SINET: Ethiop. J. Sci., 32(2): 141–148, 2009

ISSN: 0379–2897

Short communication

OLIGOTROPHICATION TREND OF LAKE ZIWAY, ETHIOPIA

Getachew Beneberu [1] and Seyoum Mengistou [2]

[1] Department of Biology, Faculty of Education, Bahir Dar University, PO Box 85
Bahir Dar, Ethiopia. E-mail: getachew13@yahoo.com
[2] Department of Biology, Faculty of Science, Addis Ababa University, PO Box 1176
Addis Ababa, Ethiopia. E-mail: Seyoumen@gmail.com

ABSTRACT: Some ecological changes have been noted in Lake Ziway since the 1980s, such as lowering of the lake level, introduction and dominance of the catfish *Clarias gariepinus* in the fishery (53%) and establishment of cladocerans such as *Daphnia barbata* and *Ceriodaphnia cornuta*. This prompted us to study the phytoplankton biomass to see whether these changes were cascaded through the trophic food chain of Lake Ziway. The dynamics of some chemical and biological parameters were studied in two littoral and one offshore sites in the lake from November 2003 to August 2004. Nutrients showed temporal as well as spatial variations. Nitrate increased in the offshore whereas soluble reactive phosphate (SRP) was high in littoral sites (20–380 μg/L), indicating anthropogenic impacts. Mean phytoplankton biomass was high at the offshore (43.85 mg Chl a m^{-3}) and almost similar at the littoral sites (Mean values 33.73 and 33.68 mg Chl a m^{-3}), but much lower than values reported earlier. Hourly rate of integral photosynthesis ($\sum A$) ranged from 57.4–726 mg O_2 m^{-2} h^{-1} at the offshore and 95–300 mg O_2 m^{-2} h^{-1} at littoral sites, respectively. Biomass-specific rate of photosynthetic production at light saturation, (photosynthetic capacity, Φmax) ranged from 5.06–28.8 mg O_2 (mg Chl a)$^{-1}$ h^{-1}, slightly higher than values reported in the 1980s (9.6–22.5), due to depressed algal biomass. Although nutrients have increased, phytoplankton biomass (as Chl a) has decreased over the last two decades, possibly due to heavy grazing by zooplankton and introduced fish. If this continues for some time, Lake Ziway will head towards oligotrophication, instead of eutrophication, as speculated by previous workers.

Key words: Biomass, Lake Ziway, littoral, nutrient, oligotrophication

INTRODUCTION

Lake Ziway has been the focus of a number of limnological investigations since the early 1980's. Wood and Talling (1988) and Girma Tilahun (1988) reported minor changes in the chemical limnology of Lake Ziway and noted that very low Chl a level (7–91 μg/L) and 'clear water' condition was reported earlier in 1938. Euphotic depth of the lake ranged from 0.4–1.06 m in 1988 (Girma Tilahun, 1988). The dominant algae were *Aphanothece microspora*, *Chroococcus disperses* and *Gleotrichia echinulata* (Wood and Talling, 1988). The zooplankton was dominated by Rotifera and the only cladocerans collected were *Diaphanosoma excisum, Alona davidii* and *Moina micrura* (Semeneh Belay, 1988; Seyoum Mengistou, Unpublished data).

Significant socio-economic developments have taken place around the rift valley lakes since the 1980s and some effects on water level, water chemistry and macrophytes were noted (Zinabu Gebre-Mariam and Elias Dadebo, 1989). Zinabau Gebre-Mariam *et al*. (2002), Halcrow (1989) and Tenalem Ayenew (2003) reported minor changes in the salinity of Lake Ziway whereas OEPO (2005) noted slight increase in salinity and mineral content as a result of evaporation, water abstraction and changes in the water balance of the lake. Over-irrigation and reduction in lake volume have resulted in soil salinization which is evident in the irrigation fields around Lake Ziway (Derege Hailu *et al*., 1996). Human impacts in the lake littoral are most severe in Lake Ziway than other rift valley lakes, with consequent impacts on macrophytes, fisheries, wetland birds and water balance. As interface between land and open water, the littoral is more easily accessible, and hence prone to the impact of human activities; moreover, this zone usually has the largest areal coverage of lakes. Wetzel (2001) reported that most of the lakes of the world are small, and their morphometry is such that the ratio of the pelagic zone (P) to the colonisable littoral zone (L) is small. The littoral is also the most productive area because of nutrient inputs from both allochthonous and autochthonous sources. It is the route of entrance for a great majority of materials (*e.g.*, urban, industrial, agricultural, fishery wastes etc) into a lake, and all these could have an impact on the long-term ecology of the lake.

