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# LONG-TERM CHANGES IN PHYTO- AND ZOOPLANKTON COMMUNITIES OF LAKE HAWASSA, ETHIOPIA

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**ABSTRACT:** We studied phyto- and zooplankton communities of Lake Hawassa (or Awassa) between November 2003 and August 2004, and compared findings with historical data since the 1980s to assess potential inter-decadal changes. The lake is located in the Ethiopian Rift Valley in the vicinity of the growing city Hawassa which receives adverse effluents from textile and ceramics industry and municipal sewage apparently with little treatment. In 2003/04, phytoplankton abundance comprised 54% Chlorophyta, 26% cyanoprokaryotes, 18% diatoms and 2% others, a proportion similar to previous records. However, the mean phytoplankton biomass in terms of chlorophyll *a* (19 µg $L^{-1}$) was lower than reported from previous studies but similar to a report in 2010. In contrary, areal rate of gross photosynthesis had increased in the last two decades with higher values recorded in 2003-04 (0.35 to 2.21 g $O_2$ $m^{-2}$ $h^{-1}$). Even though zooplankton community composition remained the same, the abundance and dominance of taxa had changed in the last decades. In 2003/04, the mean abundance of cyclopoid-copepods was 58 000 ± 9200 (SE) Indl $m^{-3}$ whereas cladocera abundance (2 600 ± 640 SE Indl $m^{-3}$) was very low in the lake. Rotifers outnumbered other zooplankton with a maximum value of 264 000 Indl $m^{-3}$, which was about five times greater than previous reports. Adult cyclopoid to nauplii ratio of 0.27 in 2003-04 study was indicative that cannibalism had diminished, probably due to increased rotifers as prey, which contradicted a previous hypothesis. Despite its closed nature, the plankton of Lake Hawassa changed erratically during a decade, probably due to intense biological interactions in the system.

**Key words/phrases**: Decadal change, Interactions, Rift valley, Phytoplankton, Zooplankton.

## INTRODUCTION

An 'ecosystem distress syndrome' is widely prevalent (Rapport *et al*., 1998), and both internal and external drivers can affect aquatic ecosystems. The external driver can be thought of as a signal and the lakes as responders (Magnuson *et al*., 2004) which react to the signal in several ways: absorbing the signals, temporarily altered or changed into an alternate stable domain (e.g. eutrophic), or in the worst scenario, the system may disappear (e.g. Lake Alemaya, Brook Lemma, 2003). Normally, changes are not abrupt but

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the sum of slow processes. A long-term view reveals a rich array of slow changes, and inter-annual and inter-decadal dynamics (Magnuson *et al*., 2006). Long-term data also provide an important baseline against which future changes can be assessed (Kunz and Richardson, 2006). Such long-term studies are well documented for temperate lakes (Magnuson *et al*., 2006). However, in tropical lakes long-term variability has been documented only sporadically (Talling and Lemoalle, 1998), and this holds true for most Ethiopian water bodies.

One exception is the comparatively well studied Lake Hawassa, which was investigated extensively during the 1980s and early 1990s with particular emphasis on its biology. Phytoplankton biomass and primary production were studied in relation to nutrients and light during this time (Demeke Kifle and Amha Belay, 1990; Elizabeth Kebede and Amha Belay, 1994) and some dominant phytoplankton species were identified including *Lyngbya nyassae* Schmidle 1902, *Botryococcus braunii* Kützing 1849 and *Microcystis* sp. Zooplankton composition, biomass and secondary production were comprehensively studied by Seyoum Mengistou (1989), with dominant taxa represented by *Mesocyclops aequatorialis* Van de Velde 1984, *Thermocyclops consimilis* Kiefer 1934, *Diaphanosoma excisum* Sars, *Brachionus* and *Keratella* spp. Since then, few studies were made on Lake Hawassa regarding plankton dynamics and their interactions (Tadesse Fetahi, 2005; Girma Tilahun and Ahlgren, 2010). However, some changes are anticipated to have taken place based on demographic pressure and industrial developments around the lake. Lake Hawassa is located in the vicinity of the growing city Hawassa, and some of the many potential adverse effects facing the lake include lack of proper sewage treatment system, poor land use management and high levels of recreational activity. Moreover, the nearby Hawassa Textile Factory drains its effluent into the lake, apparently with little treatment. Bioassay studies by Zinabu Gebre-Mariam and Zerihun Desta (2002) on the effluent from this factory showed that phytoplankton growth was either boosted or inhibited, and fish fry and adult fish almost instantly died when exposed to the undiluted effluent. On the other hand, water level fluctuations of Lake Hawassa were reported (Seyoum Mengistou and Fernando, 1991; Zinabu Gebre-Mariam *et al*., 2002) with the lake level increasing over the years. These water level changes could disturb the breeding ground of Tilapia (a commercially important fish) and other physical, chemical and biological parameters of the lake (Tudorancea and Taylor, 2002). Overfishing of Tilapia (*Oreochromis niloticus* Linnaeus 1758) was also documented (LFDP, 1998), suggesting that its preys might have been relieved from the grazing pressure. The chemistry of the lake was investigated by Elizabeth Kebede *et al*. (1994) and its long-term variations were discussed by Zinabu Gebre-mariam *et al*. (2002). Recently, Girma Tilahun and Ahlgren (2010) have also reported about the chemistry of the lake (Table 2). Lake Hawassa is naturally changing to its ecological maturity stage, as evidenced from the concept developed by Odum (1969) (Tadesse Fetahi and Seyoum Mengistou, 2007) and its water quality can easily be affected through anthropogenic effects.

