International Journal of Fisheries and Aquatic Studies 2018; 6(3): 173-186

E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2018; 6(3): 173-186

www.fisheriesjournal.com
Received: 23-03-2018
Accepted: 24-04-2018

Yirga Enawgaw
Department of Zoological Sciences, College of Natural and Computational Science, Addis Ababa University, P.O. Box, 1176, Addis Ababa, Ethiopia

Brook Lemma
Department of Zoological Sciences, College of Natural and Computational Science, Addis Ababa University, P.O. Box, 1176, Addis Ababa, Ethiopia

Correspondence
Yirga Enawgaw
Department of Zoological Sciences, College of Natural and Computational Science, Addis Ababa University, P.O. Box, 1176, Addis Ababa, Ethiopia

Phytoplankton community composition and nutrient conditions as an indicator of ecosystem productivity in Lake Tinishu Abaya, rift valley, Ethiopia

Yirga Enawgaw and Brook Lemma

Abstract
The present study was undertaken to investigate the community composition and their seasonal variations of phytoplankton with respect to the changes in various environmental factors in Lake Tinishu Abaya (Rift valley, Ethiopia). Phytoplankton samples were carried out from two predefined sampling sites (central and offshore) using bottle sampling on monthly basis between January and December 2016. The abundance of phytoplankton was estimated in terms of biovolume, and it was calculated using the appropriate geometric shape of the major species. In the study, a total of 37 phytoplankton taxa belonging to 5 divisions: Bacillariophyceae (40.5%) (15-species), Chlorophyta (29.7%) (11-species), Cyanobacteria (18.9%) (7-species), Euglenophyta (5.4%) (2-species), Cryptophyta (2.7%) (1-species), Dianophyta (1-species) were identified for the first time. The total biovolume (fresh weight) of the dominant phytoplankton taxa was calculated, and it was ranged from a low value of 7.96mm^3/L to a high value of 315.29mm^3/L at the central station and 6.47 to 239.12 mm^3/L at the offshore station. The largest biovolume of phytoplankton constituted by cyanobacteria at both stations (54% at the central station & 34% at offshore) followed by Chlorophyta at the offshore station (31%) and Bacillariophyta at the central station (22%). Euglenophyta and Dianophyta had comparatively low biovolume (10%). *Microcystis aeruginosa* is the most conspicuous phytoplankton, However, it comprised only 10% of the total biovolume of phytoplankton. The highest biovolume (about 75%) was constituted in the Pediastrum, Anabaena, Cylindrospermosis, Nitzchia, and Perdinium species. The phytoplankton showed seasonality with higher biovolume during the rainy season concurrently with high ambient inorganic nutrients from runoff the watershed via tributary rivers whilst low density reported during the dry season with high water transparency and relatively low ambient inorganic nutrients. Diversity parameter, Shannon index (H') ranged from a low value of 1.759 to high value of 2.098 at central and 1.741 to 2.161 at offshore sites. Thus the study lake was moderately polluted seeing that H' value. The various physicochemical factors responsible for the observed temporal variations in the physical, chemical and biological features of the lake are discussed and generalized that the lake water was fresh, well oxygenated, slightly warm, alkaline, contained more TSS, TDS, and EC, very turbid and low transparency. Most of the inorganic nutrients were relatively high and supports most of the aquatic life.

Keywords: Biovolume, Lake Tinishu abaya, phytoplankton, rift valley, seasonality, Shannon index

Introduction
Phytoplankton is the primary producers and good indicators of the trophic status of aquatic ecosystems. They convert solar energy to chemical energy and release oxygen to the water body and the surrounding terrestrial environment through photosynthesis. Half of the world's oxygen is produced via phytoplankton photosynthesis (J. Roach, 2004)[43]. Fish yield and organisms in other trophic level depend on the quantity and quality of primary production. Phytoplankton is currently responsible for 50% of global primary production (P. Falkowski and A. Raven, 2007) [13].
Phytoplanktons are of great significance since they comprise the major portion of primary producers in the aquatic environment (K. Barupal and R. Gehlot, 2015) [5]. Temporal variability in the structure and function of phytoplankton community is of fundamental importance to the metabolism of an aquatic system (M. Calijuri *et al*. 2002) [8]. Aquatic environments are subject to high temporal variability, with the frequent reorganization of the relative abundance and species composition of phytoplankton as a result of the interactions between physical, chemical and biological variables (CS. Reynolds 1990) [39]. Phytoplankton abundance and distribution are strongly dependent on factors such as ambient nutrient

concentrations, the physical state of the water column, and presence of grazers or herbivorous zooplankton. As phytoplankton is exposed to ever fluctuating physicochemical parameters, they exhibit wide diversity in species and abundance.

Phytoplankton distribution and species composition change continuously with variations in salinity, light, nutrient availability, water movements and grazing pressure (SL. Hsiao, 1992) [26]. Changes in species composition and diversity may produce changes in the phytoplankton growth rate and their response to irradiance or other limiting factors. It is important to understand how these changes are reflected in ecosystem functioning (P. Duarte et. al. 2006) [12]. The study of changes in phytoplankton diversity, species composition and spatiotemporal variability in water bodies is, therefore, fundamental to the understanding of water quality and fisheries. Abundance is not a good measure of growth rate or the importance of species in energy flow. Some relative rare forms grow exceptionally fast but some show little change in abundance because they are removed equally fast by predators. Therefore, in this study, we used biovolume to examine the growth of phytoplankton. Generally, knowledge of the spatial and temporal variations and community structure of phytoplankton is fundamental to the understanding of ecosystem dynamics (A. Bootsma and E. Hecky 1993) [6].

RE. Hecky (1993) [21] noted that East African lakes are regarded as among the world's most productive ecosystems. Ethiopia is endowed with a large number of standing water bodies, whose sustainable use can contribute to the economy of the country. The lakes are critical to the survival of local communities as they are the actual and potential sources of food and income. Despite their importance, the limnology of some of the Ethiopian lakes is unexplored. Lake Tinishu Abaya is one of such lake, which has not received attention in spite of its potential economic importance. Despite the fact that Lake Tinishu Abaya has a lot of functions (fish production, small-scale irrigation, domestic uses, etc.) for the local community, there has not been any planned research activity conducted on it. This is maybe predominantly due to its remote location and having a small size that made it insignificant as compared to other large rift valley lakes of Ethiopia. The purpose of this study was, therefore, to investigate the temporal dynamics in the community structure and biovolume of the major phytoplankton in relation to various environmental divers in Lake Tinishu Abaya (Rift valley) to observe the potential of the lake water productivity.