Due to intensive human pressure on the lakeshore, the trophic status of Lake Ziway was thus bound to show change with time. The 'clear water' condition reported seven decades ago is now visibly replaced by a brownish turbid Lake Ziway. Different factors have been forwarded that could change the trophic state of a lake (e.g. nutrient, waste disposal, morphometric features, other biota, turbidity etc). One of the factors that affect phytoplankton biomass is turbidity. Turbidity can result either from algal or from non-algal sources. The major source of turbidity in the open water zone of most lakes is typically phytoplankton, but closer to shore; particulates such as clay and silt from shoreline erosion, re-suspended bottom sediments, and organic detritus from stream and/or wastewater discharges can contribute. Bottom-dwelling fish may increase lake turbidity through bio-turbation and bottom-stirring activities. As turbidity of lakes change, so does the trophic interaction between different functional groups of the food web. For example, large-sized zooplankton proliferate in turbid waters because of reduced predation from visual fish predators (Brooks and Dodson, 1965, and several references thereafter).

Lake Ziway has been used for a variety of developmental activities such as fisheries, irrigated agriculture (commercial farming), livestock watering, vehicle washing, human sanitation, and most recently, floriculture farming, etc. The nearby growing town of Ziway also contributes urban wastes via runoff. The long-term effect of all these on water quality and on food webs is complex. However, if historical data are available, it is possible to ascribe some of the limnological changes in lakes to identifiable factors. Although not as pronounced as that of the nearby Lake Abijata, lake level changes were reported for Lake Ziway by Dagnachew Legesee and Tenalem Ayenew (2006) and Tenalem Ayenew and Dagnachew Legese (2007). The cladoceran zooplankton which was dominated by *Diaphanosoma*, *Alona* and *Moina* species only (Semeneh Belay, 1988; Seyoum Mengistou, unpublished data) were joined by *Ceriodaphnia cornuta* and *Daphnia barbata* (Getachew Beneberu, 2005; Adamneh Dagne *et al*., 2008). These large crustaceans have high clearance rates and can remove alga effectively. Adult *Moina micrura* were recorded in offshore sites of Lake Ziway indicating less predation by fish as compared to juveniles dominating in the littoral (Adamneh Dagne *et al*., 2008). The Lake Ziway fishery also changed drastically in the late 1990's with the catfish *Clarias gariepinus* and Crucian carp (*Carassius carassius*) suddenly overwhelming the fishery (53% and 6% of total catch, 1995–2000) and tilapia (*Oreochromis niloticus*) drastically reduced from catch of 1944 tons in 1995 to 571 tons in 2000 (Yared Tigabu, 2003). We speculated that the low Chl a values obtained in 2004 might be related to the long-term effects of these ecological changes in the lake. The objective of this study was, therefore, to analyze the phytoplankton biomass and production in 2004, and to assess their relations to the long-term changes in zooplankton and fish composition recorded earlier since the 1980s.

MATERIALS AND METHODS

Study area

Lake Ziway lies 08° 01′ N and 38° 47′ E within the Ethiopian Rift valley system at an altitude of 1636 meters above sea level. It is the shallowest of the Rift Valley lakes with maximum and mean depth of 8.95 m and 2.5 m, respectively (Von Damm and Edmond, 1984).With regard to the biological community, 122 species of phytoplankton have been identified (Tsegaye Miheretab, 1988) of which 50 species are blue green, 41 green algae and the rest 31 are diatoms. The zooplankton is dominated by *Mesocyclope*s sp., *Microcyclops* sp., *Diaphanosoma* spp., *Brachionus angularis*, and *Keratella tropica* (Semeneh Belay, 1988). The fish community of the lake is composed of *Oreochromis niloticus*, *Barbus ethiopica*, *Barbus microterolepis*, *Tilapia zilli*, *Clarias gariepinus*, *Carassius auratus*, and *Cyprinus carpio* (Zenebe Tadesse, 1988; Alemayehu Negassa, 2002).