In order to manage aquatic ecosystems, we need a broad understanding of the plankton and the interactions with the environment. Plankton communities assimilate various human and environmental impacts, thereby providing a benchmark for monitoring the synergistic effects of urbanisation and climate change (Kunz and Richardson, 2006). Accordingly, it is now common practise to use plankton as water quality indicators (Mona *et al*., 2005). We therefore aimed to analyze and document the decadal changes of plankton in a tropical rift-valley lake where anthropogenic and environmental effects were evident. Phytoplankton changes were assessed in terms of community composition, primary production and chlorophyll a (Chl *a*). Zooplankton community structure and abundance were also examined to understand long-term changes and the biotic interactions in the system. The approach taken was to compare the available historical data of Lake Hawassa since 1980s with the present study, and to account for some of the possible reasons for the changes.

## Study site

The endorheic Lake Hawassa (Fig. 1) is located at an altitude of 1680 m in the central part of the Ethiopian Rift Valley (6°33' – 7°33' N and 38°22' – 38°29' E), 275 km south of the capital city Addis Ababa. Daniel Gamachu (1977) documented that the Hawassa area has a dry, subhumid climate and receives a mean annual rainfall of 1154 mm (Fig. 2). The annual potential evapotranspiration for the area is between 1100 and 1250 mm (Elizabeth Kebede and Amha Belay, 1994), so evapotranspiration sometimes exceeds precipitation. The lake has a surface area of 90 km$^2$ and a maximum depth of 22 m (Table 1), although the latter value is subjected to seasonal variation. It is fed by a small river Tikur Weha. The lake is classified as warm, discontinuous, polymictic under the scheme proposed by Lewis (1983). Sodium and Chlorine are the dominant cation and anion, respectively and a summary of the lake chemistry is presented in Table 2.

The fish fauna of Lake Hawassa consists of *Oreochromis niloticus*, *Clarias gariepinus* Burchell 1822, *Labeobarbus intermedius intermedius* Rüppell 1835, *Barbus paludinosus* Boulenger 1903, *Aplochelichthys* sp., and *Garra* sp. (Demeke Admassu, 1996; Fishbase, 2010). Juvenile and the last three fish species are regarded as planktivore. The benthic fauna include Ostracods (dominant), Chironomids, Cyclopoids and Cladocerans. The macrophytes vegetation includes *Cyperus* sp., *Nymphea caerulea*, *Potamogeton* sp., *Typha angustifolia*, *T. latifolia*, and *Paspalidium geminatium* (Tilahun Kibret and Harrison, 1989).

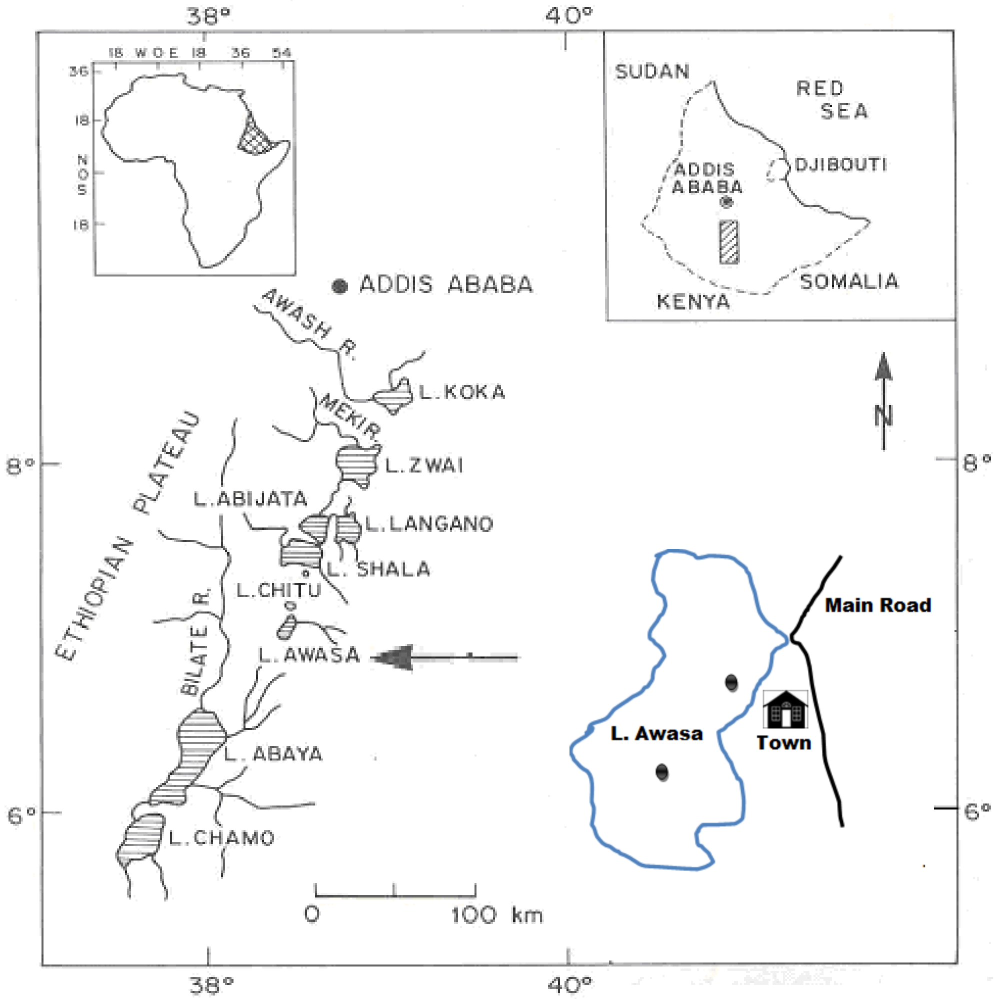


Fig. 1. Map of Ethiopia (inset) and the Rift Valley Lakes with their drainage basin pattern. The arrow indicates Lake Hawasa (Modified after Elizabeth Kebede *et al*., 1994).

