 32.8 ^{o}C of March 2006. The available meteorological data seem to suggest that the dry months (October –January) are also the coldest (see Fig. 2).The wind speed were not determined due to unavailability of the data from Koka Meteorological station.

Monthly rainfall varied from a low value October and December to 142.6 mm of August. The dry period was between October and January on the basis of the data compiled for the period between July, 2005 and April, 2006.The main rainy period was from July to September, with the largest peak (~142.6 mm) in August and the short rain season was from February to April with a smaller peak (68.3 mm)in April.

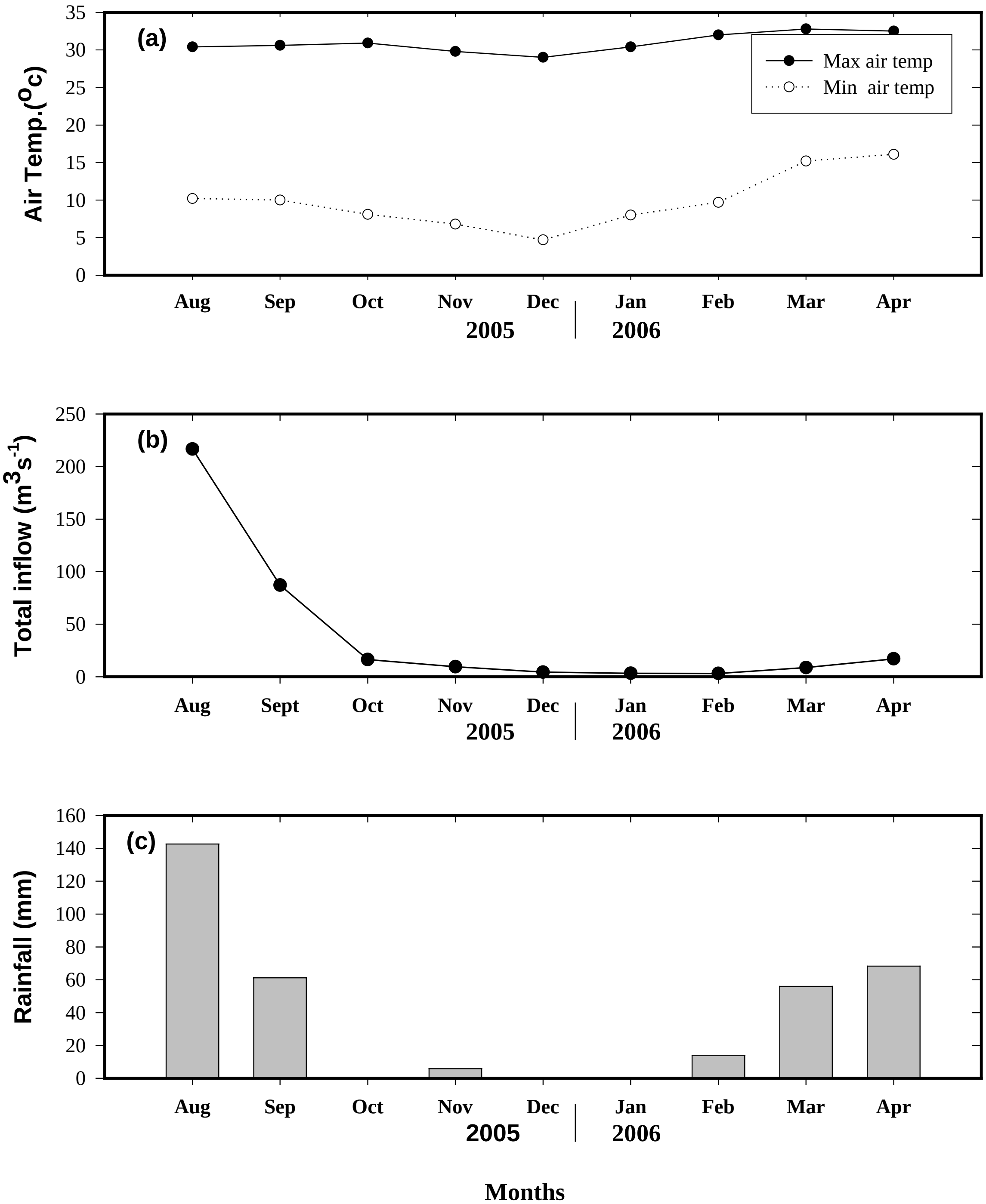

Fig 2 : Meteorological data for Koka Reservoir; (c) monthly rainfall (mm),(b) total Awash River inflow (m^3s^{-1}) and (a) monthly air temprature

6. RESULT AND DISCUSSION

6.1. Physical parameters

The physical characteristics of Koka Reservoir observed during the study period are given in Appendix 2. The temperature of the surface water of Koka Reservoir averaged 28.7^{o}C with a maximum of 32.5 ^{o}C in April, 2006 and a minimum of 26.2 ^{o}C in December, 2005 at the offshore station. The surface water temperature was positively correlated with air temperature (r = 0.91, P = 0.004) (see Appendix 10). The present surface water temperature readings are much higher than those recorded by Melaku Mesfin *et al.*, (1988) for the same reservoir.

The surface water temperatures of Koka Reservoir are closer to those reported by Ganf and Horne (1975) and Arfi. (2003) for African lakes and reservoirs respectively: Lake George, (26-36 ^{0}C) and Lake Turkana (27.5-32.5 ^{0}C) and Selingue Reservoir (24-36 ^{0}C). although they were generally higher than those measured in other Ethiopian Rift Valley lakes and Reservoirs (17-30^{0}C) including Lakes Ziway, Awassa and Chammo (Elizabeth Kebede, 1998; Girma Tilahun, 2006) and Leggedadi Reservoir (Adane Sirage, 2006).

Based on the data they generated on African lakes, Baxter *et al.*, (1965) noted that complete mixing is normally frequent in lakes with a maximum depth (Z_{max}) of less than about 15-30 m and thermal stratification is diurnal. Such shallow Ethiopian Rift Valley lakes and reservoirs as Chamo, Ziway and Koka with a maximum depth of less than 15 m, can be considered as frequently mixing (polymictic) (Elizabeth Kebede, 1996). Melaku Mesfin *et al.*, (1988) also reported the absence of marked thermal stratification in Koka Reservoir. Although depth profiles of oxygen and temperature were not determined due to instrumental failure, Koka Reservoir, with a maximum depth of 14 m and with nearly complete exposure to wind action is expected to be a frequently mixing body of water.

Appendix 2 shows Secchi depths, vertical extinction coefficients of downwelling irradiance and depth of the euphotic zone in Koka Reservoir During the study period, the transparency of the reservoir at the offshore station varied between 10 and 19 cm with a mean annual value of 12.7 cm (See Appendex-2). The present Secchi depth (Z_{SD}) values are lower than the previously recorded one (28 cm) (Elizabeth Kebede *et al.* 1994) which may be explained by the increased impact of human activities on the limnology of the lake. Most of the Secchi depth (Z_{SD}) values of Koka Reservoir are comparable to those recorded for Legedadi Reservoir (7-12 cm, Adane Sirage, 2006) and Lake Ziway (13-27, Girma Tilahun, 1988; 14-22, Girma Tilahun, 2006). The lower water transparency of Koka Reservoir is attributed to the high concentration of such suspended materials as silt, which find their way into the reservoir through the feeder River Awash or get re-suspended from the sediment as a result of wind-induced mixing (Wood *et al.*, 1978; Amha Belay and Wood, 1984; Elizabeth Kebede, 1996) and often color the water of the reservoir. Similarly low values of transparency associated with river-imported silt load have been reported for shallow reservoirs in Kenya (Mwaura, 2003) and Ethiopia (Adane Sirage, 2006).

Light attenuation, expressed as the mean vertical extinction coefficients [K_d], can be estimated from Secchi depths by the widely used equation, which was proposed by Holmes (1970) as a better estimator of the vertical extinction coefficient of total underwater light of turbid waters. Vertical extinction coefficients for the offshore station of Koka Reservoir (see Appendix 2), calculated according to Holmes (1970), ranged from 7.58 to 14.4. Most of the Kd values of Koka Reservoir are similar to those reported for Legedadi Reservoir (12 – 20.75) (Adane Sirage, 2006) and Lake Ziway (6.8-16.7, Girma Tilahun, 2006). The depth of the euphotic zone, defined as the depth of 1% level of surface irradiance, ranged from 0.32 to 0.6 m in the offshore station of the reservoir. However, the true compensation depths of the reservoir appear to lie well below the computed euphotic depths since appreciable net photosynthetic activity was found to extend down to a depth of 1 m (see Appendix-8).

6.2. CHEMICAL FEATURES

6.2.1. Dissolved Oxygen and Collective (Aggregate) Chemical Features

The surface water oxygen concentration varied with a maximum of 11.37mg l^{-1} in December, 2005 and a minimum of 5 mg l^{-1} in February, 2006. The highest oxygen concentration in December was associated with phytoplankton bloom dominated by the cyanobacterial genus *Microcystis.* Dissolved oxygen concentration was usually higher at the surface of the reservoir and declined consistently after 25cm (See Appendix 4). These higher concentrations of oxygen at the surface were probably due to the effect of turbulence on gas solubility than higher rates of photosynthesis since all depth-profiles of gross photosynthesis exhibited surface depression due to photoinhibition.

The difference between oxygen concentration at the surface and that at the deepest depth of measurement (3.25 m) was generally between 1.12 – 4.4 mg l^{-1}. Melaku Mesfin *et al.*, (1988) indicated that the oxygen concentration remained fairly constant with depth below the upper few centimeters down to about 8m.

Percentage saturation of oxygen in the upper 0-3.25 m lay between about 43 and 307% (see Appendix 4) with super-saturations occurring in November and December, 2005.

Total alkalinity values (TA) of Koka Reservoir, measured during the study period, are given in Table 2. Total alkalinity (T_A) of the Reservoir ranged from 1.9 to 2.7 meq/l. The highest value of T_A (2.7 meq/l) was recorded at the offshore station in February, 2006, while the lowest was recorded in December, 2005 and March, 2006. The high TA value of the present study is close to that reported (2.6.) by Elizabeth Kebede *et al.*, (1994) but is much lower than that found in an earlier report (3.22, Wood and Talling, 1988). Phenolphthalein alkalinity (P_A) ranged from 0 to 0.6 meq/l. From among the Ethiopian lakes similarly low TA values have been reported for Lake Kilole (2.4, Zinabu Gebre-Mariam, 1994), Zuquala and Afrera (2.1 and 2.2 respectively, Baxter, 1965). The low alkalinity values of Koka Reservoir may be related to the geochemistry of the Reservoir area with consequent low concentration of alkaline components such as HCO_3^- and CO_3^-.

The pH of the surface water of Koka varied between 8.11 in August, 2005 and 8.6 in December 2006 at the offshore station. The pH values of the present study are similar to that in an earlier report (8.3, Elizabeth Kebede and Willen, 1998). The relatively high pH values generally coincided with high phytoplankton biomass.