The study was conducted at three sites that we selected based on the degree of impact. Two sites were in the littoral designated as L1, L2 and the other one was offshore (OF). The two littoral sites were mainly dominated by macrophytes. L1 is located near the fishery research centre whereas L2 is located near the Saint Gabriel Church. The site OF is located near an island that served as roosting sites for various species of birds.

Physico-chemical and biological parameters

Secchi depth was measured using a quarterly divided Secchi disc. The determination of major algal nutrients was carried out using HACH-portable spectrophotometer (DR/2010). For pigment analysis, samples were collected from the surface and stored in polyethylene bottles then transported to the laboratory in an icebox. Chlorophyll ''a'' concentration was estimated spectrophotometrically as in Talling and Driver (1963). No correction was done for degradation products. *In situ* primary production was estimated from changes in dissolved oxygen concentrations in clear and dark bottles (Wetzel and Likens, 1991). Water samples were taken from the surface, and siphoned into 250 ml light and dark Pyrex glass bottles. Then the bottles were attached horizontally at intervals to a crossed metal rod and suspended at various depths distributed approximately over the euphotic zone.

Data analysis

The means and correlation coefficients were calculated for various parameters from the three sampling stations.

RESULTS

Nutrients

The concentration of NO_3^--N varied from nd – 800 µg/L at OF, 200 – 600 µg/L at site L1, and 0–950, µg/L at site L2 (Where nd means not detected by the instrument). In most of the sampling period, the concentration of nitrate was below the detectable limit of the instrument. The mean value during the study period was high for the offshore (400 µg/L), than the two littoral sites having a value of 185.7 µg/L (at L1) and 378.6 µg/L (at L2), respectively. The highest nitrate values coincided with the dry season of the year (Fig. 1). Soluble reactive phosphate varied from 40–170 µg/L, at OF, and 20–380 µg/L, at site L1, and nd -220 µg/L at site L2. The mean value was high in the littoral than the offshore.

Phytoplankton biomass and primary productivity

Phytoplankton biomass varied during the study period from 30.1–57.9, 27.8–45.2, and 26.3–44.8 mg Chl a m^{-3} at site OF, L1, and L2, respectively. The mean biomass was high at offshore (43.85 mg Chl a m^{-3}), whereas almost similar (L1, 33.73 and L2, 33.68 mg Chl a m^{-3}) mean values were found in the two littoral sites. *In situ* experimental measurements of rates of gross photosynthesis per unit water volume (A, mg O_2 m^{-3} h^{-1}) were also calculated. The area enclosed by each depth profile is a measure of the integral rate of photosynthesis per unit area of lake surface ($\sum A$, mg O_2 m^{-2} h^{-1}).

Hourly rates of integral photosynthesis ($\sum A$) ranged from 57.4–726 mg O_2 m^{-2} h^{-1} at the offshore and from 95–300 mg O_2 m^{-2} h^{-1} at littoral site. The daily rates of photosynthesis of Lake Ziway were also determined as used in Talling and Talling (1965) for other East African Lakes. The calculated values ranged from 0.52–6.53 g O_2 m^{-2} d^{-1} at offshore, and from 0.86–2.7 g O_2 m^{-2} d^{-1} at site L1. Photosynthetic capacity (Φ max) was determined only for the two sites (OF and L1), Φmax varied from 5.06–28.6 and 6.6–28.8 mg O_2 (mg Chl a)$^{-1}$ h^{-1} at offshore and L1, respectively (Table 1).

Table 1. Hourly, daily rate of gross photosynthesis per unit area, Biomass, Amax, and Φmax of the off shore (OF) and littoral (L1) of Lake Ziway.

Month	$\sum A$ (mg O_2 m^{-2} h^{-1})		$\sum\sum A$ (g O_2 m^{-2} d^{-1})		B (mg Chl a m^{-3})		Amax (mg O_2 m^{-3} h^{-1})		Φmax (mg O_2 (mg Chl a)$^{-1}$$h^{-1}$)	
	OF	L1	OF	L1	OF	L1	OF	L1	OF	L1
Nov, 2003	317.0	-	2.85	-	40.2	-	1150		28.6	-
Dec, 2003	726.0	128.0	6.53	1.15	-	34.2	2115	-	-	-
Jan, 2004	321.6	112.8	2.89	1.02	57.9	31.9	1105	600	19.1	18.8
Feb, 2004	247.6	142.0	2.23	1.28	55	33.3	800	800	14.5	24.0
Mar, 2004	57.4	100.0	0.52	0.90	36.5	31.9	250	700	6.8	22.0
Apr, 2004	73.3	120.0	0.66	1.08	39.5	30.7	200	800	5.1	26.1
May, 2004	264.0	95.0	2.38	0.86	30.1	34.8	500	500	16.6	14.4
Jun, 2004	320.8	300.0	2.89	2.70	42.9	27.8	900	800	21.0	28.8
Aug, 2004	374.0	202.3	3.37	1.82	48.7	45.2	1200	300	24.6	6.6
Average	300.2	150.0	2.70	1.35	43.9	33.7	913	643	18.7	20.1