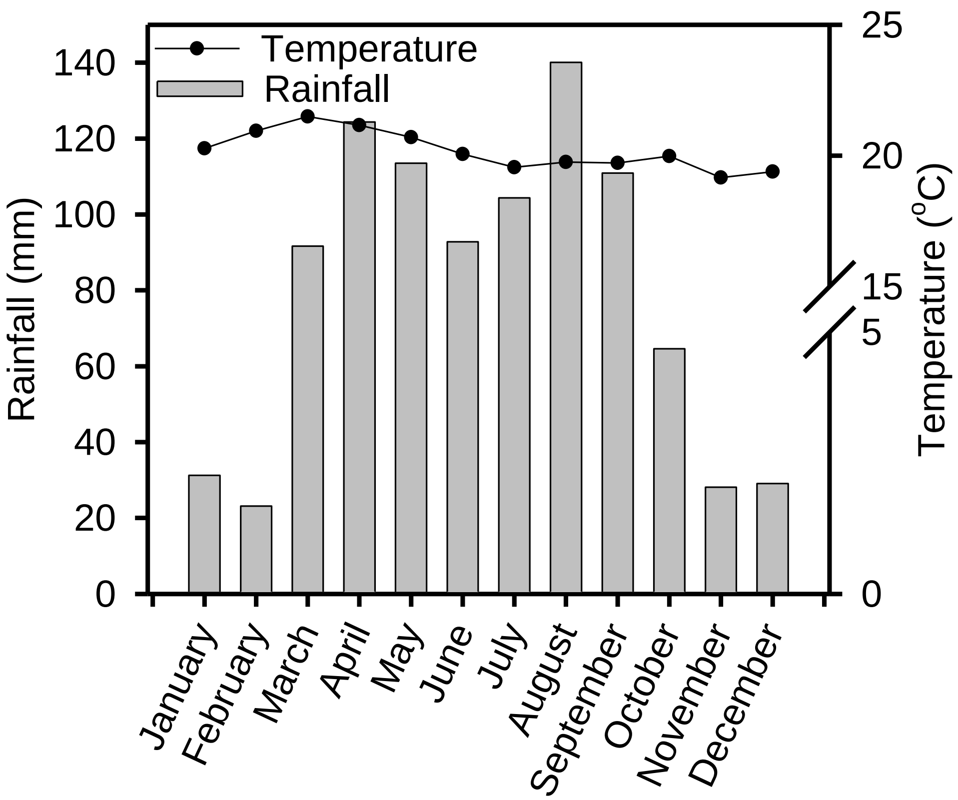


Fig. 2. Air temperature and rainfall data near Lake Hawassa during 1996–2006. Data from National Meteorological Services Agency.

Table 1. Morphometry of Lake Hawassa (from Welcome, 1972 and [a]Makin *et al*., 1975).

| **Variables** | **Values** |
|---|---|
| Catchment area | 1250 $km^2$ |
| Maximum length | 17 km |
| Maximum width | 11 km |
| Shoreline | 52 km |
| Surface area[a] | 90 $km^2$ |
| Maximum depth | 22 m |
| Mean depth | 11 m |
| Volume | $1.3*10^9$ $m^3$ |

Table 2. The chemical characteristics of Lake Hawassa, Ethiopia.

| Characteristics | Values | Reference |
|---|---|---|
| $Na^+$ | 7.1 meq $L^{-1}$ | Zinabu Gebre-Mariam *et al*. (2002) |
| $K^+$ | 0.7 meq $L^{-1}$ | » |
| $Ca^{2+}$ | 0.5 meq $L^{-1}$ | » |
| $Mg^{2+}$ | 0.5 meq $L^{-1}$ | » |
| Alkalinity | 7.8 meq $L^{-1}$ | » |
| $Cl^{-1}$ | 0.8 meq $L^{-1}$ | » |
| $SO_4^{2-}$ | 0.2 meq $L^{-1}$ | » |
| $SiO_2$ | 42.6 mg $L^{-1}$ | Elizabeth Kebede *et al*. (1994) |
| $PO_4$-P | 12.4 µg $L^{-1}$ | » |
| Total P | 36.2 µg $L^{-1}$ | » |
| $NO_3/NO_2$-N | 34.9 µg $L^{-1}$ | » |
| $NH_4$-N | 5.7 µg $L^{-1}$ | » |
| $SiO_2$ | 37.6 mg $L^{-1}$ | Girma Tilahun and Ahlgren (2010) |
| $PO_4$-P | 15.4 µg $L^{-1}$ | » |
| Total P | 34.1 µg $L^{-1}$ | » |
| $NO_3/NO_2$-N | 2.5 µg $L^{-1}$ | » |
| $NH_4$-N | 118 µg $L^{-1}$ | » |
| Conductivity | 846 µS $Cm^{-1}$ | Demeke Kifle and Amha Belay (1990) |