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 not observed in the present study for Koka Reservoir. The correlation between alkalinity and pH was positive but poor($r = 0.44$, $P= 0.22$) (see Appendix 10). Lower alkalinity value was found to coincide with a high pH value and algal bloom. This is probably the result of the removal of CO_2 from the reservoir water by phytoplankton through photosynthesis. This results in an increase in the carbonate ions, which hydrolyze to yield hydroxyl ions and raise the pH (Boyd, 1979). High rates of primary productivity allow large daytime removal of CO_2 and HCO_3^- leading to an increase in pH (Maberly, 1996). It is this biological removal of inorganic carbon sources by dense phytoplankton which was found to be responsible for the high pH levels observed in highly productive saline lakes of East Africa including Lake Arenguade (Talling *et al.,* 1973)

Table 2. Collective chemical features: pH, Total alkalinity (TA, meq l^{-1}), Phenolphthalein alkalinity (PA, meq l^{-1}) and calculated free CO_2 (mg/l) of Koka Reservoir over the study period

Sampling Date	pH	PA	TA	CO_2 (mg/l)
28/8/05	8.14	0	2	0.48
16/10/05	8.3	0	2.5	0.6
1/11/05	8.11	0	2	0.48
20/11/05	8.39	0	2.5	0.6
15/12/05	8.6	0.6	1.9	0.45
18/1/06	8.5	0	2.55	0.61
6/2/06	8.44	0	2.7	0.64
26-03-06	8.4	0.1	1.9	0.21
27/04/06	-	-	-	-

The level of free carbon dioxide was calculated from pH-alkalinity relationship at a specific temperature (Lind, 1979). The level of free carbon dioxide ranged from 0.21 to 0.64 mg l^{-1} at the offshore station with the maximum value recorded in February, 2006 and the minimum value in March, 2006 (Table 2). The data on photosynthetic activity and biomass seem to imply considerable removal of carbon dioxide during photosynthesis.

6.2.2. INORGANIC ALGAL NUTRIENTS

Appendix 5 and Fig. 3 show nutrient concentrations and their temporal variations respectively observed during the study period. The concentrations of Nitrate (NO_3-N) varied from 40 to 200 µg l^{-1} at the offshore station, from 47 to 93 µg l^{-1} at the littoral station and from 73 to 267 µg l^{-1} at the Awash River mouth station. Low concentrations corresponded to the relatively dry and short rains periods at the offshore and Littoral stations. The concentrations of nitrate were generally higher at the Awash River mouth station, which is probably related to the additional input of the nutrient from the river. The seasonal maxima in nitrate concentrations were observed in September, 2005 at the offshore station, in August, 2005 at the littoral station and in February, 2006 at the Awash River mouth station indicating the dependence of nitrate levels in the reservoir on precipitation and associated runoff. NO_3-N concentrations remained below 60 µg l^{-1} from October 2005 to April 2006 at the offshore and littoral stations. At the Awash River mouth station, nitrate concentration peaked in November and December, 2005 and February, 2006.

As the present results indicate nitrate concentrations in Koka Reservoir are often quite high (40- 267 µg l^{-1}) although they are still much lower than those of Legedadi Reservoir (240 to 1850 µg l^{-1}, Adane Sirage, 2006). The observed high nitrate levels in Koka Reservoir seem to be the result of inputs from the surrounding agricultural lands on which fertilizers are commonly applied to boost crop yield. During periods of high rainfall, nutrients may be washed into the reservoir through runoff and may also be introduced through Awash River from the upper catchments areas. (see Appendix 5 and Fig. 3).

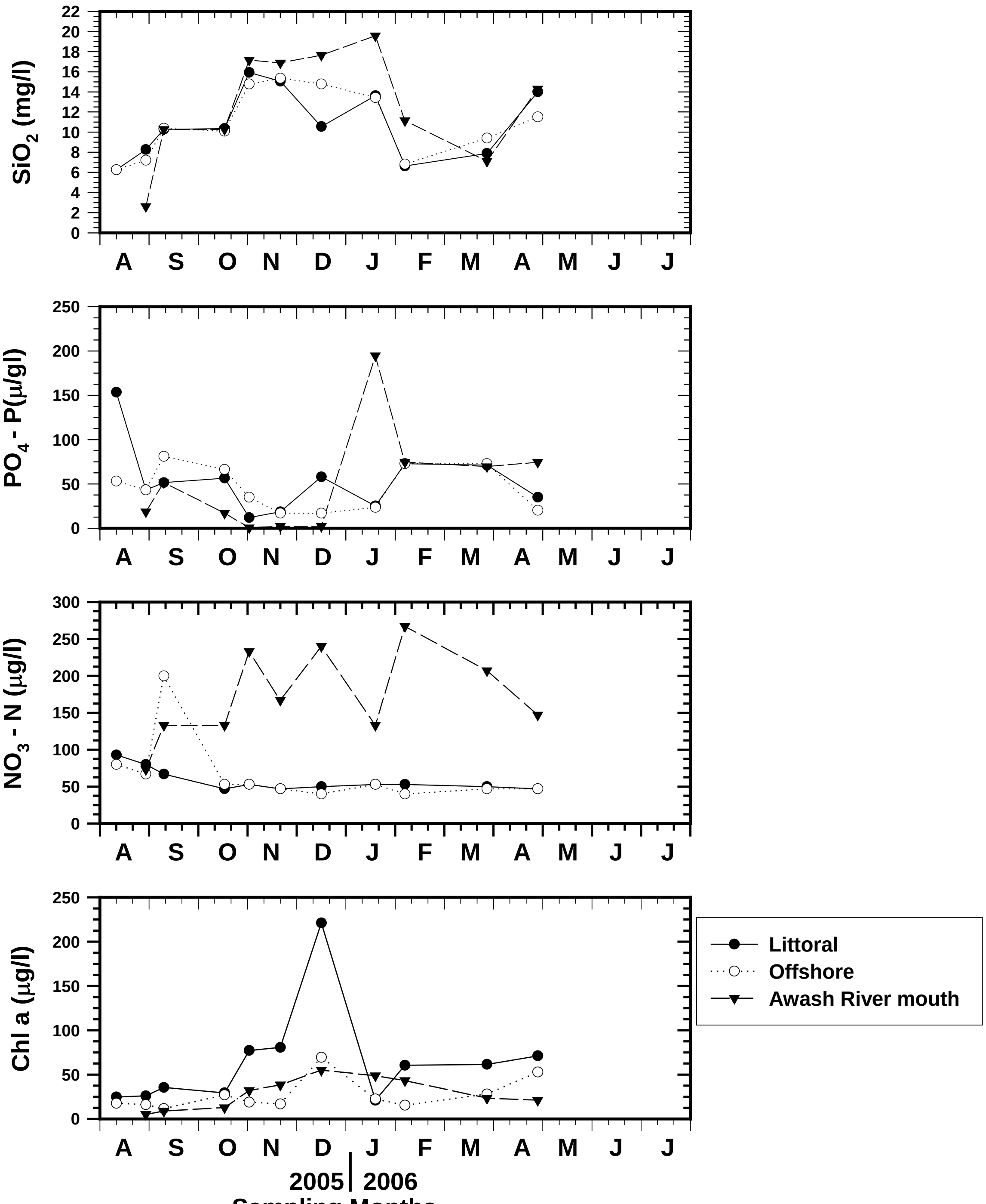

Fig.3. Temporal variations in the concentration of inorganic nutrients in relation to phytoplankton biomass at the Littoral,Offshore and Awash River mouth stations

Although the lowest concentration of NO_3-N in December coincided with the highest chlorophyll a concentration at the offshore and littoral stations, the correlation between nitrate and phytoplankton biomass was positive but poor (r = 0.38) (see Fig. 3 and Appendix 10).

Soluble Reactive Phosphate (SRP) concentrations recorded during the study period ranged from 16.86 to 81.01 μg l^{-1} at the offshore station, from 11.92 to 153.4 μg l^{-1} at the littoral station and from 0.41 to 194.52 μg l^{-1} at the Awash River Mouth station. The seasonal peak in the concentration of SRP was observed in September at the offshore station, in August at the littoral station and in January at the Awash River mouth station. The maximum SRP concentration recorded for the Awash River mouth station is closer to that reported previously for an offshore station in Koka Reservoir (224 μg l^{-1}) (Elizabeth Kebede *et al.*, 1994). The Lowest phosphate concentration was found during the dry season (November-December) at all sampling stations. The lowest values of phosphate in November-December, 2005 at the offshore and Awash River mouth stations coincided with the seasonal maxima in phytoplankton biomass while the seasonal minimum phosphate concentration at the littoral station coincided with a high algal biomass (see Fig. 3). This suggests that phytoplankton growth had dramatic depressing effect on phosphate concentration. The concentration of SRP was significantly correlated ($r=0.58$, $P=0.058$) with surface phytoplankton biomass at the offshore station (Fig. 3).

Molybdate reactive silica (SiO_2) varied from 6.25 to 15.35 mg/l at the offshore station, from 6.25 to 15.92 mg/l at the littoral and from 2.62 to 19.56 mg/l at the Awash River mouth station. In the present study, SiO_2 concentration was higher than that (2.5 mg l^{-1}) recorded by Elizabeth Kebede (1994) for the same reservoir. The peaks in SiO_2 concentration values were observed during the dry season from November, 2005 to January, 2006 (Fig.3). This period coincided with the greater abundance of diatoms, which built up their biomass until they reached their maxima in February, 2006 (Fig. 4).

In the present study, the concentrations of nitrate, orthophosphate and, silica were always in excess of their limiting levels, i.e. 20 µg l^{-1} for nitrogen (Ryding and Rast, 1994), <0.5 mg l^{-1} for silica (Reynolds, 1984 ; Wetzel and Likens, 1995) and <5 µg l^{-1} for Orthophosphate (Ryding and Rast, 1994). The absence of nutrient depletion in Koka Reservoir during the study period may be due to replenishment from the sediments by mixing as Koka Reservoir is polymictic (Elizabeth Kebede, 1996), *Cyprinus carpio* (common carp) feeding habit, input from the feeder river as well as from the surrounding agricultural lands through runoff during the wet months. Nicole (2002) also suggested that wind–

induced vertical mixing and increased freshwater input are the causes for elevated concentrations of macronutrients in the water column.

Many studies have reported that nitrogen limitation is very common in tropical lakes (Lewis, 1996; Talling and Lemollae, 1998). Although the absolute concentrations of nitrate may seem to suggest the absence of nitrogen-limitation in the reservoir, the likelihood of nitrogen-limitation can not be ruled out in light of the concentration of inorganic nitrogen relative to that of phosphorus as phytoplankton are known to take these two elements in a molar ratio (16:1, Redfield, 1958).

6.3. BIOLOGICAL FEATURES

6.3.1 SPECIES COMPOSITION AND ABUNDANCE OF PHYTOPLANKTON

Table 3 lists the major species of the phytoplankton community in Koka Reservoir. During the study period, 24 major taxa were identified although the detailed taxonomic work by Elizabeth Kebede and Willen (1998) on a single sample from Koka Reservoir resulted in the identification of 72 species. The identified major taxa of the present study belonged to five taxonomic classes: Cyanophyceae (blue-green algae) (8), Bacillariophyceae (diatoms) (4), Chlorophyceae (green algae) (7), Euglenophyceae (euglenoids) (4) and Cryptophyceae (cryptomonads) (1).