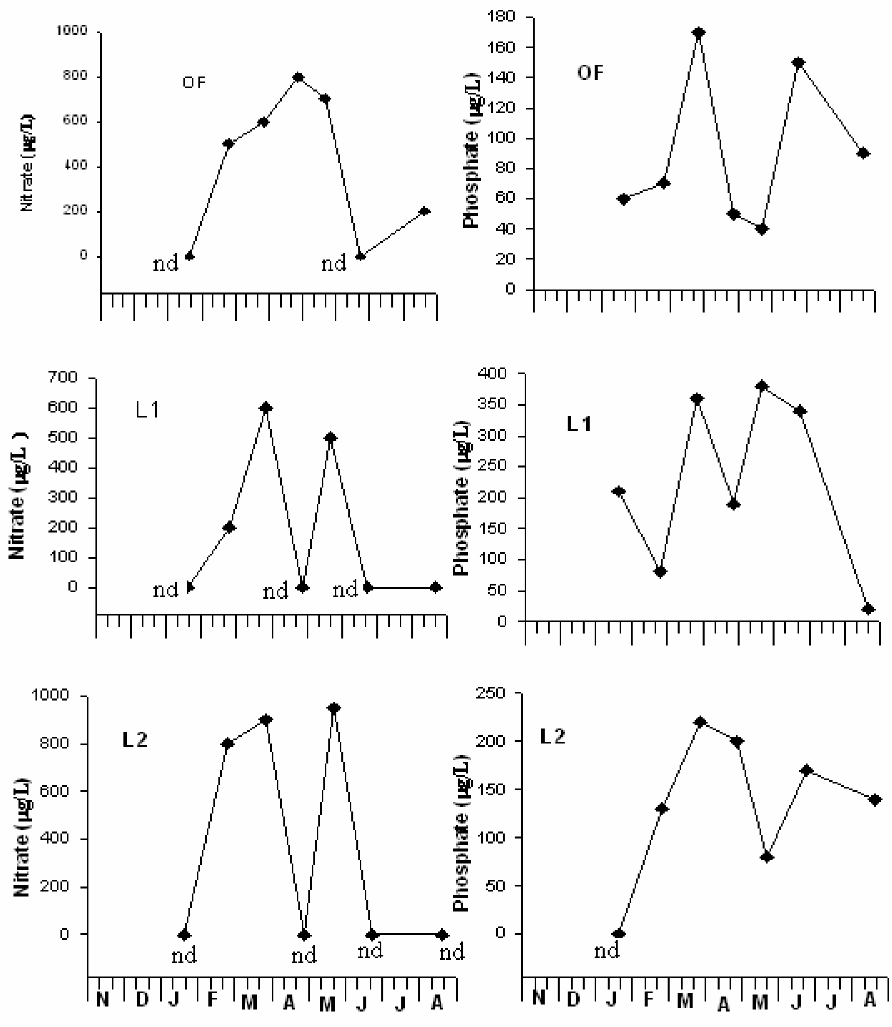

Fig. 1. Temporal variation in the concentration of nitrate and phosphate at the three study sites of Lake Ziway.

DISCUSSION

The Secchi depth in this study varied from 10.75–15, 13–19.25 and 13.5–18 cm at site L1, L2 and OF, respectively. Lower secchi depth was measured at site L1 whereas the highest was recorded at site L2. These values are much lower than the range of 0.4–1.06 m reported by Girma Tilahun (1988) and clearly indicate that the lake has become more turbid during the last two decades, possibly as a result of shoreline degradation, catchment erosion and perhaps introduced bottom-stirring fish such as carp and catfish.