Materials and Methods

Study area

Lake Tinshu Abaya, or interchangeably called, Small Abaya, is a small freshwater lake located in the Rift Valley nearly 160 km southwest of Addis Ababa, which is the capital city of Ethiopia. It located at 7^{0}29´03.65´´N, 38^{0}03`17.79´´E, and 1835 m above sea level. The lake is situated in a remote area 15 km from a small village in the township of Silttie. It is a shallow lake, having a surface area of 1253 ha (A. Kassahun *et al*., 2011) [29], with a maximum and a mean depth of 3.7 m and 2.9 m, respectively. During this study, two major perennial rivers (Rivers Dacha and Boboda) and a single outlet (River Badober) were always active. The former two rivers are relatively big. The lake has some commercially important fish species including the native *Tilapia zilli* and *Barbus* species, while Nile tilapia (*Oreochromis niloticus),* was stocked from the nearby Lake Ziway in 1997 (A. Kassahun *et al*., 2011) [29]. The major food items found in the gut of *O. niloticus* in the study area are phytoplankton, the macrophytes, detritus, and zooplankton (E. Yirga and L. Brook, 2018) [60]. The lake has nearly an oval shape (Fig. 1). For this study two study sites (open water/center and shore/offshore site) was selected purposely. An open-water site located in the center; 2.5 km far from the shoreline and the shore site is so close (nearly 50 m) to the edge of the lake. This site was considered as a direct recipient of wastes from agricultural land as well as domestic materials; thus the site was taking into consideration as impaired by human activities compared to the open-water site.

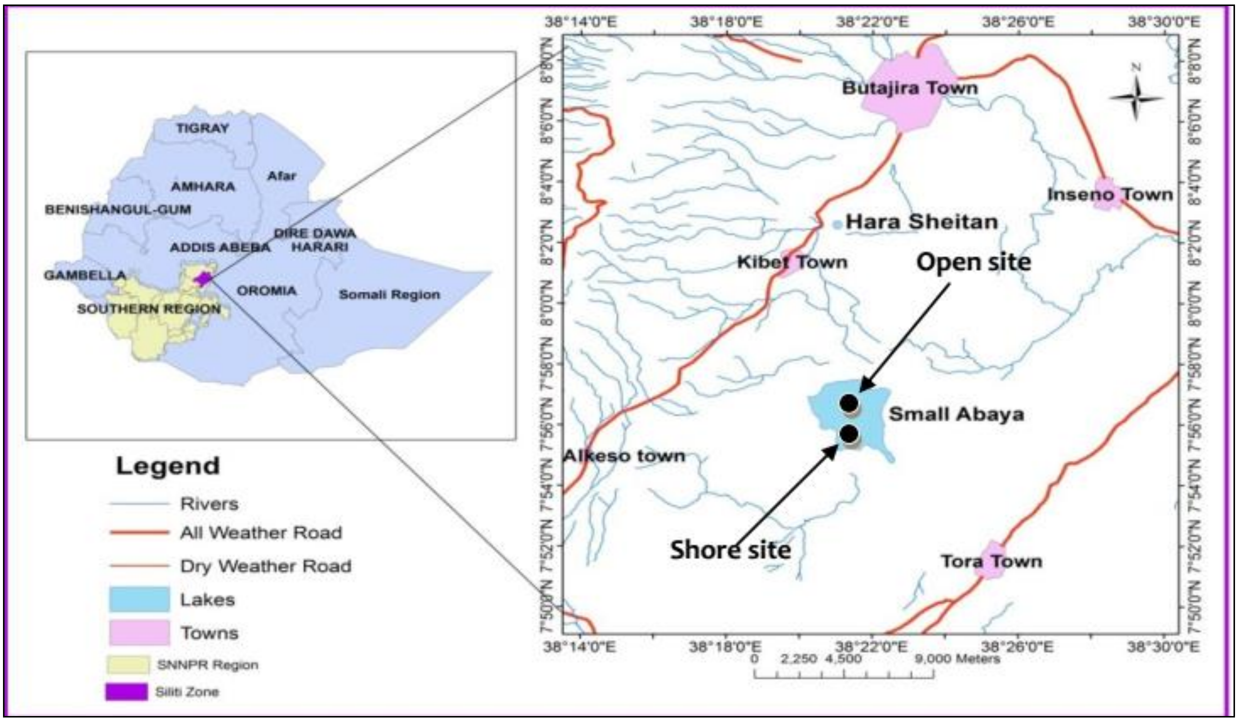


Fig 1: Location of Lake Tinishu Abaya/Small Abaya (source: www.earth.google.com) showing sampling sites.

Water sampling and measurements of physico-chemical parameters

For all physical and chemical analysis, sample collection procedures were carried out on a monthly basis for a year between January 2016 and December 2016 from two sampling stations (open and shore). Water samples were taken with bottle sampling from the surface. The collected water samples were transported to Limnology Laboratory of Addis Ababa University for further physicochemical analysis. In-situ measurements of the parameters temperature, dissolved oxygen, conductivity, and pH was measured using a portable multimeter (Model HQ 40d Multi Hach Lange). Water transparency was measured using a standard Secchi disc 30cm in diameter. The euphotic depth (Zeu), the depth at which 1% of the surface photosynthetic active radiation is detected, for the study area, was calculated from the relation Zeu = 4.6/Kd (J. Kalff, 2002)[28]. Kd (mean vertical extinction coefficient of downwelling irradiance, in m^{-2}) was computed from the relation as $Kd=1.44/Z_{SD}$ (Z_{SD}-Secchi depth, in m) RW. Holmes (1970)[24]. Turbidity was measured using portable digital turbidimeter (Model OAKTON: T-100). In the Laboratory, total suspended solids (TSS) were determined through the standardized gravimetric method for examination of TSS in water analysis by Howard 1933. Total Dissolved Solids (TDS), the portion that passes through a filter, in a sample correlates to electrical conductivity (C. Glenn, 2005)[17](TDS=0.65*electrical conductivity). The major inorganic nutrients analyzed in the present study were nitrogen (nitrite-NO_2, nitrate-NO_3-N, ammonium-NH_4-N), phosphorus (soluble reactive phosphorus-SRP and total phosphorus-TP), and dissolved silicate (SiO_2) and all.were determined using the standard method of APHA (1995)[2] at Limnology laboratory of Addis Ababa University, Ethiopia. Trophic state of the lake was determined using RE. Carlson's (1977)[10] trophic state indx (TSI) determination method. Carlson's estimated the trophic state values ranged from Oligotrophic (TSI, <40), Mesotrophic (TSI, 40-50), Eutrophic (TSI, 50-70), and Hypereutrophic(TSI, >70) states.