## MATERIALS AND METHODS

Two sampling stations were selected: a shore station (SS, 200 m offshore) with a depth of 3 m and an open water station (OS, about 3 km offshore) with a depth of 18 m. The study was conducted from November 2003 – August 2004 at monthly intervals. Water transparency was measured with a black and white painted disc of 0.20 m diameter. Net phytoplankton (30 µm) samples were collected and immediately fixed with Lugol's iodine, and taxa identification was made using different guides including John *et al*. (2002), Rott and Lenzenweger (1994), Jeeji-Bai *et al*. (1997), Hindak (2000), and Komarek and Crenberg (2001). Phytoplankton biomass was estimated from the Chl *a* concentration. Samples were collected with a 1 L container from 10 cm depth, and a defined volume was filtered through Whatman GF/C filters, ground and cold extracted with 90% acetone. After centrifuging, the supernatant absorbance was measured at 665 nm spectrophotometrically and corrected for turbidity by subtracting the corresponding reading at 750 nm (Talling and Driver, 1963). Primary productivity was measured using the light-dark bottles of Winkler titration method. Water samples were taken from the lake surface and siphoned into 300 ml Pyrex light and dark glass bottles. Two light and dark bottles were attached on a metal suspender at the surface, 0.25 m, 0.50 m, 1 m and 2 m depth, and incubated for about 2 hours.

Zooplankton samples were taken from the water column with 64 μm mesh tow net having a mouth diameter of 0.3 m. To determine abundance, the samples were hauled from 3 m depths for OS, and 0.5 m for SS. The concentrated samples were immediately preserved with formalin to yield the final concentration of approximately 5%. Zooplankton taxa were identified using different guides including Voigt and Koste (1978), Defaye (1988) and Fernando (2002). Numerical abundance was determined using a Wild Microscope with 50 X magnification power. Counts from the developmental stages (nauplii and copepodites) were lumped together. Separate counts of nauplii and adults of cyclopoids was done in order to see the naupli-adult ratio. The trophic status of Lake Hawassa was assessed using the trophic status index (TSI) of Carlson (1977), which is calculated based on Secchi disk transparency (TSI (SDT) = 60 – 14.41 ln (SDT)) and Chl *a* concentration (TSI (Chl *a*) = 9.81 ln (Chl *a*) + 30.6). A TSI < 30 is commonly considered as indicative of oligotrophic conditions, between 50 and 70 of eutrophic while values > 70 of hypereutrophic conditions (Wetzel, 2001).

**RESULTS**

Water transparency readings ranged from 0.7 to 1.2 m with a mean of 0.9 m. We found an average Chl *a* concentration of 19 µg $L^{-1}$ without significant differences between OS and SS (t-test, P = 0.635, DF = 14). The current phytoplankton biomass had a maximum in February and peaked again in August; lowest amounts were recorded in May 2004 (Fig. 3). A total of 39 phytoplankton taxa were identified, and their relative contribution to the total abundance comprised 54% Chlorophyta, 26% cyanoprokaryotes, 18% diatoms and 2% others (Fig. 4). Some taxa were new records to the lake, e.g., *Pediastrum simplex* (two sub-species) and *Scenedesmus ecornis*. The depth profile of gross photosynthesis per unit volume (g $O_2$ $m^{-3}$ $h^{-1}$; Fig. 5) of OS is a typical pattern for phytoplankton, displaying a single subsurface peak with maximum photosynthetic production occurring at a depth of around 0.5 m. Large variations of the light-saturated photosynthetic rate ($A_{max}$) were recorded with values ranging from 0.4–3.4 g $O_2$ $m^{-3}$ $h^{-1}$. Gross photosynthesis was also determined at SS for four months to compare it with the OS and no significant differences could be found. The daily areal photosynthesis for the OS ranged from 3.5 to 22.1 g $O_2$ $m^{-2}$ $d^{-1}$ exhibiting more than a six-fold variation.

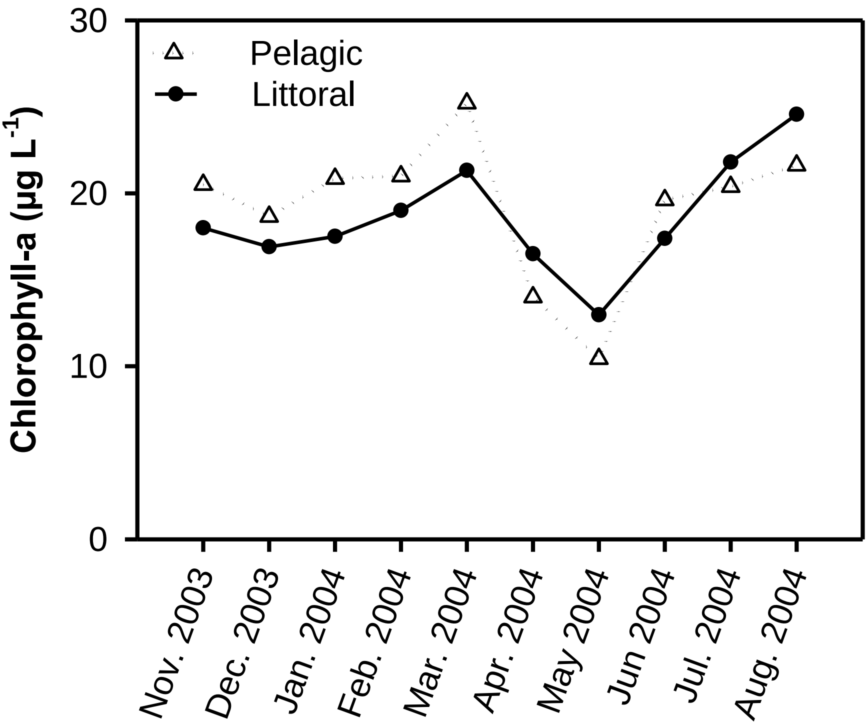


Fig. 3. Temporal variation in phytoplankton biomass of Lake Hawassa as indicated by Chl *a* at two locations in 2003/2004.