The temporal variations in the relative importance of the major algal groups to the abundance of the phytoplankton assemblage in Koka Reservoir are shown in Fig 4. Cyanophyceae (Blue-green algae) were the most abundant and persistent algal group with percentage contributions over 50% on all sampling dates except in January, 2006. Bacillariophyceae and Chlorophyceae were the second and third most abundant algal groups that made up the phytoplankton community of Koka Reservoir. Euglenophyceae and Chlorophyceae were of relatively low abundance although the latter had species richness which was comparable to that of Cyanophyceae.

Table 3. Major Species composition of phytoplankton in Koka Reservoir.

Blue-green algae (Cyanophyceae)

Anabaena cf. spiroides Kleb.
Chroococcus distans (G.M. Smith) Kom. Leng. Cronb.
Cylindrospermopsis africana Kom et Kling
Microcystis aeruginosa (Kűtz.) Kűt.z
M. flos-aquae *Wittr.) Kirchn,
M. wesenbergii (Kom.) Kom.
Planktolyngbya limnetica (Lemm.) Kom. Leng. Cronb
Raphidiopsis mediterranea Skuja

Diatoms (Bacillariophyceae)

Aulacoseira granulata (Ehr.) Simons.
Aulacoseira granulata v. granulata (Ehr.) Sim*ons.*
Fragilaria sp.
Stephanodiscus hantzschii Grun

Green algae (Chlorophyceae)

Actinastrum hantzschii Lagerh.
Closterium cf.acutum Breb.
Pediastrum duplex v. Clathratum Meyen
Pediastrum simplex Meyen
Scenedesmus acuminatus (Lagerh.) Chod.)
Scenedesmus quaricauda (Turp.)Breb.
Selenastrum sp.

Euglenoids(Euglenophyceae)
Euglena sp.
Trachelomonas
Phacus longicauda (Ehr.) Duj.
Stro*mbomonas* sp.

Cryptomonads(Cryptophyceae)
Cryptomonas spp.

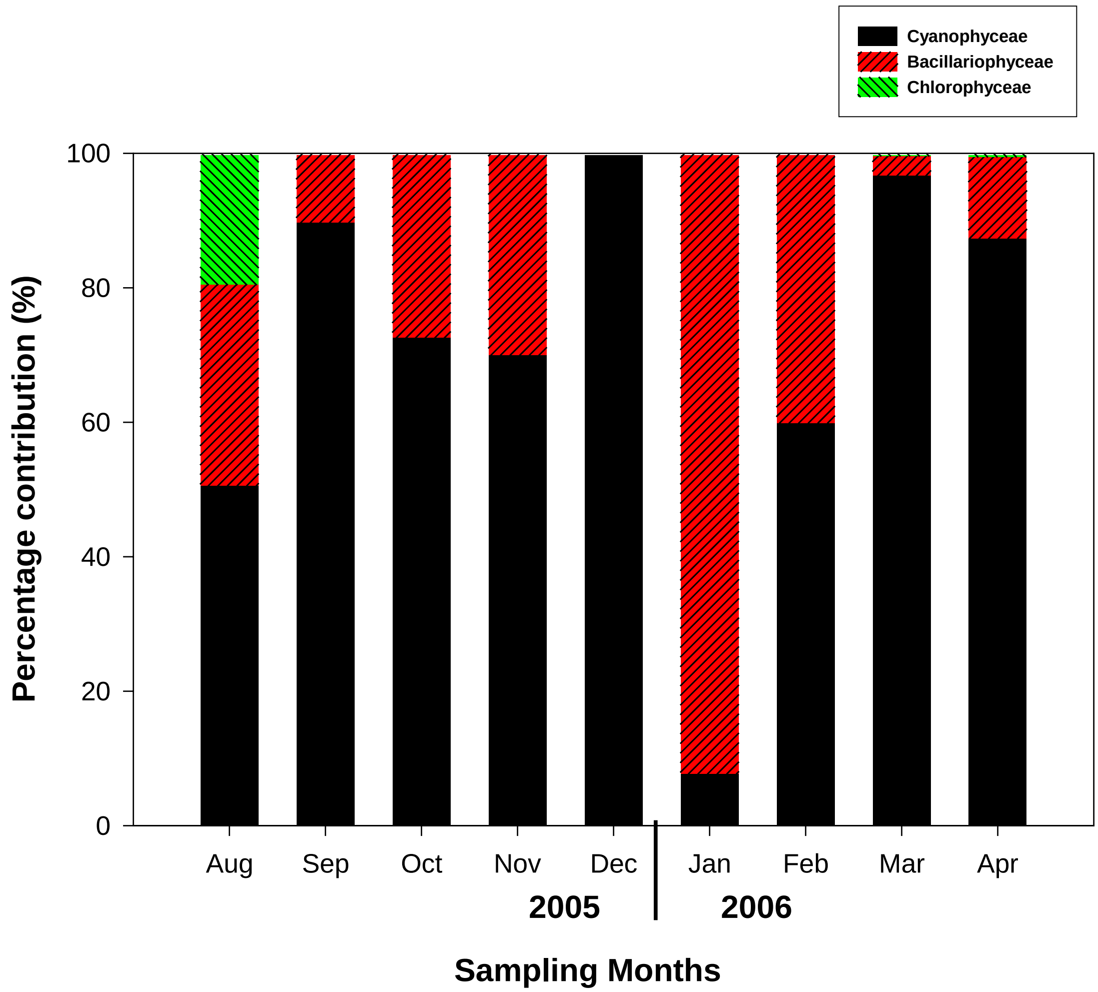

Fig.4. Temporal variation in percentage contribution of dominant taxanomic groups to the abundance of phytoplankton in Koka Resevoir.

Figure 5 shows the temporal variations in the abundance of the major taxa of the phytoplankton community in Koka Reservoir. In December, 2006, phytoplankton abundance reached its largest seasonal peak, which was followed by another smaller peak in February, 2006.

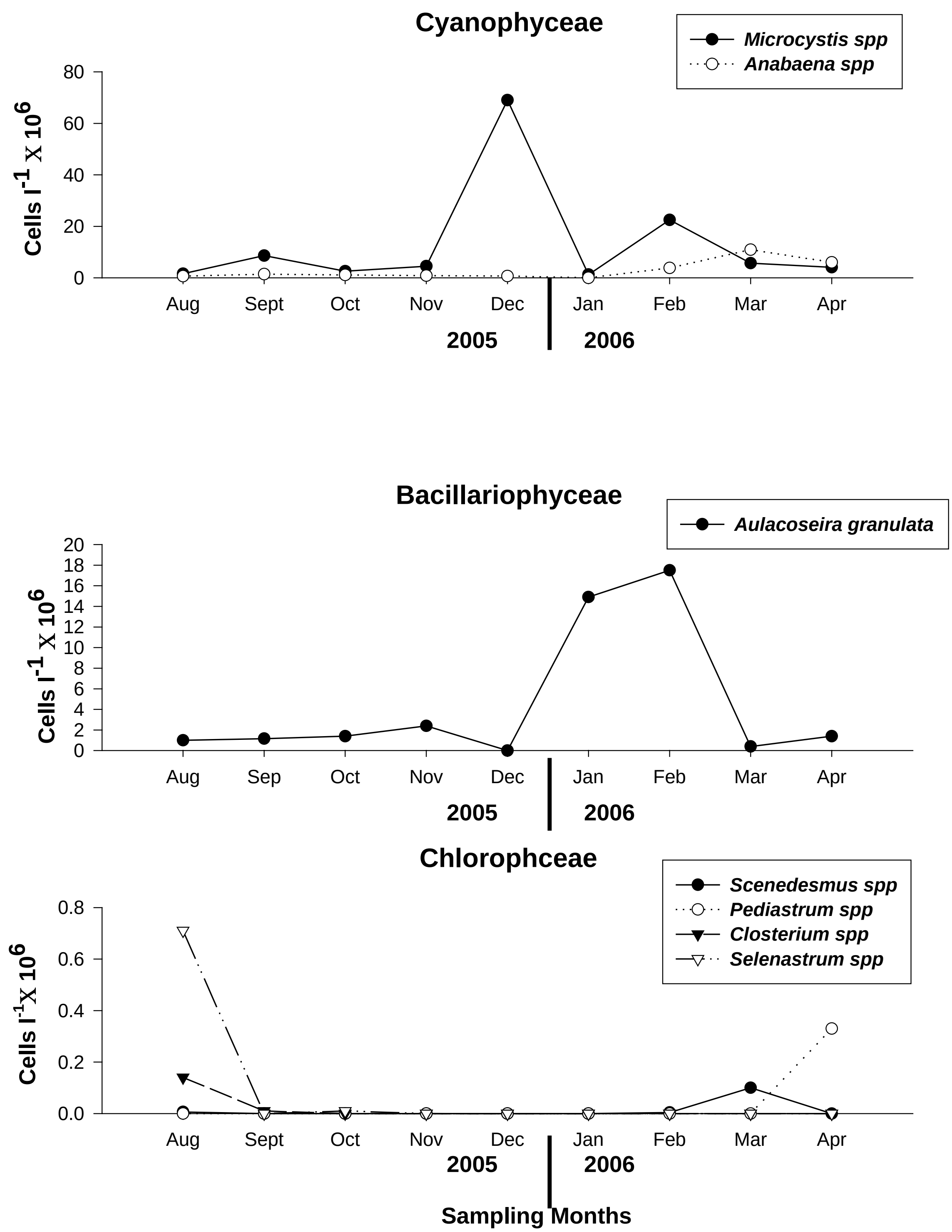

Fig.5 Temporal variations in abundance of major speciesof the dominant taxonomic groups at offshore station of Koka Reservoir

The largest peak of abundance in December was almost exclusively constituted by species of *Microcystis (M. aeruginosa, M. flosaquae and M. wesenbergii*) while the smaller peak of abundance was due to the diatom *Aulacoseira granulata* and species of *Anabaena (Anabaena circinalis and A. cf. spiroides*). The species which comprised the abundance of the phytoplankton community during the months of the major (August-September) and minor (March-April) rainy periods belonged to the green algal genera *Pediastrum, Selenastrum, Scenedesmus and Closterium.*

The dominance of the phytoplankton community in Koka Reservoir by *Microcystis spp*, particularly *M. aeruginosa*, was reported earlier by Melaku Mesfin *et al.*, 1988 for the same reservoir. From their taxonomic work on a single sample collected from Koka Reservoir during the period of short rains in 1991, Elizabeth Kebede and Willen (1998) also reported the dominance of the phytoplankton community by the diatom *Aulacoseira granulata*.