The mean concentration of nitrate was higher than phosphate and high for the offshore than the two littoral sites. The present nitrate values are higher than previously reported values for the same lake (28–136.5 µg/L, Girma Tilahun, 1988), indicating eutrophication trend with time. However, nitrate varied more than soluble reactive phosphate (SRP) and was frequently absent from the water column, suggesting that it may be a limiting factor for phytoplankton growth in Lake Ziway. Talling and Talling (1965) highlighted that nitrogen was the limiting nutrient for phytoplankton growth in tropical African lakes, since nitrate levels were frequently very low and undetectable. Though the concentration of nitrate seems very high, its concentration was below the detection limit of the instrument in most sampling periods possibly due to the low sensitivity of the HACH instrument.

Dissolved oxygen greatly affected the concentration of nitrate in Lake Ziway. In the littoral, nitrate concentration changed drastically with depth, and attained a zero value at the upper few centimeters (Getachew Beneberu, 2005). Dissolved oxygen attained a zero value at a depth of 25 and 50 cm at site L2 and L1, respectively. This unexpected result in the littoral could be due to mass of decaying macrophytes and other organic wastes in the littoral, which people often use as dump sites. Caffrey and Kemp (1992) contend that denitrification accompanying anoxia characteristically brings nitrate concentration in the anoxic portion of the hypolimnia virtually to zero, thus reducing the amount of inorganic nitrogen available in the water column at the time of net mixing. In this way, denitrification may restrict the nitrogen supply to autotrophs.

In general soluble reactive phosphate was high in the two littoral sites ($\bar{x}$= 211.4 µg/L at site L1 and 134.3 µg/L at site L2, respectively) whereas the offshore has a mean value of 90 µg/L. The value of phosphate is higher than previously reported for the same lake (5.5–16.2 µg/L, Girma Tilahun, 1988), or Lake Chamo (22.6–91.7, µg/L Eyasu Shumbulo, 2004). The high concentration of phosphate in the littoral could be due to influx of pollutants and organic matter from lakeshores. Previously, Girma Tilahun (1988) reported low concentration of phosphate under high phytoplankton biomass. The phytoplankton biomass in the present study was very low, so the high concentration of phosphate in the present study can also be due to low phytoplankton biomass.

The farm lands located near the shore use fertilizers which are rich in nutrients, especially phosphates and nitrates. Beside this, other contributions from the effect of fishermen, detergents and the Fish Corporation and fish offal could be high. Fish offal is rich in nutrients, and hence can increase the concentration of SRP. However the contribution of fish offal is controversial. Some workers maintain that it has direct effect, as it is rich in phosphorus, whereas others (NIWR ,1985) assume based on qualitative observation, that the decomposition of fish does not result in net nutrient release to the lake except insofar as the dead fish are subsequently grazed by piscivorous birds, which subsequently release their droppings into the lake. *Pelicans* and *Marabou storks a*re the dominant bird species in Lake Ziway which feed on fish offal (Personal observation) and definitely release their droppings there.

Phytoplankton biomass varied during the study period from 30.1–57.9, 27.8–45.2, and 26.3–44.8 mg Chl a m^{-3} at sites OF, L1, and L2, respectively. The mean biomass was high at offshore, whereas almost similar mean values were found at the two littoral sites. This is in contrast to what is expected in the littoral; normally the littoral is expected to have high phytoplankton biomass than the offshore, because of immediate nutrient input both from allochthonous and autochthonous sources (Wetzel, 2001). Low phytoplankton biomass was found during present study as compared with previous results. For example high phytoplankton biomass of 334 mg Chl a m^{-3} and 149.5–212 mg Chl a m^{-3} was reported for the same lake by Elizabeth Kebede *et al*. (1994) and Girma Tilahun, (1988), respectively. Zinabu Gebre-Mariam *et al*. (2002) reported a mean value of 82.4 with ranges of 23–224 µg/L of Chl a for Lake Ziway, again much higher than the values recorded in this study. Taking the mean algal biomass of Lake Ziway in 2004 as ~ 38 mg Chl a m^{-3}, we estimate that since the early 1980 to 2004, the phytoplankton biomass of Lake Ziway has been reduced by a factor of three to nine.