Phytoplankton sampling and estimation of biovolume

For phytoplankton identification and biovolume estimation, water samples were collected from two predefined sampling stations (open-water/central and offshore) at the surface using bottle sampling technique in a 1L bottle sampler on monthly basis for a year from January to December 2016. The collected water samples were immediately fixed with Lugol's iodine solution. In the laboratory, the preserved samples were concentrated in 1 L measuring cylinders for 24-48 hours in the dark to produce 10 times concentrated samples. After a period of 48 hours, the upper 900 ml of the sample was siphoned off and the remaining 100 ml was homogenized. For the identification of diatoms, samples were cleaned with cold H_2O_2 cleaning technique (J. Taylor *et al*., 2007)[50]. From the homogenized sample, 1ml sample was pipetted into Sedgwick Rafter cell. In the counting chambers, cells/individuals/colonies were counted randomly up to a minimum of 400 individuals under an inverted microscope (Motic/AE31) at a magnification of 4-100 x with a fixed camera. The cell number (cells/ml) was calculated according to Wetzel and Likens (2000). The volume of individual taxa was estimated by applying equivalent geometric shapes to cell forms by direct measurement of the cell dimensions (H. Hillebrand *et al*. 1999; J. Sun and D. Liu, 2003) [23, 48] then the biovolume (mm^3/L) was taken as a product of individual volume and its density.

Statistical Analysis

The relationships between the dominant phytoplankton taxa/species and significant environmental variables were analyzed using a constrained Redundancy Analyses (RDA, CANOCO for Windows 4) using PAST software (J. Leps and P. Smilauer, 2003)[32]. Pearson correlation 'r' was used to check the affinities of various physico-chemical parameters and its correlation with phytoplankton abundance/biovolume. Shannon and Equitability diversify indices were applied to show the diversity of phytoplankton. One way analysis of variance (ANOVA) was used to analyze the temporal distribution pattern of physicochemical parameters and phytoplankton biovolume. Since only two study site had, a t-test was used to check the spatial variation of the various environmental parameters and phytoplankton communities. SPSS software package version 20 was used for ANOVA and t-test statistical analysis. Statistical significance was set at P = 0.05

Results

Physicochemical features and nutrient conditions

The different physicochemical features which were responsible for the diversity and abundance of phytoplankton in Lake Tinishu Abya were measured (Table 1). As expected from a small-sized and shallow lake, and occurrence of complete mixing, most of the physicochemical parameters was more significantly varied seasonally ($p<0.05$) than spatially ($p>0.05$). The value of surface temperature ranged from 18.5 ^{0}C to 27^{0}C at the open station and 18.5^{0}C to 29.2^{0}C at shore station, while surface dissolved oxygen (DO) ranged from 5.85 mg/L to 15.1 mg/L and 6.1mg/L to 11.62 mg/L at open and offshore stations, respectively. Surface temperature and dissolved oxygen were correlated negatively and strongly (r= -0.46). The minimum and the maximum value of temperature observed in December (dry period) and June (rainy period), respectively at both shore stations. The maximum value of DO was recorded in January (dry season).

The pH of the study lake was ranged from a minimum of 8.11 to a maximum of 9.27 at the open station and 8.15 to 9.22 at a shore station. Total alkalinity was varied from 1.44-8.26 meq/L and 0.96-6.94 meq/L at open and shore stations, respectively. There was a seasonal effect on the distribution of pH (p=0.000) and alkalinity (p=0.004). High pH and alkalinity values were seen during the dry season (January-May and October to December). pH and alkalinity were correlated positively and significantly (r= 0.98).

The electrical conductivity (EC) of surface water for the study lake varied from 181.1 μScm^{-1} to 1006 μScm^{-1}at open station and 147.7 μScm^{-1} to 1006 μScm^{-1}at shore station. There was a significant variation of electrical conductivity between months ($p<0.05$). The high values of conductivity were recorded during the dry period (January to March). In this study, both sites have shown a fairly high amount of total dissolved solids (TDS). It was varied from a low value of 117.7mg/L to a high value of 653.9 mg/L at the open station and 96 mg/L to 653.9 mg/L at a shore station. There was a seasonal effect ($p<0.05$) on the distribution of TDS with high values were observed in the dry period (January to March), and sharply decreased from April to September. EC and TDS were correlated perfectly and positively (r= 1).

Table 1: The various physichochemical parameters recorded in Lake Tinishu Abaya.

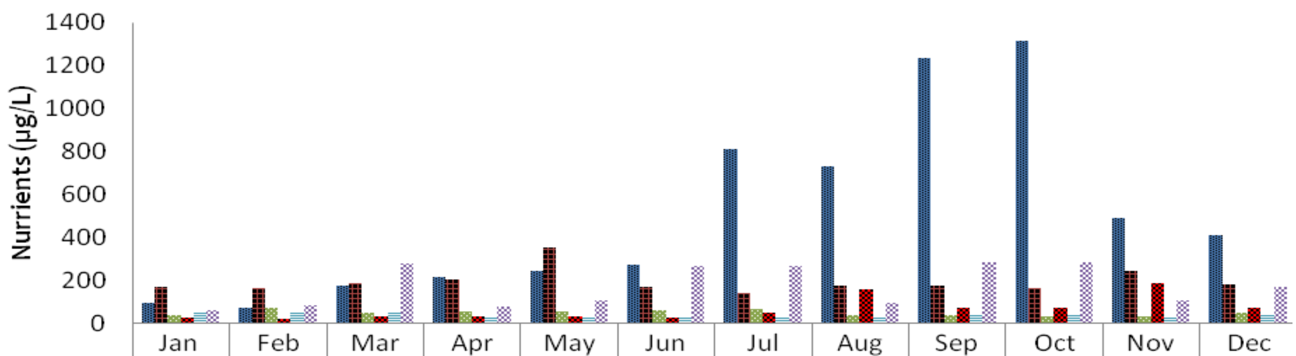
Phsicho-chemical Parameters	Site	Mean~SD	Range	N
Temperature (^{0}C)	Open	23.08~3.0	18.5-27	12
	Shore	23.23 ~3.32	18.5-29.2	12
TSS (mgCaCO$_3$/L)	Open	148.32~56.76	73-243	12
	Shore	200.47~89.19	76-368	12
TDS (mg/L)	Open	273.3~310	117.7-653.9	12
	Shore	249.9~407	96.0-653.9	12
DO (mg/L)	Open	9.04 ~3.07	5.58-15.1	12
	Shore	8.53~1.77	6.1-11.62	12
Chlorophyll *a* (µg/L)	Open	31.2 ~13.77	18.97-65.05	12
	Shore	26.30 ~13.30	12.13-48.77	12
Total alkalinity (meq/L)	Open	4.56 ~2.64	1.44-8.26	12
	Shore	3.89 ~1.99	0.96-6.94	12
Sechi Disk (cm)	Open	22.03 ~4.42	16-28.5	12
	Shore	14.22 ~1.40	12-16.5	12
pH	Open	8.47 ~0.39	8.11-9.27	12
	Shore	8.53~0.35	8.15-9.22	12
Conductivity (µS/cm)	Open	420.53 ~352.34	181.1-1006	12
	Shore	384.53 ~315.03	147.7-1006	12
Turbidity (NTU)	Open	111.5 ~31.32	57-143	12
	Shore	135.42 ~44.47	71-188	12