Microcystis and *Anabaena* spp are known for their development into blooms worldwide under eutrophic and hypertrophic conditions (Paerl, 1996). These two taxa were found to be the most abundant and persistent phytoplankton in the nutrient-rich turbid and moderately turbulent Legedadi Reservoir (Adane Sirage, 2006) and the crater Lakes Babogaya (Yeshiemebet Major, 2006) and Hora (Abebaw Wondie, 2006).

The dominance of blue-green algae may be associated with several environmental factors such as low turbulence (Reynolds and Walsby, 1975; Reynolds, 1987; Pearl, 1995 ; Oliver and Ganf, 2000), low light (Smith, 1986), high temperature (Shapiro, 1990), low carbon dioxide or high pH (Caraco and Muler, 1998) and high total phosphate (Watson *et al.,* 1997). *Microcystis,* which is the most dominant taxon in the reservoir, grows well under low light intensities of 12-50 μmole quanta m^{-2} s^{-1}(Hadas, 2002). Even under low light conditions or in turbid waters such as Koka Reservoir, *Microcystis* spp. have higher growth rates than any other algae (NSW, 2002) owing to their ability to regulate their vertical position in the water column (Reynolds, 1987). The observed low level of DIC in Koka Reservoir may have contributed to the dominance and persistence of the scum-forming blue-green alga *Microcystis spp.* under bloom conditions (Paerl, 1983) since it gains a competitive advantage over other algae owing to the high affinity of its permease system for carbon dioxide (Sommer, 1984) reflected in its lowest half-saturation constant for the same (Yamamoto and Nakahara, 2005) and hence its most effective carbon dioxide concentrating mechanisms (Badger and Price, 2003). In light of the present concentrations of nitrate relative to those of phosphate in Koka Reservoir, the ratio of nitrogen to phosphorus may have also been responsible for the dominance of *Microcystis* as a study in Lake Kasumigaura, Japan (Takamura *et al.*, 1992) and experimental studies under various N:P supply ratios (Fujimoto *et al.*,

1997) have shown the replacement of *Microcystis* by other algae under increased N:P ratios. The contribution of its ability to minimize grazing (Hanley, 1987), resulting from large size and possible toxicity, to its dominance should not also be overlooked.

Aulacoseira granulata Ralfs (also known *Melosira granulata*) is a rapidly sinking planktonic diatom (Reynolds, 1994) known for its wide distribution (Gasse *et al.,* 1983). It is the most common diatom species in shallow mixing lakes and in deeper lakes during high turbulence (Kilham and Kilham, 1975; Hecky and Kling, 1987). The frequently turbulent water column conditions of Koka reservoir and its adaptation to low light conditions (Reynolds, 1994) seem to favor its persistence and abundance in the reservoir.

6.3.2 PHYTOPLANKTON BIOMASS

Phytoplankton biomass estimated as chlorophyll a concentration showed both temporal and spatial variations over the study period (See appendix 7 and Figs. 3, 6 and 7). The surface water chlorophyll a concentrations varied between 20.85 and 221.01, 11.47 and 69.5 and 4.86 and 54.9 mg m^{-3} at the littoral, offshore and Awash River mouth stations respectively.

Phytoplankton biomass was consistently higher at the littoral station than at the other two stations. The annual mean concentration of Chl a was the highest (64.34 mg m^{-3}) at the littoral, intermediate (28.69 mg m^{-3}) at the mouth of the Awash River and lowest at the Offshore station. There was a nearly consistent increase in algal biomass from October, 2005 to December, 2005 at all stations although it was marked at the littoral station in December, 2005. The observed seasonal maximum concentration of Chl a of the surface water at the littoral station (221.01 mg m^{-3}) was the result of the bloom of *Microcystis* spp. Despite the fact that nutrients were generally higher at the Awash River mouth station than at the other two stations, the seasonal maximum of Chl a was observed at the littoral station. The highest peak of Chl a in the reservoir observed at the littoral station may not necessarily be the result of *in situ* development as the biomass of buoyant organisms at or near the surface is liable to removal from its area of formation by shoreward wind-drift (Reynolds, 1984). The thick mass of algal material, which originated exclusively from the bloom of *Microcystis* and found at the shore of Koka Reservoir facing the asphalted road (outside the reservoir water) at a distance of about 99.5 km from Addis Ababa in Mid-December, 2007 (Demeke Kifle, Personal communication) seems to corroborate the generalization made by Reynolds (1984).

High surface chlorophyll a values of the dry season often coincided with low levels of nitrate and phosphate at the offshore and littoral stations (Fig. 3) although the correlation between chlorophyll a and phosphate was poor ($r = 0.14$) for the littoral station. On the other hand, phytoplankton biomass of the offshore station was positively and moderately correlated with phosphate ($r = 0.58$) while its correlation with nitrate and silica was positive but weak ($r = 0.38$, $P=0.24$). For the Awash River mouth station, the correlations between Chl a and nitrate ($r=0.65$) and silica ($r=0.77$) were much higher than that with phosphate ($r=0.25$). The observed greater correlation of phytoplankton biomass with inorganic nitrogen, and not phosphorus, at the littoral and Awash River Mouth station, is consistent with the observations made in such tropical water bodies as Lake Lano (Lewis, 1974) and some reservoirs of the Nile River (Talling and Rzoska, 1967), in which reduced algal productivity was associated with nitrate depletion.

Talling and Talling (1965) also gave nitrogen the role of a limiting nutrient in tropical African lakes. This may not, however, be true for Koka Reservoir in which ambient concentrations of nitrate were high even at times of greatest phytoplankton growth.

The seasonal peaks of phytoplankton biomass occurred during the dry season - period of low precipitation and hence low Awash River inflow (see Fig. 6) which probably favored greater water column stability. Observations made on south Indian lakes by Zafar (1986) have shown that temporal variations in phytoplankton biomass and production are regulated primarily by factors of climatic origin. Melaku Mesfin and Amha Belay (1989) also concluded that the physico-chemical conditions of Legedadi Reservoir were dictated by precipitation. For Koka Reservoir, low and positive correlations were found between phytoplankton biomass and precipitation ($r= 0.42$, $p=0.08$) and Awash River inflow ($r=0.43$).

The phytoplankton biomass values of the present study in Koka Reservoir are higher than those of earlier reports, which were based on one month sampling (22.4 mg Chl a m^{-3}, Melaku Mesfin *et al.*, 1988; 16 mg Chl a m^{-3}, Elizabeth Kebede *et al.*, 1994). The phytoplankton biomass values of the non-bloom period of Koka Reservoir are comparable to those of Legedadi Resevoir (22.19 to 39.45 mg m^{-3}, Adane Sirage, 2006) while most of the high values of Chl a concentration in November-December in Koka Reservoir are similar to those of Tissawewa Resevoir (15 to 70 mg m^{-3}, Amaasinghe and Vijverberg, 2002) and Harbeespoort Resevoir (62 mg m^{-3}, Robarts and Zohary, 1986)

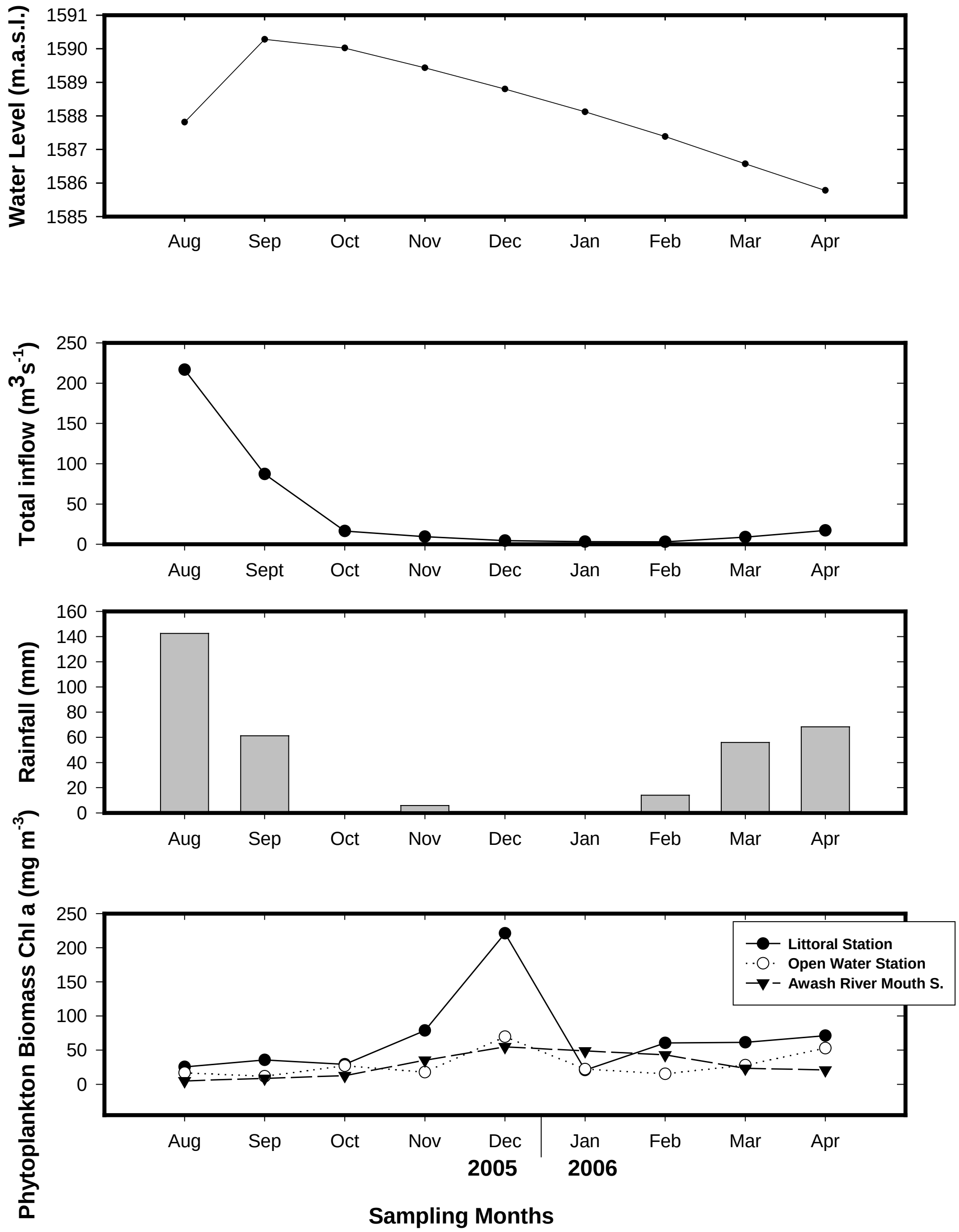

Fig. 6 Temporal changes in the surface concentrations of chlorophyll a in relation to rainfall , Awash River water inflow and water level during the study period in the Koka Reservior.