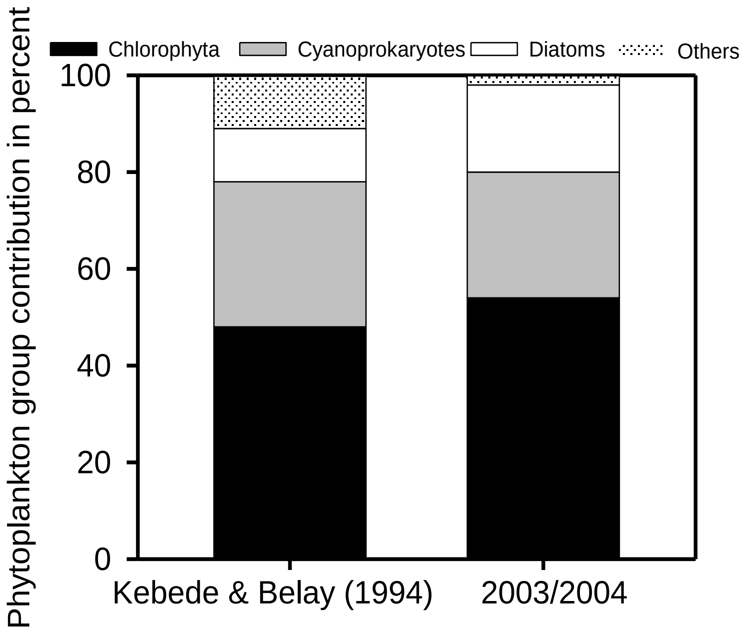


Fig. 4. Relative algal proportion of major phytoplankton groups in Lake Hawassa.

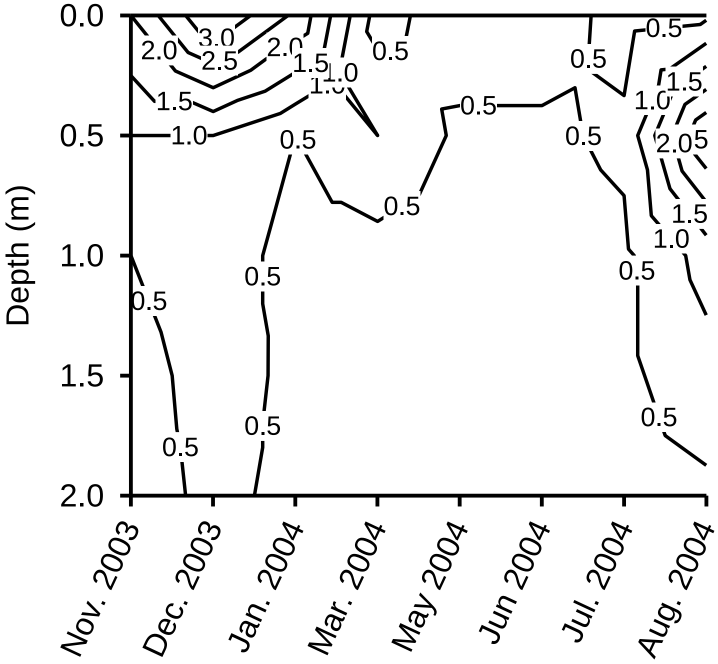


Fig. 5. Gross primary productivity (g $O_2$ $m^{-3}$ $h^{-1}$) of Lake Hawassa, Open Zone, studied from November 2003 to August 2004.

Rotifers contributed to 69% of the total zooplankton density, whereas cyclopoid copepods and cladocerans contributed 28% and 3%, respectively (Fig. 6). The mean abundance of cyclopoid copepods was about 58 000 ± 9200 (SE) Indl $m^{-3}$, with a maximum of 134 420 Indl $m^{-3}$ recorded in August 2004 and the minimum (31020 Indl $m^{-3}$) observed in May 2004. Cladoceran density was very low in 2003-04 study with an average of 2 616 ± 640 Indl $m^{-3}$. The abundance of rotifers was high in comparison to the other two groups, with a mean value of 95 500 ± 25 600 Indl $m^{-3}$ (maximum of 264 000 Indl $m^{-3}$ in June 2004). A separate count of nauplii and adult cyclopoid was made in order to see the proportion of the adults to their juveniles. It was found that the open water of Lake Hawassa had a mean of 22% and 78% of adult and nauplii, respectively, and the littoral had 14% and 86% of the same. At both sites, nauplii were the major contributors to the total cyclopoid abundance.