N-number of sampling months

In the study lake, TSS was estimated and it was ranged from 73.24-243 mgCaCO3/L and 76-368 mgCaCO3/L at open and shore stations, respectively. TSS was significantly varied seasonally (P=.000) by means of high values were reported in the rainy period (June to August) and low values were observed from November to January (Dry period). The other most important parameters measured in the present study was water turbidity. Lake Tinishu Abaya was highly turbid throughout the year and it was varied from 57 to 143 NTU at the open station and 71 to 188 NTU at a shore station. Turbidity was significantly varied seasonally (P= 0.008) with high values were reported during the main rainy season (June and July). Comparatively, low turbidity was reported in the dry season (January to April). Water transparency (Secchi disk) of the lake was also detected during the study. Secchi disk of Lake Tinishu Abaya varied from a low value of 16 cm to a high value of 28.5 cm at the open station and 12cm to 16.5 cm at a shore station. There were significant seasonal variations of Secchi disk between sites (0.042) and months (p=0.025). Secchi disk was higher at the open station than a shore station and during the time of the rainy season (June-September). The euphotic depth (Zeu), the depth at which 1% of the surface photosynthetic active radiation (PAR) is detected, for the study area, was calculated at the open station, and it was ranged from a low value of 0.51 m to a high value of 0.91m.

The concentration of chlorophyll-*a* that was recorded in the study lake was varied from 18.97µg/L to 65.05µg/L at the open station and 12.13 µg/L to 48.77µg/L at a shore station. The annual mean chlorophyll values were 31.21 µg/L and 26.3 µg/L at open and shore stations, respectively (Table 1). There was a seasonal effect (p=0.029) in the distribution of chlorophyll *a* and it was high during the dry season (January t0 May and October to December). Pearson correlation coefficient analysis indicated that chlorophyll *a* was correlated positively and strongly with pH (r=0.543), conductivity (r=0.485), Secchi disk (r=0.467), and alkalinity (r=0.576) while it was correlated negatively and strongly with NO_2 (r= -0.550), TP (r= -0.411) and TSS (r= -0.658).

The major inorganic nutrients analyzed in the present study were nitrogen (nitrite-NO_2, nitrate-NO_3-N, ammonium-NH_4-N), phosphorus (soluble reactive phosphorus-SRP and total phosphorus-TP), and dissolved silicate (SiO_2) (Fig. 2). The annual mean concentration of NO_2, NO3, NH4, SRP, TP, and SiO2 were, 503.82, 192.14, 47.44, 36.11, 172.13, and 62.80µg/L at the open station and 626.32, 42.26, 51.34, 42.26, 184.41, and 62.48µg/L at the offshore station, respectively. Nitrite and ammonium nutrients were significantly varied seasonally (p<0.05) with high concentrations were reported during the rainy season (June to September). Conversely, nitrate was high in the dry season (January-May and October-December). Phosphorus nutrients showed a significant seasonal variation (p<0.05). A clear oscillation was observed in the concentrations of TP. It was maximum from May to July and from September to October. The peak value of SRP was seen from January to March (dry period). Reasonably, low dissolved silica was reported in the study lake throughout the study period.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NO2	94.3	68.11	174.35	214.37	241.05	273.58	807.2	727.2	1234.1	1314.2	487.04	410.33
NO3	165.9	163	184.78	200.41	351.44	166.55	141.8	175.7	171.8	165.25	240.77	178.27
NH4	35.54	71	49.36	52.12	54.33	59.26	66.5	38.3	36.1	30.01	28.91	47.84
SiO2	22.27	21	28.27	30	32.77	25.49	45.3	154.8	68.5	68.83	185.67	70.74
SRP	48.13	45	48.13	29.73	31.1	25.77	24.1	32.7	37.8	42.97	28.35	39.53
TP	56.73	84	275.17	75.65	104.89	266.57	268.3	91.1	285.5	283.77	106.61	167.24

Fig 2: Temporal distribution patterns of the major inorganic nutrients in Lake Tinishu Abaya

Trophic State

In the present study, the trophic state of Lake Tinishu Abaya was determined (Table). Trophic state index (TSI) in terms of the Secchi disk (TSI-SD), total phosphorus (TSI-TP) and chlorophyll-*a (*TSI-CHL*A)* was ranged from 78.3-86.4, 59.25-81.66 and 59.56-71.56 at the open station and 85.96- 90.55, 66.49-86.12 and 55.06-67.91 at shore station, respectively. The annual mean values of TSI-SD, TSI-TP, and TSI-Ch-*a* were 82.04$^{\pm 8.1}$, 72.34$^{\pm 22.41}$ and 62.5$^{\pm 15}$ at the open station and 88.17$^{\pm 4.56}$, 77.56$^{\pm 19.63}$ and 61.52$^{\pm 14.91}$ at shore station, respectively. Carlson's trophic state index (CTSI-the mean of the three STI's) varied from 67.72-77.92 and 71.23-78.9 with a mean value of 72.31$^{\pm 10.2}$ and 75. 75$^{\pm 7.67}$at open and shore station respectively (Table 2).

Based on the Carlson (1977) trophic state classification (Table-2), the results of TSI values in the present investigations given strongly suggested that Lake Tinishu Abaya classified as a hypereutrophic state based on the mean values of TSI-SD and TSI-TP and eutrophic state based on the mean value of TSI-CHL*A* (Table 3). The overall trophic state of Lake Tinishu Abaya was a hypereutrophic system based on the average value of the three TSI's values (CTSI). The trophic state index in terms of chlorophyll-a was lower than the trophic state indices of Secchi disk and total phosphorus which indicated that the hypereutrophic state of Lake Tinishu Abaya is as a result of the presence of high concentration of phosphorus and low water transparency rather than algal bloom/algal turbidity.

TSI-TP was higher during the rainy time (June to September) and relatively low during the dry period(January to May and October to December). TSI-SD were above 70 throughout the study period which indicated in the hypereutrophic sate of the lake water year round. TSI-SD was high from May to July and low from August to September and from January to April. Generally, high TSI-SD was observed during the dry season with a peak in December at both stations. Except for December (TSI-CHLA=71.56), STI-CHLA was found between 50-70 throughout the study period indicated eutrophic state. TSI-CHLA progressively decreasing from January to August and then increased from September to December in 2016 (Fig 3).