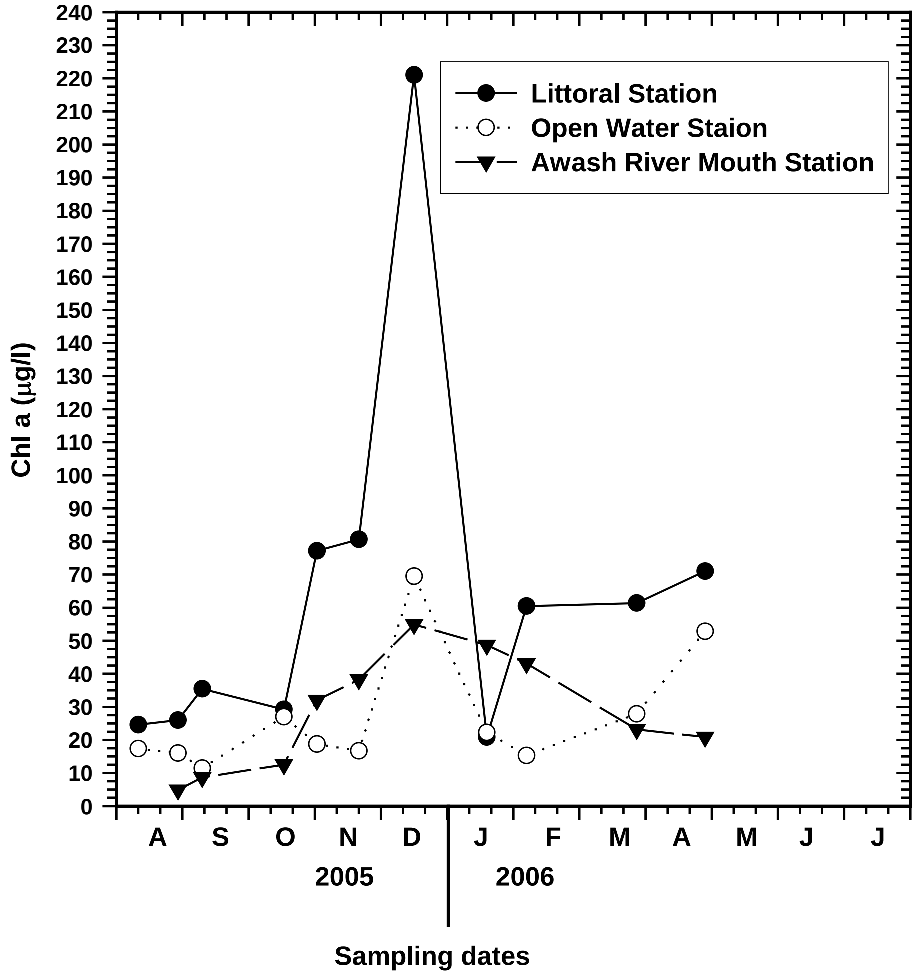

Fig. 7. Spatial variations in the concentration of surface phytoplankton biomass at the Littoral,Offshore and Awash River mouth stations

Considering the differences in biomass values observed between the offshore and littoral sampling stations (see Fig. 7), a t-test was conducted to determine if the spatial variation was significant. The t-test conducted at p = 0.042 gave a value of 2.17, which was greater than the tabulated (see Appendex 11) indicating that the spatial variation of phytoplankton biomass was significant.

The magnitude of the temporal variations in phytoplankton biomass observed in Koka Reservoir was assessed by applying Melack's (1979b) Coefficient of Variation (CV = Standard deviation/ mean). The CV values of chlorophyll a were 87.5% for the Littoral station, 67% for the offshore station and 60.5% for the Awash River mouth station. The results put the reservoir with other lakes of pattern A (CV greater than 25%), a pattern which shows pronounced seasonal fluctuation.

6.3.3. PHOTOSYNTHETIC PRODUCTIVITY

6.3.3.1 DEPTH PROFILES OF GROSS PHOTOSYNTHESIS

In situ experimental measurements of gross photosynthesis per unit water volume at the offshore station are shown in Fig.14 and Appendix 8. Because composite samples were used for the determination of photosynthetic production of phytoplankton at the offshore station, the observed depth variations in photosynthetic rates were due to the different responses of similar phytoplankton biomasses to differing underwater light climate. The depth distribution of gross photosynthesis per unit water volume (A, mg O_2 m^{-3} h^{-1}) showed a pattern, which is typical of phytoplankton, with a sub-surface peak in production rates on all sampling dates. The maximum depth of measurement was always 1 m and the maximum (light-saturated) rates of photosynthesis were always observed at a depth of 0.25 m (Fig. 8).

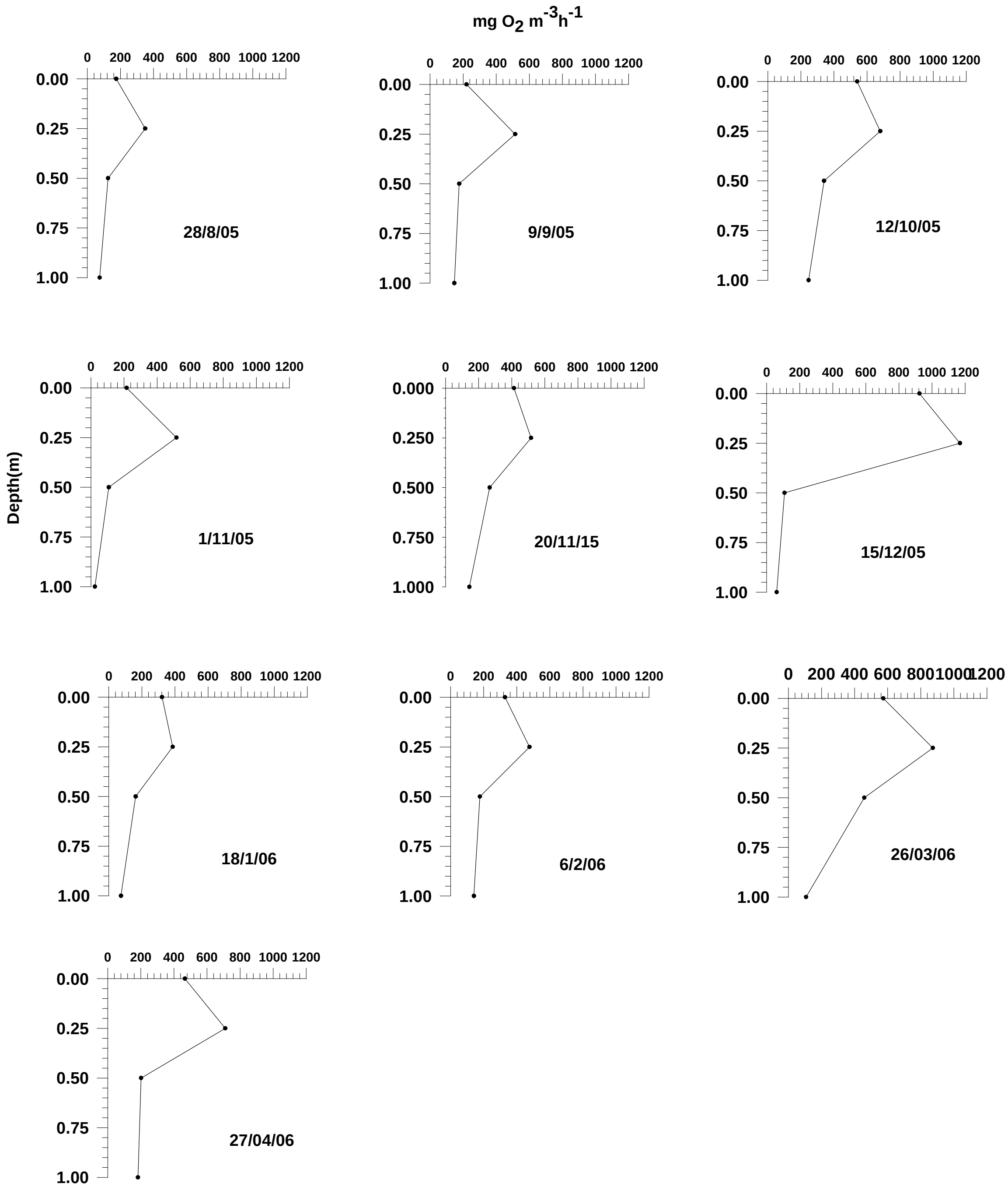

Fig 8. Depth profiles of gross photosynthesis per unit Volume (mg O_2 m^{-3} h^{-1}) at the offshore station in Koka Reservoir.

Photosynthetic rates at the surface of the Reservoir, which were always lower than the rates measured at a depth just below it (0.25 m), varied from 175 mg O_2 m^{-3} h^{-1} of August, 2005 to 924 mg O_2 m^{-3} h^{-1} of December, 2005. In i*n situ* measurements of primary productivity, reduced surface photosynthetic activity has been documented for many African Lakes including those in Ethiopia (Amha Belay and Wood, 1984; Girma Tilahun, 1988; Demeke Kifle and Amha Belay, 1990; Eyasu Shimbulo, 2004; Getachew Beneberu, 2005) and in Kenya (Melack, 1981; Vareschi, 1982). Photo-inhibition is the explanation for the lower photosynthetic activity at the surface of the reservoir, which is the result of the presence of excess photons (Lewis, 1974). Photo-inhibition is associated with increased photorespiration (Harris and Lott, 1973), inactivation of enzymes involved in photosynthesis (Steeman-Nielson Jorgensen, 1962) or photo-oxidative disruption of pigment systems (Falkowski and Raven, 1997).

Calculating the difference between the photosynthetic rate at the surface and A_{max} and expressing it as a percentage of the latter can estimate the extent of photo-inhibition. The magnitude of photoinhibition of photosynthesis at the water surface of Koka Reservoir varied between 17 and 68 %.

Depressed photosynthetic rate at the surface of a water body is a common feature of photosynthesis-depth profiles of phytoplankton in tropical lakes (Talling and Lemollae, 1998) and has been reported for many Ethiopian lakes (Talling *et al.*, 1973; Amha Belay and Wood, 1984: Girma Tilahun, 1988, 2006: Demeke Kifle and Amha Belay, 1990; Eyasu Shumbulo, 2004: Abebaw Wondie, 2006: Adane Sirage, 2006; Yeshiemebet Major, 2006).

As a function of irradiance, the extent of inhibition of photosynthetic production was variable. Hence, the maximum irradiance (13.7 E m^{-2} h^{-1}) (PAR) recorded on February 6, 2006, produced only 31% reduction from the light-saturated rate (A_{max}), while a slightly lower irradiance of 12.1 E m^{-2} h^{-1} on December 20, 2005 caused 68% reduction from A_{max}. It, therefore, 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 photo-inhibition varies with previous light-history (Kok, 1956), photo-acclimatization state and the species-specific differences in photo-acclimation strategies (Jorgensen, 1964; Behrenfeld *et al.*, 1998).

6.3.3.2. PRODUCTIVITY PARAMETERS

Light-saturated rates of gross photosynthesis (A_{max}, mg O_2 m^{-3} h^{-1}), biomass-specific rates of gross photosynthesis at light-saturation, termed photosynthetic capacity or assimilation number , (P_{max}, mg O_2 (mg Chl a)$^{-1}$ h^{-1}), hourly ($\sum A$, mg O_2 m^{-2} h^{-1}) and daily ($\Sigma\Sigma A$, g O_2 m^{-2} d^{-1}) integral rates of photosynthesis and light-utilization efficiency (%) of phytoplankton in Koka Reservoir are given in Appendix 9 and their temporal changes in relation to phytoplankton biomass and integral irradiance are shown in Fig. 9.