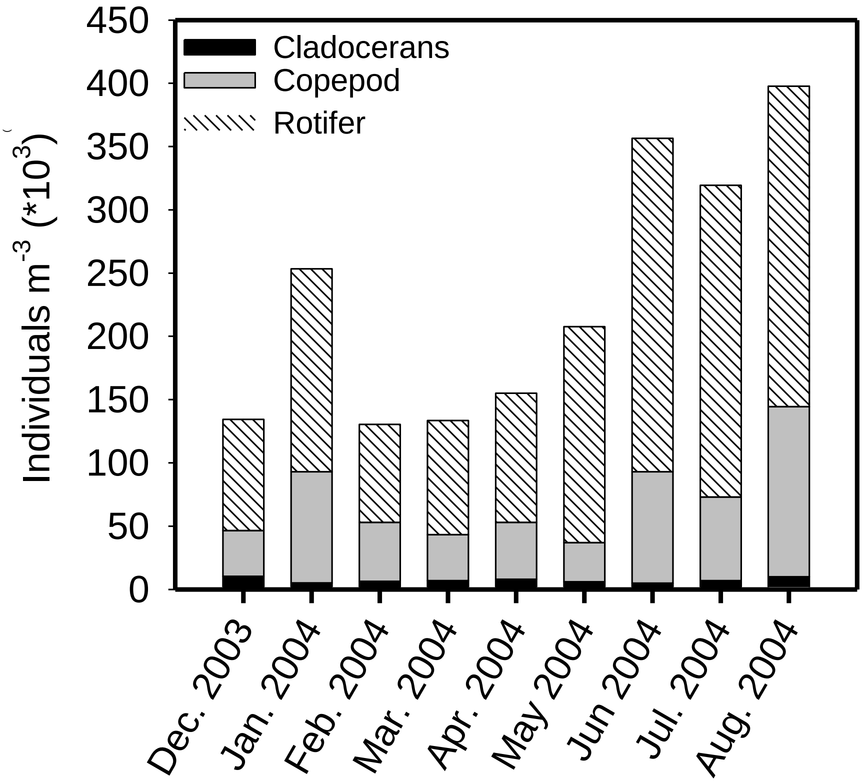


Fig. 6. Mean monthly zooplankton abundance (individual $m^{-3}$) in Lake Hawassa during 2003 to 2004.

## DISCUSSION

The water chemistry of Lake Hawassa has been investigated since the 1990s (Table 2). One obvious difference in the chemistry of the lake is that the primary form of nitrogen $NO_3$-N in Elizabeth Kebede *et al*. (1994) is replaced by $NH_4$-N in the recent investigation (Girma Tilahun and Ahlgren, 2010). This could be an internal signal as $NH_4$-N is generally high in anoxic condition. $NH_4$-N is oxidized rapidly to nitrate in aerobic waters such as in rivers and streams. However, in lakes, $NO_3$-N is rapidly reduced into organic compounds within organisms and liberated as ammonia during the metabolism of these organisms (Quirós, 2003). Organic matter due to aquatic vegetation as well as from the catchment could be high in the lake. Lake Hawassa is categorized as eutrophic water body (water transparency TSI = 62; Chl *a* TSI = 59.5) based on TSI indices, and $NH_4$-N: $NO_3$-N ratio is consistently very high for eutrophic and hypertrophic lakes (Quirós, 2003).

The phytoplankton taxa were similar with Elizabeth Kebede and Amha Belay (1994), except some that are identified in 2003/04 such as *Pediastrum simplex* (two sub-species) and *Scenedesmus ecornis*. The mean phytoplankton biomass of SS (19 µg $L^{-1}$) and OS (20 µg $L^{-1}$) were comparable. However, when taking a closer look at the temporal variations, OS experienced higher biomass than SS from November to June (except the depression point in May; Fig. 3), which was overcompensated later on. Elizabeth Kebede and Amha Belay (1994) as well as Girma Tilahun and Ahlgren (2010) observed a very similar seasonal variability of biomass in Lake Hawassa. A first phytoplankton biomass peak (Fig. 3) could be associated with the effect of mixing. High biomass of phytoplankton was observed in February as there was high solar radiation and possibly high inorganic nutrients available. The second biomass rise in August 2004 coincided with the major rainy season (June to August) where nutrients are drained from the catchment; a complete mixing was observed as well. The biomass minimum at both stations occurred in May 2004 and could be related to stratification and nutrient depletion. Moreover, rotifers may have played a role in reducing phytoplankton biomass. Previously, Taylor and Zinabu Gebre-Mariam (1989) suggested that rotifers and ciliates are important grazers of smaller phytoplankton forms in Lake Hawassa. Additionally, a recent study showed that smaller-sized phytoplankton contributes much to the biomass of Lake Hawassa (Girma Tilahun, 2007). However, complete control of phytobiomass by rotifers is unlikely, as Lake Hawassa is eutrophic and high filtering efficiency and success of biomanipulation is generally ascribed to large-sized cladocerans (Scheffer, 1998; Lampert and Sommer, 1997).

The relative contribution of the phytoplankton abundance is similar to the earlier report of Elizabeth Kebede and Amha Belay (1994) (Fig. 4), but when comparing the inter-annual variation of biomass between 1980s and the current values, a declining trend is clearly visible in the last 15 years (Fig. 7). This is probably associated with a decrease in nutrient availability, as Zinabu Gebre-Mariam *et al*. (2002) showed that the concentration of Soluble Reactive Phosphorus (SRP) and silicate decreased in the 1990s compared to previous data. These authors also demonstrated a significant decline of conductivity in the system. Recently, Girma Tilahun and Ahlgren (2010) have also reported a strong P limitation to algal growth using TN/TP ratio.