Table 2: Trophic State Index (TSI) for Lake Tinishu Abaya in terms of Secchi disk (SD), total phosphorous (TP) and chlorophyll *a* (CHL*A*) and the average of each TSI's (CTSI-Carlson's trophic state index) (mean and range value)

TSI parameters	Site	Mean$^{\pm SD}$	Range	N
TSI-SD	OS	82.04$^{\pm 8.1}$	78.3-86.4	12
	SS	88.17$^{\pm 4.56}$	85.96-90.55	12
TSI-TP	OS	72.34$^{\pm 22.41}$	59.25-81.66	12
	SS	77.56$^{\pm 19.63}$	66.49-86.12	12
TSI-CHLA	OS	62.5$^{\pm 15}$	59.56-71.56	12
	SS	61.52$^{\pm 14.91}$	55.06 - 67.91	12
CTSI	OS	72.31$^{\pm 10.2}$	67.72-77.92	12
	SS	75. 75$^{\pm 7.67}$	71.23-78.9	12

N-Number of studying months

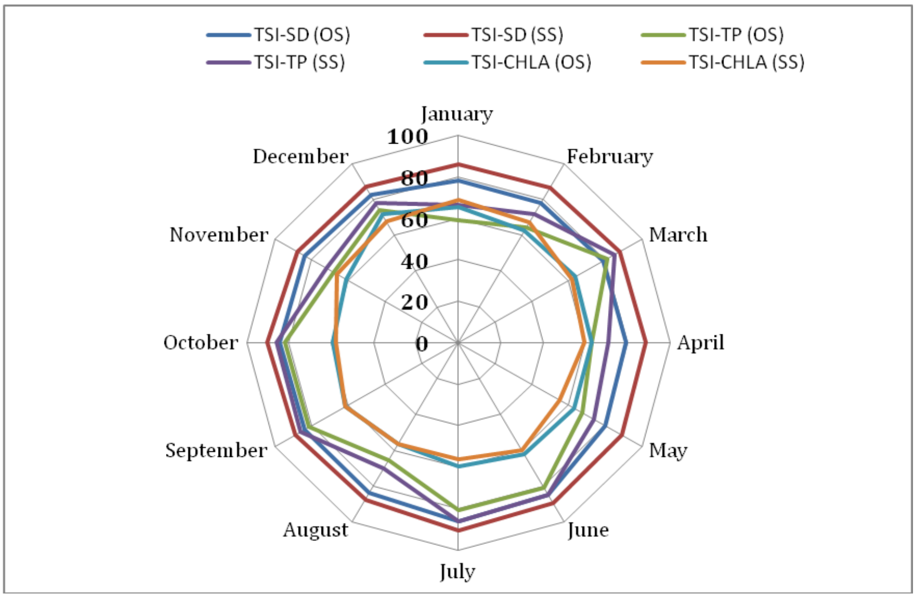


Fig 3: Radar diagram in the spatiotemporal variations of TSI values for each parameter (Secchi disk, TP, Chl-*a*) for Lake Tinishu Abaya at the open station (OS) and shore station (SS).

Phytoplankton diversity and abundance

In the study Lake, a total of 37 phytoplankton taxa/species belonging to 6 divisions were identified. The phytoplankton included 15 Bacillarophyta taxa, 11 Chlorophyta taxa, 7 Cyanobacteria taxa, 2 Euglenophyta taxa, 1 Dinophyta taxa, and 1 Cryptophyta species (table 3.). Species composition indicated that Bacillariophyceae (diatoms) had the highest (40.5%) number of taxa/richness followed by the division Chlorophyceae (green algae) (29.7%) and Cyanobacteria (blue-green algae) (18.9%). Euglenophyceae (5.4%), Dinophyceae (2.7), and Cryptophyceae (2.7%) had low species richness throughout the study period. The Shannon diversity index was higher for cyanobacteria (2.098) at open station and for Chlorophyta (2.161) at shore station than other group of phytoplankton. Shannon index was low for Cryptophyta (1.759) at open station and for Euglenophyta (1.741) at shore station. This was shown the two group of phytoplankton, cyanobacteria and Chlorophyta, were more diverse than other phytoplankton in the study area.

In this study area, the abundance of phytoplankton was anticipated in termers of biovolume in cubic millimeter per Litter of water (mm^3/L) for the dominant taxa (table 4). The total biovolume of phytoplankton which was computed in Lake Tinishu Abaya, was ranged from a low value of 7.96 mm^3/L to a high value of 315.29 mm^3/L at the open water station and 6.47 mm^3/L to 239.12 mm^3/L at the offshore station. The distribution pattern of biovolume in the study lake showed a seasonal effect ($p<0.05$). It was progressively decreased from January to April and increased from May to October with a sharp increase in August at the open water station and in December at the offshore station (Fig. 4). The total biovolume of phytoplankton represented by the five major groups (Cyanobacteria, Chlorophyta, Bacillariophyceae, Euglenophyta, and Dianophyta) (Table 4).

The largest biovolume of phytoplankton constituted in cyanobacteria (blue-green algae) at both stations. This group of phytoplankton comprised about 54% and 34% of the total biovolume of phytoplankton at open water and offshore stations, respectively. Next to cyanobacteria, Chlorophyta (green algae) and Bacillariophyta (diatoms) had relatively high biovolume, by means of Chlorophyta constituted 31% at the offshore station and 12.8% at open water station whereas, Bacillariophyta comprised 22.3% and 22.9% at open water and offshore stations, respectively. Euglenophyta and Dianophyta had comparatively low (10%) biovolume at both stations. About 75% of the total biovolume of phytoplankton was contributed by *Pediastrum simplex*, *Microcystis aeruginosa, Anabaena, Cylindrospermopsis, Nitzschia,* and *Peridinium.* The remaining 25% was attributed to other groups of phytoplankton (Table 5).

The calculated biovolume of Cyanobacteria (blue-green algae), dominant group of phytoplankton, was ranged from a low value of 0.32 9mm^3/L to a high value of 89.32 mm^3/L at the open water station and 0.2 mm^3/L to 170.12 mm^3/L at the offshore station. There was a seasonal effect ($p=0.002$) on the distribution of Cyanobacteria biovolume. It gradually decreased from January to March and increased from April to August. The maximum biovolume of Cyanobacteria was seen in August (rainy period) at the open water station and in October (dry period) at the offshore station, whereas the minimum value was seen in March (dry period) (Fig. 5). The abundance/biovolume of Cyanobacteria correlated positively and strongly with turbidity ($r=0.570$), NO_2 ($r=0.753$) and SiO_2 ($r=0.597$), while it correlated negatively and significantly with pH ($r= -0.436$), temperature ($r= -0.577$), conductivity ($r= -0.638$), total alkalinity ($r= -0.720$) and NH_4 ($r= -0.496$).