In the present study, the seasonal maximum photosynthetic rate (A_{max}, 1169 mg O_2 m^{-3} h^{-1}) was observed in December, 2006 coinciding with the seasonal maximum in phytoplankton biomass, which was associated with the bloom of *Microcystis* spp., while the minimum value (350 mg O_2 m^{-2} h^{-1}) was recorded in August, 2005 at the time of low phytoplankton biomass.

A_{max} was positively but weakly correlated (r= 0.42) with phytoplankton biomass. Similarly weak correlations were found for phytoplankton of Lake Chamo (r = 0.3; Eyasu shumblo, 2004) and Ziway (r =0.36; Girma Thilhun; 1988). A_{max} values were also positively but weakly correlated with the biomass-specific rates of photosynthesis (P_{max})(r = 0.27)

The seasonal peak in A_{max} of Koka Reservoir is close to that reported (in mg O_2 m^{-3} h^{-1}) for Legedadi Reservoir (238- 952; Adane Sirage, 2006) although it is much higher than those recorded for Lake Awassa (217-425; Demeke Kifle and Amha Belay, 1990), Sonachi, Kenya (130- 850; Melack, 1976) and several perennial irrigation Reservoirs in Sri Lanka (110 to 640; Silva *et al.*, 2002).

Biomass-specific rates of gross photosynthesis at light-saturation [$P_{max,}$ mg O_2 (mg Chl a)$^{-1}$ h^{-1}) ranged from 19.4 to 37.5 mg O_2 (mg Chl a) h^{-1} (see Appendix 9). The peak value of the specific rate of photosynthesis at light-saturation (P_{max}) occurred in September. Talling (1965) and Ganf (1975) found maximum photosynthetic rates (up to 31 mg O_2 (mg Chl a)$^{-1}$ m^{-3} h^{-1}) from warm tropical lakes in Africa. The mean value of the lake, 27.69 mg O_2 (mg Chl a) h^{-1}, falls within the range for tropical lakes.

P_{max} values of magnitude similar to those of Koka Reservoir were reported for Lake Kilole (16.3 - 33.7; Talling *et al.,* 1973) and an offshore station in Lake Victoria, Uganda (14 - 35; Talling, 1965). The upper values of the range of P_{max} for Koka Reservoir are considerably higher than those reported for Lake Ziway (9.6 - 22.5; Amha Belay and Wood, 1984; Girma Tilahun, 1988), Lake Awassa (4-19; Demeke Kifle and Amha Belay, 1990), Lake Abijata (14.8; Amha Belay and Wood, 1984) and Lake Arenguade (11-18; Talling *et al.*,1973), all in Ethiopia and Lakes Simbi and Sonachi, Kenya (15-17 and 8-14 respectively, Melack, 1981). In lakes of temperate regions, values rarely exceed 20 mg O_2 (mg Chl a)$^{-1}$ h^{-1} (Bindloss, 1974).

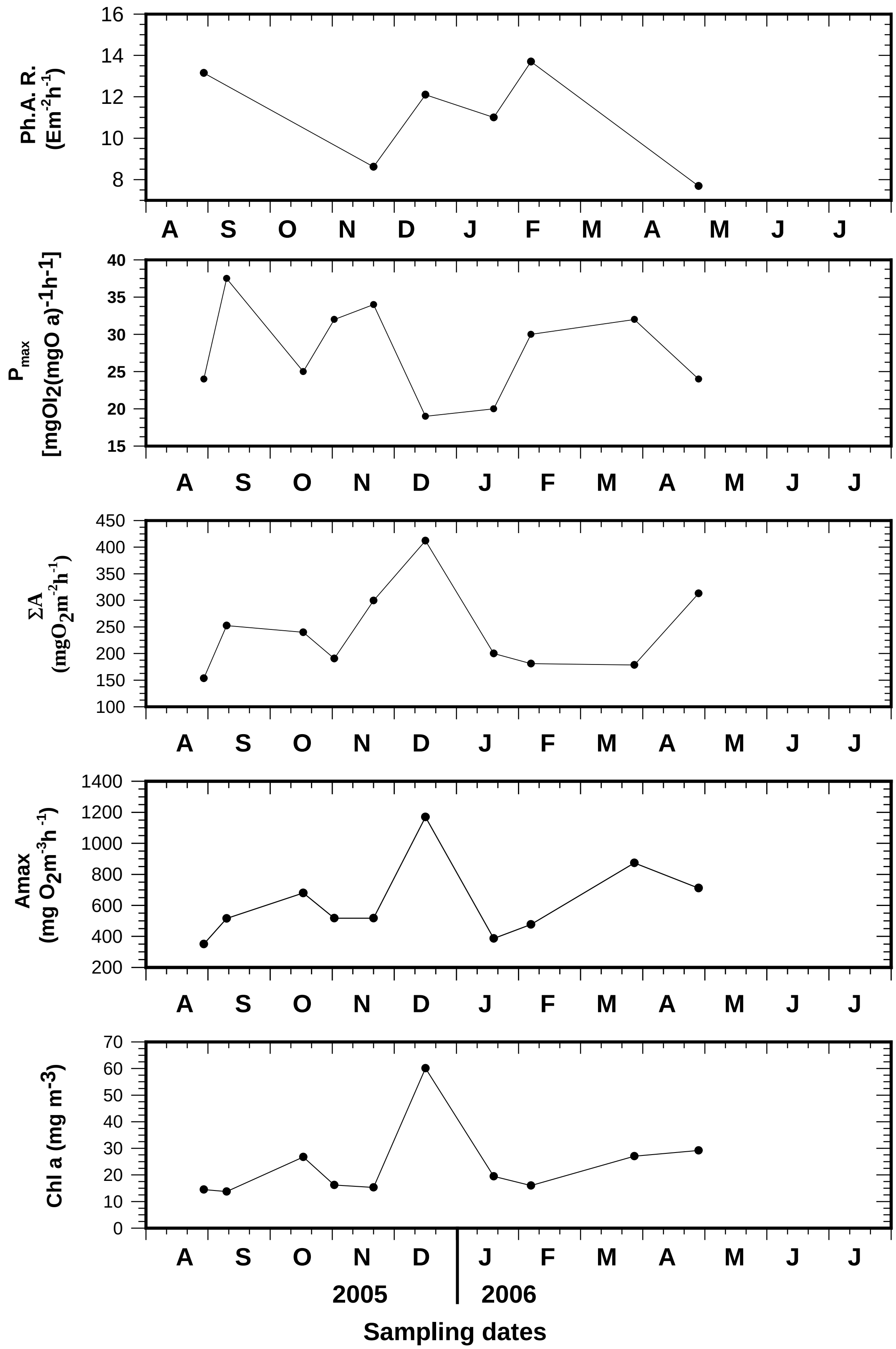

Fig. 9.Temporal changes of photosynthetic parameters in relation to phytoplankton biomass and integral irradiance at the offshore station in Koka Reservoir

Light utilization efficiency (Φ) varied from a minimum value of 0.07 % in September to a maximum value of 0.25% in April (see Appendix 9). The light utilization efficiency of freshwater communities are usually less than 2 % (Lind, 1979). In Koka Reservoir, efficiency of utilisation of radiant energy was generally unusually low, which may be due to the high turbidity of the reservoir as the calculation of the efficiency involved the use of above surface irradiance.

6.3.3.3. AREAL PRODUCTION

Hourly (∑A; g O_2 m^{-2} h^{-1}) and daily (∑∑A; g O_2 m^{-2} d^{-1}) rates of gross photosynthesis per unit area are given in Appendix 9 and their seasonal variations shown in Fig. 8.

Hourly integral values were estimated by the Grid Enumeration Analysis (Oslon, 1960). Hourly integral photosynthesis (∑A) ranged from 0.15 to 0.41g O_2 (≈ 0.056 to 0.154 g C≈) m^{-2} h^{-1}. The seasonal peak of hourly integral coincided with the seasonal peak in $A_{max,}$ which was observed when the phytoplankton biomass was at maximum. The ∑A values of Koka Reservoir (in g O_2 m^{-2} h^{-1}) are broadly similar to those reported for Legedadi Reservoir(0.067 to 0.58; Adane Sirage,2006), Lake Ziway (0.0574 to 0.726; Getachew Beneberu, 2005), Lake Awassa (0.3 to 0.725; Demeke Kifle and Amha Belay, 1990), Bara Bonita Reservoir in Brazil

(0.24 to 0.36; Calijuri and Dos Santos, 2001), and several Reservoirs in Sri Lanka (0.439 to 0.541; Silva *et al.*, 2002).

A positive and strong correlation was found between A_{max} and $\sum A$ (r =69) and positive but weak correlation between Ph.A.R. and $\sum A$ (r=0.45) (see Appendix 10).

The hourly integral rates of productivity were converted to daily rates, by multiplying by a factor of 0.9 used by Talling (1965) for East African lakes and the product was multiplied by the number of hours of sunshine generally assumed for tropical lakes, 10 hours. The calculated values of daily production rates per unit area ($\sum\sum A$, g O_2 (g C) m^{-2} d^{-1}) varied from a minimum of 1.37 (≈0.51) in August, 2005 to a maximum of 3.7 (≈1.39) in December, 2005. The seasonal peak of $\sum\sum A$ (in g O_2 m^{-2} d^{-1}) for Koka Reservoir is close to those reported for several Sri Lankan Reservoirs (Silva *et al.*, 2002) including Udawawewa (4.39) and Chandrikawawe (4.48) although it is considerably smaller than those of Ethiopian Rift valley Lakes, Ziway (6.53; Getachew Benberu, 2005), Abijata (5.6, Amha Belay and Wood, 1984) and Awassa (7.8; Demeke Kifle and Amha Belay, 1990).

7. ENVIRONMENTAL REGULATION OF PHYTOPLANKTON DYNAMICS IN KOKA RESERVOIR

Koka Reservoir is a shallow, turbid and frequently mixing reservoir. It is regarded as a eutrophic body of water in light of the measured phytoplankton biomass and nutrient concentrations (Forsberg and Ryding, 1980). The phytoplankton community of the reservoir is dominated by blue-green algae, particularly the genera *Microcystis* and *Anabaena* although the diatom *Aulacoseira granulata* dominated the phytoplankton assemblage of February, 2006. The observed seasonal dominance of the blue-green algae *Microcystis* and *Anabaena* and the diatom *Aulacoseira granulata* seems to be associated with the adaptation of the organisms to low underwater irradiance and nutrient-rich and moderately turbulent condition of the water column.

Temporal and spatial variations in phytoplankton biomass were observed in Koka Reservoir and seem to be associated with the seasonal cycle of hydrological and hydrographic conditions (river discharge, runoff, water column turbulence) which were presumably responsible for the observed generally high levels of inorganic nutrients.