Previous studies, based on time series of chlorophyll a analysis speculated that Lake Ziway shows a progressive increase towards eutrophy (Zinabu Gebre-Mariam *et al*., 2002), but the result of the present study shows a different trend (Table 2). Therefore, if the situation now continues as it is, Lake Ziway will return to its previous oligotrophic status like that of the year 1938 or even commence towards oligotrophication.

The decrease in biomass in the present study as compared to previous results can be attributed either to zooplankton grazing, other biota and/or increased turbidity. The increment in turbidity was reflected by the low Secchi depth measured during the study period as compared to previous records. The highest Secchi depth was about 19.25 cm. Zooplankton abundance was noted to be higher than earlier reports (Getachew Beneberu, 2005), and new unreported Cladcocera such as *Daphnia barbata* was observed for the first time in Lake Ziway; hence, the low phytoplankton biomass might be due to grazing by zooplankton. The low biomass and nutrients especially nitrate in the littoral might be due to the effect of macrophytes, as macrophytes compete for the same nutrients with algae. Beside this, they can also suppress the growth of algae through the production of suppressive chemicals and/or shading. The importance of macrophytes to the total functioning of Lake Ziway ecosystem began recently (Girum Tamire, pers. Comm.) and more conclusive results on macrophytes will emerge in future.

Table 2. Phytoplankton biomass of Lake Ziway during the years 1937–2004.

Date	Chl a(µg/L)	
1937–38	Clear water	[Cannicci & Almagia (1947)]
Oct. 1966	7 (b)	[Wood *et al.* (1978)]
Apr.1980	91(c)	[Amha Belay& Wood (1984)]
Jul-86	334 (d)	[Elizabeth Kebede *et al.* (1994)]
Feb.1987- Feb' 88	150–212	[Girma Tilahun (1988)]
Mar-91	154	[Elizabeth Kebede & Willen (1998)]
2003–2004	30.1–57.9 (OF)	[present study]
	27.8–45.2 (L1)	
	26.3–44.8 (L2)	

Total gross primary production is generally expected to be high in the littoral than the offshore; this is because of nutrient input from various sources, and the presence of different groups of plants. Macrophytes, epiphytic algae, free-floating algae and bacteria all contribute to the total primary productivity. For instance in the present study the hourly rates of integral photosynthesis ($\sum A$) ranged from 57.4–726 mg O_2 m^{-2} h^{-1} at the offshore and from 95–300 mg O_2 m^{-2} h^{-1} at littoral sites. Although the littoral is considered to be more productive than the offshore, in the present study, only freely floating algae were considered, and it is because of these that the production is higher in the offshore. Besides this, the magnitude of irradiance reaching the lake surface greatly affects production. Light may not penetrate deep in the littoral than the offshore for reasons related to the dense macrophyte cover and high turbidity; all this might reduce planktonic production. Williame and Lenton (1975) found little planktonic production in the swampy area of Lake Chiliwa-Malawi that had low light levels.

Light-saturated rates of photosynthesis (Amax) varied during the study period from 200 to 2115 mg O_2 m^{-3} h^{-1} at offshore and from 300 to 800 mg O_2 m^{-3} h^{-1} at littoral sites. Most of the values are considerably lower than those reported for the same lake (1640–4670 mg O_2 m^{-3} h^{-1} (Girma Tilahun, 1988), but higher than those recorded for Lake Awassa (217–425 mg O_2 m^{-3} h^{-1}) (Demeke Kifle and Amha Belay, 1990). Light-saturated rates of photosynthesis are known to be a function of primarily variable biomass concentration and photosynthetic capacity (Talling and Lemoalle, 1998). In both littoral and offshore, there was a strong positive correlation between Amax and Φmax, with r values of 0.98 and 0.92, respectively. The correlation between Amax and biomass is different in the two sites. In the offshore Amax is positively correlated with phytoplankton biomass (r =0.59), but in the littoral it was negatively correlated (r = -0.88). This negative correlation in the littoral might be due to the intensity of irradiance. In the offshore, the light may not penetrate deep, but in the littoral since it is shallow, it can get sufficient light provided that there are no aquatic macrophytes. This could be the reason for negative correlation in the littoral. Lack of correspondence between biomass and Amax was also reported for phytoplankton of several reservoirs in Sri Lanka (Silva *et al*., 2002), Lakes Arenguade (Talling *et al*., 1973) and Awassa (Demeke Kifle and Amha Belay, 1990) in Ethiopia. Higher P max values in this study are due to lower algal biomass. Thus although the gross primary production of Lake Ziway has not changed much over the last three decades, its productivity has, partly because of change in composition of the dominant phytoplankton, and the low algal biomass. Clearly, Lake Ziway shows oligotrophication trend recently, and not eutrophication as has been suggested for rift valley lakes in Ethiopia facing increasing human pressure (Zinabu Gebre-Mariam *et al*., 2002).