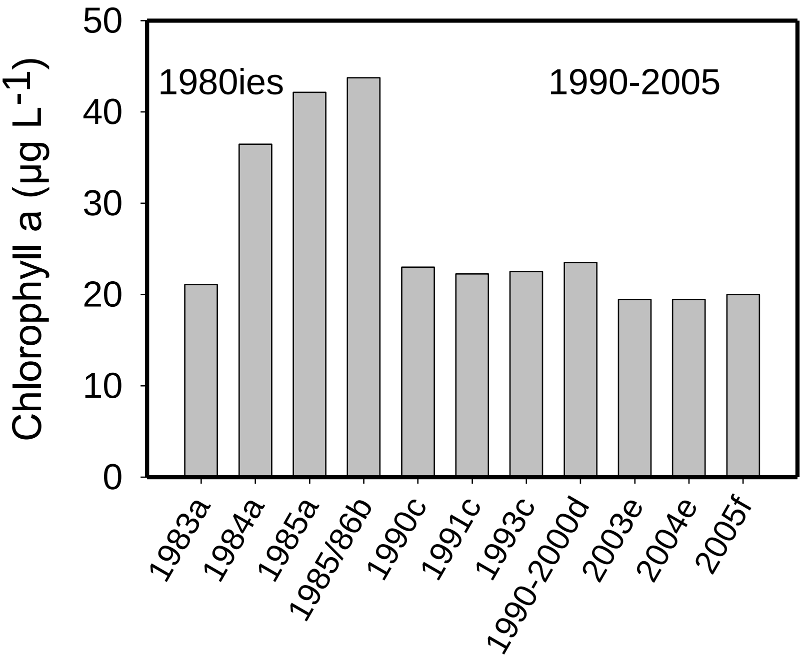


Fig. 7. Inter-annual variation of phytoplankton biomass in Lake Hawassa from 1980s to 2004. [a]Demeke Kifle and Amha Belay (1990); [b]Elizabeth Kebede and Amha Belay (1994); [c]Zinabu Gebre-Mariam and Taylor (1989); [d]Zinabu Gebre-Mariam *et al*. (2002); [e]Tadesse Fetahi (2005), [f]Girma Tilahun and Ahlgren (2010).

The daily integral gross primary productivity ranged from 3.5 to 22.1 g $O_2$ $m^{-2}$ $d^{-1}$ exhibiting more than six-fold variation between the minimum and maximum values. Compared to previous reports (3.0–7.3 g $O_2$ $m^{-2}$ $d^{-1}$ by Demeke Kifle and Amha Belay, 1990; 9.9 g $O_2$ $m^{-2}$ $d^{-1}$ by Zinabu Gebre-Mariam, 1988) and current values (4.8–12.28 g $O_2$ $m^{-2}$ $d^{-1}$) of Girma Tilahun and Ahlgren (2010), it appears that the integral rate of gross photosynthesis of Lake Hawassa has changed in the past two decades with some higher values in 2003/04 (Fig. 8). As the euphotic depth (derived from Secchi disc readings) remained more or less constant when the present study is compared with the previous works such as Demeke Kifle and Amha Belay (1990), the 2003-04 higher values were probably caused by the smaller-sized nanophytoplankton, which contributed > 50% to the total biomass (Girma Tilahun, 2007), because small-sized organisms are more productive (Wetzel, 2001). Furthermore, the high PP can be related to the current high $NH_4$-N concentration compared to $NO_3$-N (Table 2). $NH_4$-N is rapidly taken up by algae and is the most energetically efficient form of combined inorganic nitrogen (Rosenberg and Ramus, 1984; Hurd *et al*., 1995). For

$NO_3^-$, there is an additional step of reduction to $NH_4^+$ by nitrate reductase after uptake (Hurd *et al*., 1995). One explanation for $NH_4^+$ affinity may be that energy required for nitrate reduction to ammonium could be saved (Rosenberg and Ramus, 1984). However, further study is required to understand the increasing trend of primary production in Lake Hawassa.

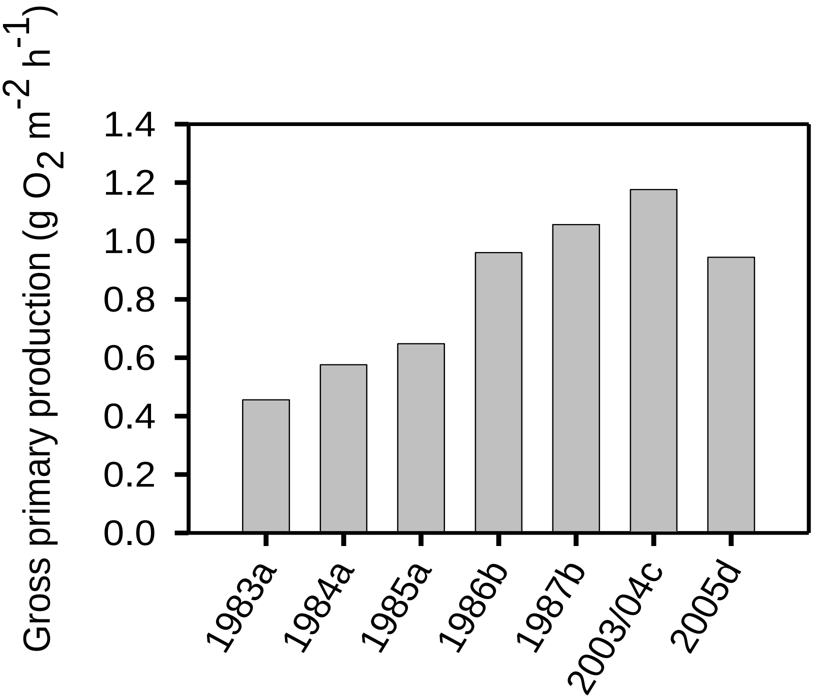


Fig. 8. Inter-annual temporal variation of integral primary production of Lake Hawassa from 1980s to 2005. [a]Demeke Kifle and Amha Belay (1990); [b]Elizabeth Kebede and Amha Belay (1994); [c]Tadesse Fetahi (2005), [d]Girma Tilahun and Ahlgren (2010).