The hydrological and hydrographic conditions impacted the phytoplankton through their effects on turbidity and water column stability as has been shown for other aquatic ecosystems (Reynolds and

Walsby, 1975; Pearl, 1995 and Oliver and Ganf, 2000). Those planktonic species with adaptive features emerged as dominants of the assemblage of the phytoplankton in the reservoir. The greatest dominance and persistence of the species of phytoplankton which the water column conditions selected for *Microcystis* spp. are related to the turbulence (Reynolds,1987), low light (Smith,1986), low euphotic to mixing depth ratio (Jensen *et al.*, 1994), high temperature (Shapiro,1990), low total N to total P ratio (Smith,1983) and possibly, high total Phosphorus concentration (McQueen and Lean,1987) in addition to their structural and physiological adaptations for phosphorus storage (Pettersson *et al.*, 1993) and buoyancy regulation (Reynolds,1987).

The high concentration of non-living particulate materials such as silt in Koka Reservoir results in abiogenic turbidity, which light-limits photosynthesis and therefore restricts biomass development. However, phytoplankton productivity essentially follows the same pattern in turbid water as in clear water systems (Schageri and Oduor, 2003). The only difference is that the depth profiles of photosynthetic production in turbid waters like Koka Reservoir are compressed into a shallow euphotic depth (Grobellar, 1984; 1985).

The chlorophyll a concentration of Koka Reservoir was quite high (221.01 mg m^{-3}) in December. This level of phytoplankton biomass has obviously affected the taste and odour of the reservoir water, which is used as a supply source of drinking water by the local farmers. Surveys of water blooms in different countries have shown that a high percentage (25-90%) of cyanobacterial blooms is toxic (Carmichael, 1988). Adeneji *et al.*, (1981) reported that cyanobacterial algal blooms in a number of Africa's man made lakes produced lethal levels of toxins. The toxic material released from Cyanobacteria can have a sever impact on the aquatic food webs (Christoffersen, 1998). Cyanobaterial toxins can also cause serious health problems for wild and domestic animals and are an increasing hazard to human health (Carmichael, 1992a). Blooms of *Microcystis* in Koka reservoir in the early 1990s were responsible for the death of wild and domestic animals (Demeke Kifle, Pers. comm.). Local farmers have also revealed the fact that cattle watered from this reservoir always had damaged liver when slaughtered and this seems to be associated with the cyanobacterial blooms whose biomass accumulates in the near-shores of the reservoir to which cattle have access.

8. CONCLUSIONS AND RECOMMENDATIONS

Koka Reservoir is a eutrophic water body which supports a phytoplankton community that exhibits temporal and/or spatial variations in species composition and biomass, which seem to be associated with hydrological and hydrographic. The phytoplankton community of Koka Reservoir was largely made up of three taxa: Cyanophyceae, Bacillariophyeae and Chlorophyceae, with the cyanophyceae (primarily *Microcystis* and *Anabaena*) accounting for over 50% of the abundance of the phytoplankton assemblage during most of the study period in the reservoir.

Phytoplankton primary production in Koka reservoir peaked in December, 2006 coincident with the seasonal peak in biomass, which was associated with the bloom of *Microcystis* spp., whose recurrent blooms represent a serious threat to the health of wild and domestic animals and human health

Based on the results obtained during the study period, the following recommendations are made with a view to protect the ecological integrity of the aquatic ecosystem and minimize the risk associated with environmental degradation:

More detailed studies on the hydrological and hydrographic conditions of the water column that favor the development into blooms of *Microcystis* spp and other cyanobacteria and also to determine whether the present ecological races of *Microcystis* spp are actually toxin-producers. Also further research on Z_{mix} depth, retention time,internal nutrient loading and zooplankton grazing roles in Koka Reservoir is required.

Raising the awareness of local farmers and owners of industrial establishments about environmental issues should be seen as an important factor in ensuring the control and prevention of algal bloom. The education for local farmers should focus on how to reduce runoff in order to reduce input of nutrients from the surrounding agricultural lands. Moreover, the tanning industries should also be advised to dispose chemicals that eventually find their way into the inflowing Awash and Mojo Rivers

Human activities (cultivation of vegetables along the shore-line, expansion of floriculture and tanning industries disposing untreated chemical to inflowing Awash and Mojo rivers etc) in and around the Reservoir are increasing with an alarming rate. Therefore, there is an urgent need for appropriate measures to avoid the potential risks. Management and conservation strategies should, therefore, be developed at the earliest possible time with a view to avoid the occurrence of irreversible changes.

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10. APPENDICES

Appendix 1. Meteorological data of Koka Reservoir: mean monthly maximum and minimum air temperature, total monthly Rainfall and Awash River inflow

Date	Mean Maximum Air Temperature	Mean Minimum Air Temperature	Total Monthly Rainfall	Awash River Inflow (m^3s^{-1})	Water Level (m.a.s.l)
July(2005)	29.8	10	92.8		
August(2005)	30.4	10.2	142.6	104.289	1587.81
September(2005	30.6	10	61.2	216.5840	1590.28
October(2005	30.9	8.1	0	87.1170	1590.02
November(2005	29.8	6.8	5.8	16.3700	1589.43
December(2005	29	4.7	0	9.4580	1588.8
January(2006)	30.4	8	0.3	4.3890	1588.12
February(2006)	32.0	9.7	14	3.2050	1587.38
March (2006)	32.8	15.2	56	3.1260	1586.57
April(2006)	32.5	16.1	68.3	8.7140	1585.78

Appendix 2. Secchi depths (Z_{SD}) ,mean vertical extinction coefficients (K_d) and euphotic depths (Z_{eu}) at the offshore Station of Koka Reservoir

Sampling Date	Surface Water Temp.(^oC)	Z_{SD}(m)	Kd (units m^{-1})	Z_{eu}(m)
28/8/05	27.8	0.10	14.4	0.32
9/9/05	30.2	0.13	11.07	0.41
1/10//05	27.5	0.10	14.4	0.32
20/11/05	26.2	0.17	8.47	0.54
15/12/05	25.9	0.19	7.58	0.60
6/2/05	31	0.10	14.4	0.32
27/04/06	32.5	0.10	13.71	0.33
Average	28.7	0.127	12	0.40

Appendix 3. Integral Photosynthetically Active Radiation (PhAR) measured during the incubation period on days of primary production measurement in Koka Reservoir.

Date of record	Ph.A.R. ($Em^{-2}.h^{-1}$)	Weather
28/8/05	13.15	Clear cloud/windy
20/11/05	8.62	cloudy/windy
15/12/06	12.1	Sunny/calm wind
18/1/06	11	Cloudy/calm
6/2/06	13.7	Sunny/windy
27/04/06	7.69	Cloudy/calm

Appendix4. Depth profile of oxygen and temperature in the upper part of the water column (0-3.25m) at the offshore station in Koka Reservoir.

Date	Depth (m)	O_2(mg l^{-1})	Temp(^oC)	Percentage Saturation
28/8/05	**0.0**	6.06	27.8	81.4
	0.25	5.91	27.6	76.7
	0.5	5.71	27.5	74.1
	0.75	5.55	27.3	70.1
	1.25	5.42	27.3	68.5
	1.75	5.06	27.3	65.1
	2.25	4.92	27.2	62.7
	2.75	4.74	27.3	60.2
	3.25	4.71	27.3	59.6
9/10/05	**0.0**		30.1	76.1
	0.25		30.2	75
	0.5		29.5	71.2
	0.75		29	69.4
	1.25		28.8	69.5
	1.75		28.6	68
	2.25		28.4	65
	2.75		28.3	64.8
	3.25		28.2	64.8
1/11/05	**0.0**	10.79	27.5	307.4
	0.25	9.34	25	271.5
	0.5	9.22	24.2	243.4
	0.75	8.61	22.3	199
	1.25	7.2	22.9	164.7
	1.75	8.3	22.7	152.2
	2.25	9.45	22.5	140.2
	2.75	9.27	22.4	121
	3.25	9.35	22.5	113.5
	0.0	9.62	26.2	140

20/11/05	**0.0**	9.62	26.2	140
	0.25 / 0.5	9.19 / 8.44	25.9 / 24.5	160 / 174
	0.75	9.2	24.7	174
	1.25	9	24.4	177
	1.75	8.8	24.2	172
	2.25	9.2	24	179
	2.75	8.6	23.9	170
	3.25	8.5	23.9	169
15/12/05	**0.0**	11.37	25.9	124
	0.25	11.89	25.2	142.8
	0.5	11.73	23.1	140.2
	0.75	11.8	21.8	141.8
	1.25	12.67	20.7	148.4
	1.75	12.58	20.1	138.4
	2.25	12	19.7	137
	2.75	12.43	19.3	130.8
	3.25	12.17	19.2	129.2
6/2/06	**0.0**	5	31	81.5
	0.25	4.8	30.5	60.1
	0.5	4.3	29.8	58
	0.75	4.3	28.9	55.3
	1.25	4.2	28.2	54
	1.75	4.1	27.3	51
	2.25	3.9	26.7	50.2
	2.75	1.2	25.7	16
	3.25	0.6	25.4	4.4
	0.0	6.6	32.5	76.8
	0.25	5.3	32.3	81
	0.5	4.3	32.1	60
	0.75	3.7	32	56.5
	1.25	3.6	30.3	50
	1.75	3.8	29.7	50
	2.25	3.2	28.3	46.9
	2.75	2.8	29	38.4
	3.25	2.7	-	34

Appendix 5. Ambient concentrations of inorganic nutrients recorded over the study period for the surface water of Koka Reservoir

Sampling Date	Sampling Date	NO_3-N µg/l	PO_4-P µg/l	SiO_2 mg/l	Biomass µg/l
Offshore Station	10/8/05	80	53.05	6.25	17.37
	28/8/05	67	43.16	7.21	16
	9/9/05	200	81.01	10.37	11.47
	16/10/05	53	66.21	10.08	18.07
	1/11/05	53	34.96	14.77	18.76
	20/11/05	47	16.86	15.35	16.68
	15/12/05	40	16.86	14.77	69.5
	18/1/06	53	23.44	13.43	22.24
	6/2/06	40	72.8	6.83	15.28
	26/3/06	47	72.8	9.41	20.85
	27/04/06	47	20.15	11.5	52.82
Littoral Station	10/8/05	93	153.4	6.25	24.62
	28/8/05	80	43.18	8.26	25.99
	9/9/05	67	51.4	10.27	35.44
	16/10/05	47	56.34	10.36	29.19
	1/11/05	53	11.92	15.92	77.14
	20/11/05	47	18.5	15.06	80.62
	15/12/05	50	57.99	10.56	221.01
	18/1/06	53	25.09	13.62	20.85
	6/2/06	53	72.8	6.64	60.48
	26/3/06	50	71.15	7.88	61.39
	27/04/06	47	34.91	14	71.04
Awash River Mouth Station	28/8/05	73	18.5	2.62	4.86
	9/9/05	133	51.4	10.27	8.68
	16/10/05	133	16.86	10.27	12.51
	1/11/05	233	0.41	17.16	31.97
	20/11/05	167	2.06	16.88	38.22
	15/12/05	240	2.06	17.64	54.9
	18/1/06	133	194.52	19.56	48.65
	6/2/06	267	74.44	11.14	43.09
	26/3/06	207	69.5	7.11	23.17
	27/04/06	147	74.4	14.29	20.85