CONCLUSION

In general, nutrients have increased in Lake Ziway, with nitrate higher in the offshore than the littoral. In contrast, the concentration of phosphate is higher in the littoral than the offshore. Factors such as waste disposal, runoff, fertilizer application and fish offal contribute to nutrient increase. However, this has not been followed by increased algal blooms and eutrophication. The present (2004) phytoplankton biomass has been reduced by a factor of three to nine (Table 2). Previous reported values in the late 1980s and our data show that algal biomass has been decreasing at faster rates recently. If the situation continues as it is, definitely Lake Ziway will shift to the process of oligotrophication instead of eutrophication as speculated by previous authors. This work supports the conclusion that Lake Ziway is not undergoing eutrophication as a result of human pressure, but oligotrophication as a result of trophic changes in the food web. Therefore, serious measures must be taken in order to conserve the lake and its biodiversity.

ACKNOWLEDGEMENTS

We would like to thank the Department of Biology (AAU) for financing the project. We also appreciate the contribution and collaborative effort made by the staff members of Ziway Fishery Research Centre. We also acknowledge the two anonymous reviewers for their critical and constructive comments of the manuscript.

REFERENCES

1. Adamneh Dagne, Herzig, A., Jersabek, C.D. and Zenebe Tadese (2008). Abundance, species composition and spatial distribution of planktonic rotifers and crustaceans in Lake Ziway (Rift Valley, Ethiopia). *Int. Rev. Hydrobiol*. **93**:210–226.
2. Alemayehu Negassa (2002).The status of introduced exotic fish species, *Tilapia zillii* Gervais (piscesi *cichlidae*) and its relation with native *Oreochromis niloticus* in lake Ziway, Ethiopia. MSc Thesis. Addis Ababa University, p. 76.
3. Brooks, J.L. and Dodson, S.I. (1965). Predation, body size and composition of plankton. *Science* **150**:28–35.
4. Caffrey, J.M. and Kemp, W.M. (1992). Influence of the submerged plant, *Potamogeton perfoliatus*, on nitrogen cycling in estuarine sediments. *Limnol .Oceanogr*. **37**:1483–1495.
5. Dagnachew Legesse and Tenalem Ayenew (2006). Effects of improper water and land resource utilization on the central Main Ethiopian Rift lakes. *Quaternary International* **148**:8–18.
6. Demeke Kifle and Amha Belay (1990). Seasonal variation in phytoplankton primary production in relation to light and nutrients in Lake Awassa, Ethiopia. *Hydrobiologia* **196**:217–227.
7. Elizabeth Kebede, Zinabu Gebre-Mariam, and Ahlgreen, A. (1994). The Ethiopian Rift Valley lakes. Chemical characteristics along a salinity- alkalinity series. *Hydrobiologia* **288**:1–12.
8. Eyasu Shumbulo (2004). The temporal and spatial variations in the biomass photosynthetic production of phytoplankton in relation to some physico-chemical environmental factors in Lake Chamo, Ethiopia. MSc Thesis. Addis Ababa University, 65 pp.
9. Getachew Beneberu (2005). Nutrient and plankton dynamics in the littoral and offshore zones of Lake Ziway, Ethiopia. MSc Thesis. Addis Ababa University, Addis Ababa, 67pp.
10. Girma Tilahun (1988). A seasonal study on phytoplankton primary production in relation to light and nutrients in Lake Ziway, Ethiopia. MSc Thesis. Addis Ababa University, Addis Ababa, 62 pp.
11. Derege Hailu, Hess, M. and Tenalem Ayenew (1996). The problem of high rise ground water in Amibara Irrigation Project, Middle Awash Basin. Ethiopian Science and Technology Commision, Unpublished report, Addis Ababa, Ethiopia.
12. Halcrow (1989). *Master Plan for the Development of Surface Water Resources in Ten Awash Basin*, Vol. 6. Ministry of Water Resources, Addis Ababa, Ethiopia.
13. NIWR (National Institute for Fresh Water Research) (1985). The Limnology of Hart bee spoort Dam. S. Afr. Nat. Scu. Prog. Rep. 110.CSIR, Pretoria.
14. Oromia Environmental Protection Office (OEPO) (2005). A review of the current status and an outline of a future management plan for Lakes Abiyata and Ziway. Unpublished technical report, OEPO, Addis Ababa, Ethiopia.
15. Semeneh Belay. (1988). Zooplankton composition and seasonal dynamics in Lake Ziway, Ethiopia. MSc Thesis. Addis Ababa University, Addis Ababa. 121 pp.
16. Silva, E.L.L., Amarasinghe, U.S., De Silva, S.S., Nissanka, C. and Schiemer, F. (2002). Some aspects of photosynthetic characteristics in a set of perennial irrigation reservoirs located in the river basins in Sri Lanka. *Hydrobiologia* **485**:19–33.
17. Talling, J.F. and Talling, I.B. (1965). The chemical composition of African lake waters. *Int. Ree. Ges. Hydrobiologie* **50:**421–465.
18. Talling, J.F. and Driver, D. (1963). Some problems in the estimation of chlorophyll 'a' in phytoplankto. *Proceeding, Conference on Primary Productivity Measurement, Marine and Freshwater*, pp. 142–146. Atomic Energy Comm., TID -763 USA.
19. Talling, J.F. and Lemoalle, J. (1998). Ecological dynamics of tropical inland waters.