Microcystis aeruginosa was the most conspicuous species of cyanobacteria all year round. However, this species comprised relatively low biovolume (< 10%) (Table 5). Another species of Cyanobacteria, apart from, *M. aeruginosa*, occurred regularly were *Anabaena*, *Cylindrospermopsis africana*, *Pseudoanabaena sp,* and *Oscillatoria sp. Anabaena sp* were co-dominant with *M. aeruginosa.* At open water station, the maximum percentage of the total biovolume of phytoplankton was contributed by Anabaena sp. It consisting 25% and 15% of the total biovolume of phytoplankton at open water and offshore stations, respectively. *Cylindrospermopsis* comparatively had high biovolume. It accounts 18% and 8% of the total biovolume of phytoplankton at open water and offshore stations, respectively. Whereas *Pseudoanabaena* and *Oscillatoria* contributed an insignificant amount for the total phytoplankton biovolume. They comprised less than 2% of the total bivolume of phytoplankton.

There was a temporal distribution pattern in the biovolume of *M. aeruginosa* in the study lake. The biovolume of *M. aeruginosa* was relatively high during the wet season (June to September) and low from January to April (dry season). Relatively, high biovolume of *Anabaena* was seen at the beginning of sampling (January) and from June to September (rainy period) and October to December (dry season). It was progressively down from February to May (dry season) with a quick decrement in April and May (Fig. 6). The higher biovolume of *C. africana* was computed in September and October at the open water station and offshore stations, respectively. Low biovolume was seen from January to May (dry season). It increased with time, from July to September (rainy period) and November to December (dry season). Though *Oscillatoria sp* conspicuously occurred, the species comprised insignificant biovolume (< 2%). Among the Cyanobacteria species foundin the resent study lake, *Spirulina sp* and *Merismopedia sp* occurred hardly. *Spirulina* reported only in January, February, and April and totally absent in the other sampling months. *Merismopedia* did not occur from July to October at both stations. The contribution of the two species for the total biovolume was almost negligible by means each species comprised less than 0.5% of the total phytoplankton biovolume (Table 5).

The biovolume of Chlorophyta (green algae) in the study lake was calculated, and it was ranged from a low value of 0.89mm^3/L to a high value of 201.07 mm^3/L at the open water station and 0.5 mm^3/L to 99.45mm^3/L at the offshore station. Biovolume of Chlorophyta was significantly varied seasonally ($p=0.008$). It decreased from January to April until it pointed low in May at both stations. Despite low biovolume of green algae in the rainy season, at open water station moderately high value was reported from June-August. The maximum biovolume of green algae were seen in December (dry period) (Fig. 5).

Coelastrum sp., *Cosmarium sp*, and *Botryococcus sp.* were dominated the Chlorophyta (green algae). However, the biovolume of Chlorophyta was broadly dominated by a single species, *Pediastrum simplex.* It comprised 83% and 95% of the total biovolume of Chlorophyta at open water and offshore stations, respectively. This species also consisted the highest biovolume (29.6%) of the total phytoplankton biovolume at the offshore site (Table 4). *Cosmarium sp.* contributed relatively high (12%) value of the total biovolume of Chlorophyta next to *Pediastrum.* High biovolume of *Pediastrum* was seen *in* most of the dry season (November to December and January to February). In June and July (rainy period) relatively high *Pediastrum* biovolume was also seen. In main rainy season (June to September) the largest biovolume of Chlorophyta was contributed by another species other than *Pediastrum. Coelastrum sp.* was maximum in July at both stations, whereas *Cosmarium* and *Botryococcus* species were at peak population in August. All these dominant species of Chlorophyta was maximum in time of the rainy season (Fig. 6).

The contribution of Bacillariophyceae (diatoms) for the total biovolume of phytoplankton was relatively high (22%). The value was ranged from 0.83-82.77 mm^3/L and 0.58-57.72mm^3/L at open water and offshore stations, respectively. The biovolume of Bacillariophyceae in the study lake showed a significant temporal variation (p=0.000) with high values reported from June to August (rainy season) and progressively decreased from September to November. Relatively, low biovolume was reported from January to April (dry period)(Fig. 5). The biovolume of Bacillariophyta correlated positively and significantly with turbidity (r=0.491) and TSS (r=0.832) and it correlated negatively and strongly with pH (r= -0.655), conductivity(r= -0.458), total alkalinity (r= -0.517), and SRP (r= -0.405).

Nitzschia sp. was extensively dominated the biovolume of Bacillorophta. It comprised 85% and 80% of the total biovolume of diatom at open water and offshore stations, respectively. *Nitzschia sp.* was also contributed high (about 19%) of the total biovolume of phytoplankton. *Synedrulna* and *Cyclotella sp.* were co-dominant with *Nitzschia sp. Synedra ulna* accounted about 10% whereas *Cyclotella* consisted 6% of the total biovolume of the diatoms, respectively (Table 5). The peak biovolume of *Synedra ulna.* was reported in May. The relatively low biovolume of *Synedra ulna* was seen from February to April (dry season) and August to September (wet season) while high biovolume was observed in June (wet) and May and December (dry period). No *Synedrulna* biovolume in October and November (dry period) was computed. *Cylotella sp.* was more conspicuous in December, and it was relatively high in July and August (wet period) and October and December (dry period). *Cymbella sp, Nitzschia sp, Synedra ulna, Frgilaria sp, Navicula sp., and Melosira sp* were the diatom taxa which occurred regularly, yet they comprised almost negligible (<1.5%) biovolume.

Euglenophyta was another group of phytoplankton which frequently occurred in Lake Tinishu Abaya. The biovolume of this phytoplankton was computed (Table 2). The maximum biovolume of Euglenophyta was to be 86.75mm^3/L and 47.26 mm^3/L at open water and offshore stations, respectively. It was seasonally varied with significant differences (p=0.000) by means of high values were seen during the rainy season (June-September). Low biovolume of Euglenophyta was reported in most of the dry season (January-April). Three taxa (*Euglena*, *Peridinium*, *Phacus*) of Euglenophyta were found in the study lake. *Euglenoid* and *Peridinium* sp. occurred frequently while *Phacus sp.* was occurred rarely. The biovolume of Euglenophyta was widely dominated by a single taxon, *Peridinium.* It comprised 95% of the total biovolume of Euglenophyta. This species also contributed somewhat high (10%) to the total biovolume of phytoplankton. Euglenoid accounted low (5%) biovolume of Eglunophyta and *Phacus sp.* accounted insignificant (<1%) biovolume year round. The peak biovolume of Euglena and Perdinum was observed in October and June at both stations, respectively. Though the relative maximum biovolume of Euglena reported in October (dry period), it was low in most of the dry season (January to April and December). Perdinum was prominent during the main rainy season (June to September).