Appendix 6. The relative importance of different phytoplankton groups to the abundance of the phytoplankton community in Koka Reservoir by periods at the offshore Station

Period I (August–December)	Period II (January)	Period III (February)	Period IV (March - April)
August 37% *Microcystis spp* 23%*Aulacoseira spp* 16 % *Scenedesmus spp* 16% *Selenastrum spp* 13% *Anabaena spp*	**January** 92% *Aulacoseira spp* 8% *Microcystis spp*	**February** 51% *Microcystis spp* 40% *Aulacoseira spp* 8.6% *Anabaena spp*	**March** 62.4% *Anabaena spp* 32.6% *Microcystis spp* 2.3% *Aulacoseira spp*
September 77% *Microcystis spp* 12.6% *Anabaena spp* 10% *Aulacoseira spp*			**April** 52% *Anabaena spp* 31.4% *Microcystis spp* 12% *Aulacoseira spp*
October 51% *Microcystis spp* 27% *Aulacoseira spp* 22% *Anabaena spp*			
November 58% *Microcystis spp* 11% *Anabaena spp* 31% *Aulacoseira spp*			
December *99% Microcystis spp* 1% *Anabaena spp*			

Appendix 7. Phytoplankton Biomass (B) as mg chl a/m^{-3} at the littoral, offshore and Awash River mouth stations

Date	Stations			
	Littoral	Offshore		Awash river mouth
		surface	composite	
10/8/05	24.62	17.37	-	-
28/8/05	25.99	16	14.5	4.86
9/9/05	35.44	11.47	13.73	8.68
16/10/05	29.19	27	26.75	12.51
1/11/05	77.14	18.76	16.24	31.97
20/11/05	80.62	16.68	15.29	38.22
15/12/05	221.01	69.5	60.1	54.9
18/1/06	20.85	22.24	19.46	48.65
6/2/06	60.48	15.28	16	43.09
26/3/06	61.39	27.85	27	23.17
27/04/06	71.04	52.82	29.19	20.85
Mean	**64.34**	**25.37**	**17.45**	**28.69**

Appendix 8. Depth profiles of gross photosynthesis (A), Net Photosynthesis(NP), Specific rate of photosynthesis (P_{max}), extent of surface depression of photosynthesis due to photoinhibition and Areal production.

Sampling Date	Depth (m)	Gross Photosynthesis (mg O_2 $m^{-3}h^{-1}$)	Net photosynthesis (mg O_2 $m^{-3}h^{-1}$)	Specific rate of photosynthesis (mg O_2(mg Chl a)h^{-1})	% reduction from A_{max} due to photo-inhibition	Gross Photosynthesis per unit area (mg O_2 m^{-2} h^{-1})
28/8/05	0	175	50	12	50	
	0.25	350	225	24		
	0.5	125	0	8.6		
	1	75	-5	5		
						153.22
9/9/05	0	220	164	16	62	
	0.25	515	441	37.5		
	0.5	176	97	13		
	1	147	66	11		
						252.4
16/10/05	0	540	447	20	21	
	0.25	680	587	24		
	0.5	340	247	13		
	1	247	154	9		
						240
1/11/05	0	216	72	13	68	
	0.25	517	373	32		
	0.5	108	-36	7		
	1	24	-12	1		
						190.54
20/11/05	0	414	41	7	20	
	0.25	517	575	34		
	0.5	267	206	17		
	1	144	82	9		
						299.4
15/12/05	0	924	62	4	21	
	0.25	1169	985	19.4		
	0.5	108	-77	2		
	1	61.5	0	1		
						412.1
18/1/06	0	322	171	16.5	17	
	0.25	387	197	20		
	0.5	162.6	116	8		
	1	74	51	4		
						200.09
6/2/06	0	329	188	21	31	
	0.25	477	265	30		
	0.5	177	- 35	11		
	1	141	-71	9		
						181.2
26/03/06	0	574	390	21	34	
	0.25	873	689	32		
	0.5	459	257	9.5		
	1	107	107	4		
						178.65
27/04/06	0	467	367	16	34	
	0.25	711	562	24		
	0.5	202	167	7		
	1	183	83	6		
						313

Appendix 9. Light-saturated rates of photosynthesis (**A_{max}**), Phytoplankton biomass as chlorophyll per unit water volume (**B**), Specific rate of photosynthesis at light saturation (**P_{max}**) , hourly and daily integral rates of photosynthesis and photosynthetic efficiency of light utilization(Φ,%)

Sampling **Date**	**A_{max} (mg $O_2 m^{-3} h^{-1}$)**	**B (mg Chl a m^{-3})**	**P_{max} [mg O_2(mg chl a)$^{-1}h^{-1}$]**	**ΣA (mg O_2 $m^{-2} h^{-1}$)**	**ΣΣA (mg O_2 $m^{-2}d^{-1}$**	Φ (%)
28/8/05	350	14.5	24	153.22	1379	0.07
9/9/05	515	13.73	37.5	252.4	2272	-
16/10/05	680	26.75	25	240	2160	-
1/11/05	517	16.24	32	190.54	1715	-
20/11/05	517	15.29	34	299.4	2695	0.21
15/12/05	1169	60.1	19	412.1	3709	0.21
18/1/06	387	19.46	20	200.09	1808	0.11
6/2/06	477	16	30	181.2	1631	0.08
26/03/06	873	27	32	178.65	1608	-
27/04/06	711	29.19	24	313	2871	0.25

Appendix 10. Statistical relations among physico- chemical and biological parameters Predictor(X) and Response(Y) variables at 95 % confidence Interval (CI)

Station	X	Y	Relationship	r^2	r	P
Offshore	Air Temp	Surface water Temp	Y=8.85 +0.99x	0.83	0.91	0.0043
	P^H	TA	Y=4.93 – 0.33 x	0.2	0.44	0.226
	Nitrate	Surface Chl a	Y=36.74-0.15 x	0.145	0.38	0.2464
	Phosphate	Surface Chl a	Y=45.12-0.43.x	0.34	0.58	0.058
	Silica	Surface Chl a	Y= 4.3 +2.06x	0.14	0.38	0.24
	Composite Chl a	A_{max}	Y=93.6 - 13.16x	0.18	0.42	0.11
	Ph.A.R	A_{max}	Y=755.62 – 13.92x	0.012	0.11	0.833
	P max	A_{max}	Y=926.41 -11.05 x	0.07	0.27	0.43
	Phosphate	A_{max}	Y=676.59 – 1.27 x	0.017	0.13	0.714
	Composte Ch a	$\sum A$	Y=138.98 + 4.32 x	0.57	0.75	0.011
	Ph.A.R	$\sum A$	Y=461.96 – 18.3x	0.2	0.45	0.36
	A_{max}	$\sum A$	Y=103.69 – 0.223x	0.48	0.69	0.025
	Rainfall	Chl a	Y=32.08 – 0.08x	0.04	0.2	0.6
	Awash River Inflow	Chl a	Y=32.78 – 0.09x	0.11	0.34	0.36
	Water Level	Chl a	Y=5832.06-3.65x	0.082	0.29	0.45
Littoral	Nitrate	Chl a	Y=148.7-1.45 x	0.154	0.39	0.23
	Phosphate	Chl a	Y=75.35-0.2.x	0.019	0.138	0.68
	Silica	Chl a	Y=33.66+2.84x	0.029	0.17	0.615
	Rainfall	Chla	Y=83.63 -0.42x	0.11	0.335	0.37
	Awash River Inflow	Chl a	Y=78.93 -0.29x	0.11	0.33	0.37
	Water Level	Chl a	Y=303.03- 0.15x	0.000013	0.0037	0.9924
Awash River Mouth	Nitrate	Chl a	Y=-3.79+ 0.187x	0.43	0.65	0.0381
	Phosphate	Chl a	Y = 24.98 + 0.073x	0.062	0.25	0.4853
	Silica	Chl a	Y=-2.98 + 2.49 x	0.592	0.769	0.0092
	Rainfall	Chl a	Y=38.3 – 0.226	0.43	0.7	0.0329
	Awash River Inflow	Chl a	Y = 34.83 – 0.16 x	0.43	0.65	0.054

Appendex 11 .T- test on Biomass between offshore, littoral and Awash River mouth stations.

	Stations		T value	P value	Df
Biomass	Littoral	Offshore	2.17	0.042	20
Biomass	Littoral	Awash River Mouth	1.907	0.071	19
	Offshore	Awash River Mouth	-0.42	0.675	19

DECLARATION

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

Name : Hadgembes Tesfay ______________

Signature :__________________________

Place : Addis Ababa University __________

Date of Submission:__________________

This work has been presented with my approval as supervisor

Name : Demeke Kifle(Ph.D) ____________

Signature:___________________________

Date:_______________________________

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ABSTRACT

The temporal and spatial changes in the biomass and primary production of phytoplankton in the turbid, frequently mixing eutrophic Koka Reservoir were studied from August, 2005 to April, 2006.The physico – chemical and biological features of the lake varied temporally and spatially during the study period. Inorganic nutrients, which remained at high levels throughout the study period, varied temporally with their low and high concentration levels generally corresponding to the dry and rainy periods of the year, respectively. The phytoplankton community in the reservoir was dominated persistently by Cyanophyceae, which were largely constituted by *Microcystis* spp. accounting for over 50% of the abundance of the phytoplankton assemblage on all sampling occasions except in February, 2006 when the diatom *Aulacoseira granulate* became dominant. The surface chlorophyll a concentrations ranged from 20.85 to 221.01, 11.47 to 69.5 and 4.86 to 54.9mg m^{-3} at the littoral, offshore and Awash River mouth Stations, respectively, with seasonal maximum in December, 2005 at all stations coincident with the bloom of *Microcystis* spp. The vertical distribution of photosynthetic activity was a typical pattern for phytoplankton with light-inhibition on all sampling dates. The light-saturated rate of photosynthesis (A_{max}) ranged from 350 mgO_2 $m^{-2}h^{-1}$ of August to 1169 mg O_2 $m^{-2}h^{-1}$ of December, 2005 coinciding with low and maximum phytoplankton biomass, respectively. The biomass - specific rates of photosynthesis (P_{max}) ranged from 19.4-37.5 mg O_2 (mg Chl a) h^{-1} . Hourly integral photosynthesis ($\sum A$) ranged from 0.15 –0.41g O_2 m^{-2} h^{-1} (≈ 0.056 to 0.154 g C≈) with highest seasonal peaks coinciding with the seasonal maximum of phytoplankton biomass. Light utilization efficiency of the phytoplankton assemblage of Koka Reservoir varied from 0.07 to 0.25 %. The temporal and spatial variations in phytoplankton biomass and primary production seem to be linked to the hydrological and hydrographic conditions of the reservoir. Factors responsible for the observed variations in the physico–chemical and biological conditions of the reservoir are discussed and appropriate conservation strategies for the reservoir are recommended.