Cambridge University Press, Cambridge, 441 pp.

20. Talling, J.F., Wood, R.B., Prosser, M.V. and Baxter, R.M. (1973). The upper limit of photosynthetic productivity by phytoplankton: evidence from Ethiopian soda lakes. *Freshwater Biol.* **3**:53–76.

21. Tenalem Ayenew (2003). Environmental isotope-based integrated hydrogeological study of some Ethiopian Rift lakes. *J. Radioanal. Nucl.* **257**:11–16.

22. Tenalem Ayenew and Dagnachew Legesse (2007). The changing face of the Ethiopian rift lakes and their environs: call of the time. *Research and management* **12**:149–165.

23. Tsegaye Miheretab (1988). A seasonal study on the species composition and Phytoplankton biomass in Lake Ziway, Ethiopia. MSc Thesis Addis Ababa University, Addis Ababa, 72 pp.

24. Von Damm, K.L. and Edmond, I.M. (1984). Reverse weathering in the closed basin lakes of Ethiopian Rift. *Amer. J. Sci.* **284**:835–862.

25. Wetzel, R.G. (2001). *Limnology*, 3rd ed., W.B. Saunders, Philadelphia, 1006 pp.

26. Wetzel, R.G. and Likens, G.E. (1991). *Limnological Analysis*, 2nd ed., Springer-Verlag New York, 391 pp.

27. Williame, C.F. and Lenton, G.M. (1975). The role of the littoral zone in the functioning of a shallow tropical lake ecosystem. *Freshwat. Biol.* **5**:445–457.

28. Wood, R.B. and Talling, J.F. (1988). Chemical and algae relationships in a salinity series of Ethiopian inland waters. *Hydrobiologia* **158**:29–67.

29. Yared Tigabu (2003). The current status of Lake Ziway. **In**: *Wetlands and Aquatic Resources of Ethiopia: Status, Challenges and Prospects. Proceeding of the workshop organized by Biological Society of Ethiopia* (Feb. 12–13, 2003), pp. 1–10, (Seyoum Mengistou, Abebe Getahun and Ensermu Kelbesa, eds). Addis Ababa, Ethiopia.

30. Zenebe Tadesse (1988). Studies on some aspects of the biology of *Oreochromis niloticus* in Lake Ziway, Ethiopia. MSc Thesis. Addis Ababa University, Addis Ababa, 78 pp.

31. Zinabu Gebre-Mariam, Elizabeth Kebede and Zerihun Desta (2002). Long-term changes in the chemical features of waters of seven Ethiopian rift-valley lakes. *Hydrobiologia* **477**:81–91.

32. Zinabu Gebre-Mariam and Elias Dadebo (1989). Water resources and fisheries management in the Ethiopian Rift-Valley lakes. SINET: *Ethiop. J. Sci.* **12:**95–109.