Table 3: Phytoplankton taxa/species found in Lake Tinishu Abaya from January-December, 2016'

	Phytoplankoton Taxa				
Bacillariophyceae	**Chlorophyceae**	**Cyanobacteria**	**Euglenophyceae**	**Cryptophyceae**	**Dianophyta**
Asterionella sp	*Ankistrodesmus sp*	*Anabena sp*	*Euglena sp*	*Cryptomonas sp*	*Peridinium sp*
Aulacoseira sp	*Botryococcus sp*	*Cylindrospermopsis africana*	*Phacus sp*		
Cyclotella sp	*Closterium sp*	*Merismopedia sp*			
Cymbella sp	*Coelastrum sp*	*Microcystis aeruginosa*			
Epithemia sp	*Cosmarium sp*	*Oscillatoria sp*			
Fragilaria sp	*Oocystis sp*	*Pseudoanabaena sp*			
Gyrosigma sp	*Pediastrum duplex*	*Sprirulina sp*			
Melosira sp	*Pediastrum simplex*				
Navicula sp	*Scenedesmus armatus*				
Nitzschia sp	*Volvox sp*				
Pinnularia sp	*Zygnema sp*				
Stauroneis sp					
Surirella sp					
Synedra ulna					
Thalassiosira sp					

Table 4: The biovolume (mm^3/L) of the major phytoplankton group for Lake Tinishu Abaya in the study period (January-December, 2016) (mean, minimum and maximum)

Phytoplankton taxa	N	Site	Minimum	Maximum	Mean	SD
Chlorophyta	12	Open	0.32	89.32	15.06	24.21
	12	Shore	0.2	170.12	27.48	56.30
Cyanophyta	12	Open	201.07	63.43	79.43	201.1
	12	Shore	0.50	99.45	31.16	34.5
Bacillariophta	12	Open	0.83	84.018	26.13	32.52
	12	Shore	0.58	57.72	20.2	22.34
Euglenophyta	12	Open	0	86.75	12.58	24.23
	12	Shore	0	47.26	9.12	13.82

Table 5: Percentage contributions of biovolume of the dominant phytoplankton taxa in Lake Tinishu Abaya. a-represents the spices which are relatively contributed significant value for the total biovolume

Phytoplankton	Site	
	Open water	**Offshore**
Anabena	25.46[a]	15.03[a]
Cosmarium	1.58	1.02
Cylindrospermopsis	17.59[a]	8.03[a]
Microcystis aeruginosa	8.68[a]	9.99[a]
Nitzschia sp	19[a]	18.46[a]
Oscillatoria	1.20	1.81
Pediastrum duplex	0.29	0.33
Pediastrum simplex	10.63[a]	29.59[a]
Peridinium sp	10.2[a]	9.88[a]
Synedra ulna	1.76	2.3

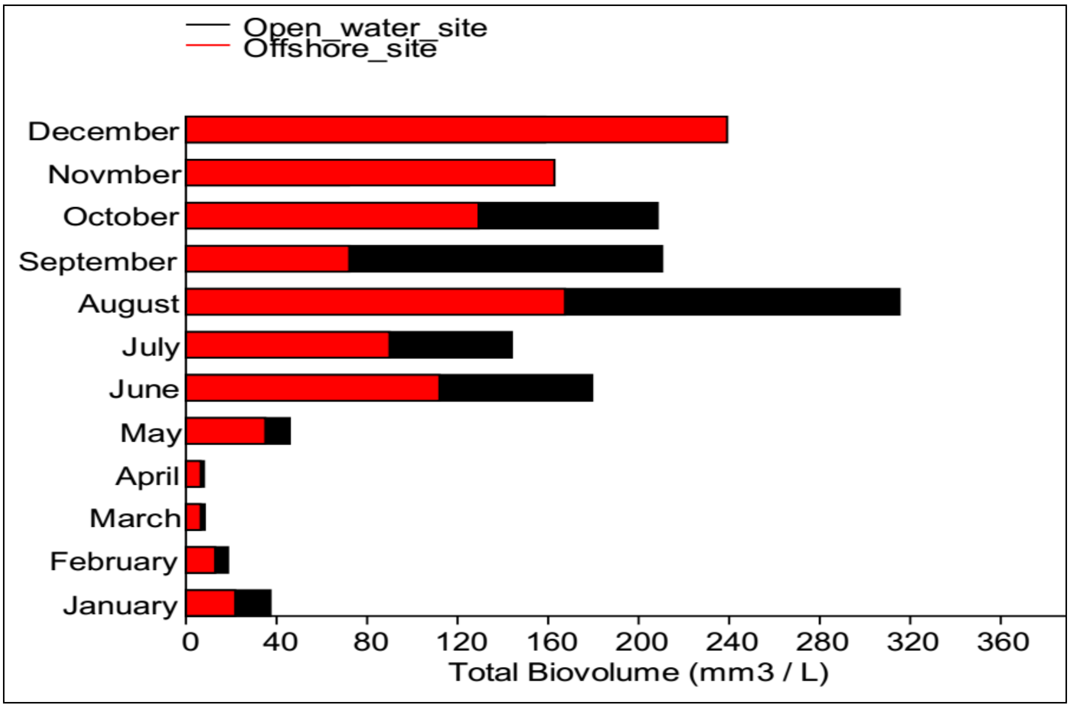


Fig 4: Temporal patterns of the total biovolume of phytoplankton in Lake Tinishu Abaya