Compared to previous studies, some differences of zooplankton abundances are evident. We found a mean annual abundance of cyclopoid copepods of 58 000 ± 9200 (SE) Indl $m^{-3}$, whereas Seyoum Mengistou (1989) reported 68 000 ± 4300 Indl $m^{-3}$. The average cladocerans density 2 600 ± 640 (SE) Indl $m^{-3}$ was very low in the current study. In contrary, Seyoum Mengistou (1989) reported a maximum of 18 000 Indl $m^{-3}$. The abundance of copepods and cladocerans in 2003-04 study was particularly low in the littoral zone, which is an area of nursery and feeding ground of juvenile and unexploited fishes that consume mainly zooplankton at this developmental stage (Fernando, 1994). A separate count of nauplii and adult cyclopoids showed that the major contributors for the total abundance of the taxa were nauplii.

However, Seyoum Mengistou (1989) reported that more than 90% of the total zooplankton was contributed by adult cyclopoids. It seems that the former larger contribution of adult cyclopoids is now replaced by nauplii indicating that cannibalism may be diminished under present conditions. The cannibalistic nature of cyclopoids may have changed due to the presence of large number of rotifers in the current study, which is a potential prey in Lake Hawassa (Taylor and Zinabu Gebre-Mariam, 1989).

Large-bodied zooplankton affects rotifers in two ways: (i) it can compete with rotifers for available algal food through exploitative competition (Neill and Peacock, 1980) and (ii) it can also feed on rotifers causing direct mortality in a form of interference competition (Gilbert and Stemberger, 1985), the latter interaction probably being more important (Schneider, 1990). Taylor and Zinabu Gebre-Mariam (1989) suggested that rotifers are consumed by cyclopoid copepods in Lake Hawassa, which might be an explanation for reduced rotifer abundances in former times. However, in 2003-04 study, it appears that the small number of adult cyclopoids resulted in low grazing pressure on rotifers that may give rotifers a break to reproduce well. Consequently, we reported a maximum rotifer abundance of more than 263 600 Indl $m^{-3}$ that is about five-times greater than that estimated by Seyoum Mengistou (1989). A similar scenario was found by Brook Lemma (2003) for Lake Hora-Kilole where cladoceran populations were replaced by rotifers due to high predation pressure from the dominant juvenile *Barbus* species. The dominant rotifer taxa reported by Seyoum Mengistou (1989) were *Brachionus* and *Keratella* which were replaced by *Filinia* and *Trichocerca* in most months of the recent study. This species replacement may be due to predation pressure on *Keratella* and *Brachionus* by planktivorous fish and/or cyclopoids.

In various lakes, strong top-down effects on phytoplankton biomass have been reported for cladoceran-dominated zooplankton (Sommer, 1986; Lampert, 1988). However, Lake Hawassa did not follow similar trends, therefore, large amounts of phytoplankton biomass were converted into detritus (Tadesse Fetahi and Seyoum Mengistou, 2007; Seyoum Mengistou and Fernando, 1991). This can be due to the fact that the larger herbivorous *Daphnia* responsible for effective grazing are largely absent from Lake Hawassa (Seyoum Mengistou, 1989). Furthermore, cladocerans such as *Diaphanosoma* are heavily consumed by the planktivorous fish species (Tadesse Fetahi and Seyoum Mengistou, 2007), and thus very low in abundance (Fig. 6), which relieves the pressure on the phytoplankton. Additionally, large colonial and filamentous phytoplankton species may sometimes be dominant in the lake (Elizabeth Kebede and Amha Belay, 1994) and they are more resistant against grazing than small-sized phytoplankton. The average phytoplankton biomass of Lake Hawassa (34 t $km^{-2}$) is much greater than that of the zooplankton (2.8 t $km^{-2}$) (Tadesse Fetahi and Seyoum Mengistou, 2007) indicating that bottom-up (resource) control of phytoplankton is more significant than top-down effects. This supports the studies of Talling and Talling (1965), who have documented that bottom-up control is more important than top-down control in tropical systems.

In conclusion, the proportion of phytoplankton taxa and groups in the present study was quite similar to previous studies. Primary production has increased through time even though biomass has decreased in the system. The composition of zooplankton has remained the same but the abundance and the dominant taxa have changed in the last decades. The abundance of adult copepods and cladocerans in 2003-04 was very low but rotifers flourished in the system. Besides biotic interactions, such changes in the plankton communities could be enhanced by human interventions. Lake Hawassa is located nearby the fast growing Hawassa city, where demographic pressure is high. The lake is used for fishing and recreation, and the commercially important *O. niloticus* is over-exploited (LFDP, 1998). Moreover, the lake is surrounded by agricultural land, hence anthropogenic influences are inevitable. Besides, it receives effluents from nearby industries (e.g. Zinabu Gebre-Mariam and Zerihun Desta, 2002). Once the concentration of pollutants passes the threshold limit, it will bring irreversible damage to the ecosystem such as algal blooming and associated oxygen depletion and massive fish kill. It appears that the long-term data on the plankton community supports erratic and unpredictable changes in such a closed system as Lake Hawassa. So care and appropriate management should be taken in such lakes before some ecological damage happens, which would affect not only the lake biodiversity but the livelihood of the community as well.

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