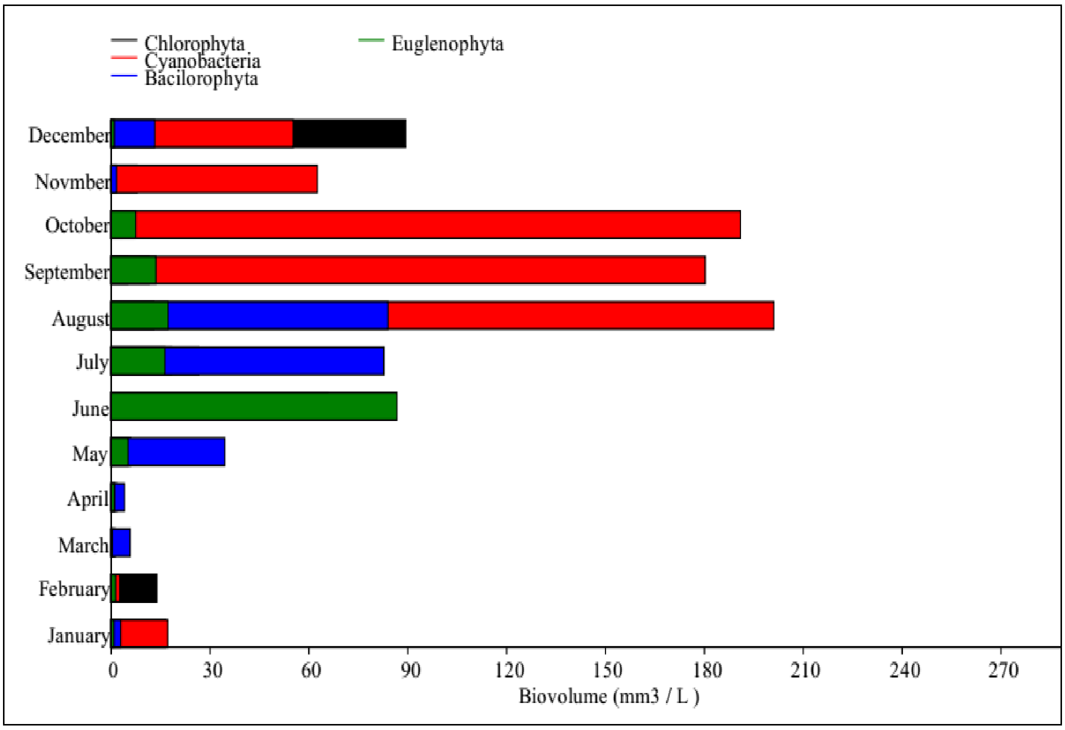


Fig 5: Temporal patterns of the biovolume of the major phytoplankton at open water station in Lake Tinishu Abaya

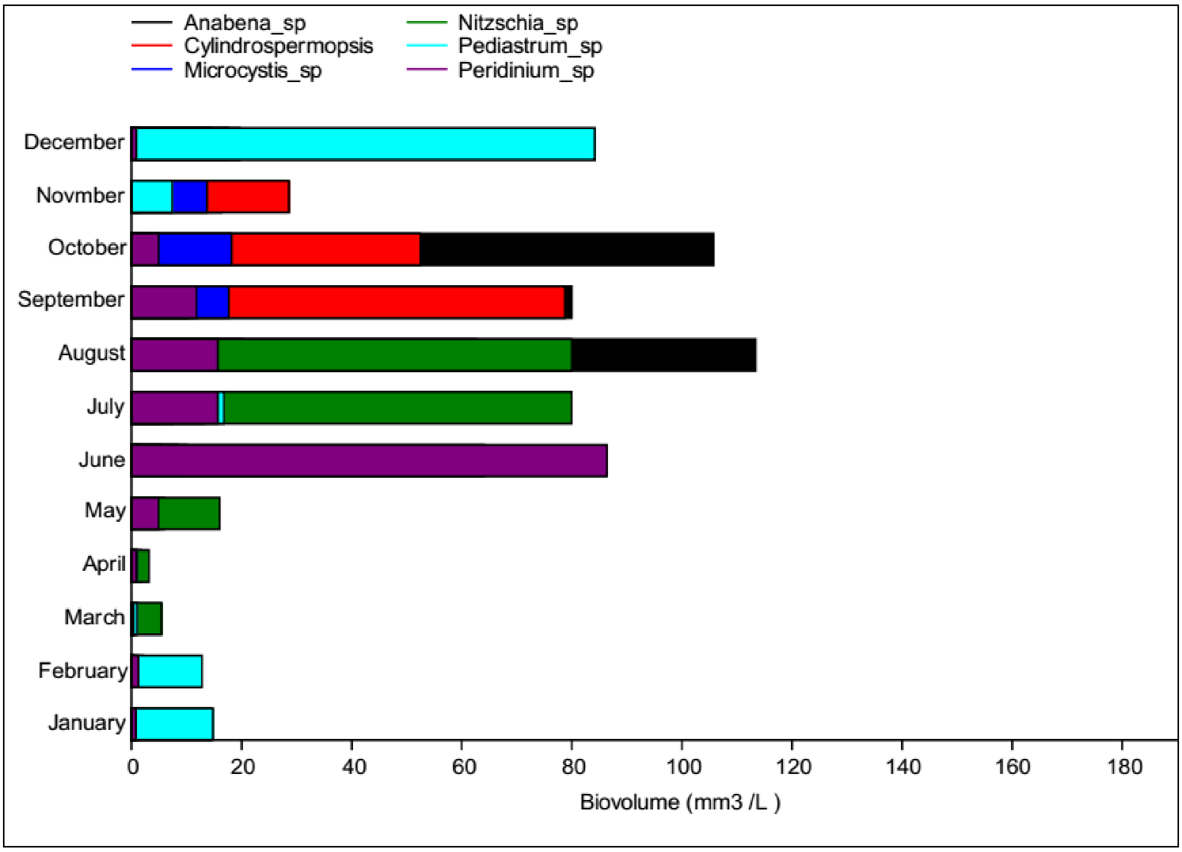


Fig 6: Temporal patterns of the biovolume of the major phytoplankton species at open water station in Lake Tinishu Abaya

Redundancy Analysis (RDA)

The relationships between the major phytoplankton species and various key environmental drivers which regulate the diversity and abundance of phytoplankton in Lake Tinishu Abaya were analyzed using a constrained Redundancy Analyses (RDA) graph (Fig. 7). The first and second axes of the RDA graph together explained 79.2% of the cumulative percentage variance of species-environment relation. The first axis and the second axis explain 65.3% and 13.9%, respectively (Table 6). Axis 1 of RDA correlated positively and strongly with NO_3, NH_4, and temperature while it correlated negatively with turbidity, NO_2, TP, SiO_2, and SRP. On the other hand, the second axis correlated positively with TSS, turbidity, TP, NO_2, NO_3, and NH_4 and it correlated negatively with SRP, Secchi disk, DO, pH, conductivity, and temperature. The occurrence of the dominant phytoplankton species, *M. aeruginosa*, and *Coelastrum* sp, correlated positively and strongly with turbidity, NO_2, and TP while they correlated negatively and strongly with temperature, total alkalinity, pH, DO, Secchi disk and conductivity. *Nitzschia* sp. correlated positively and strongly with TSS and turbidity. *C. africana* correlated strongly and positively with SiO_2. *Pediastrum* correlated positively and strongly with SRP.

Table 6: Summary of the statistics of RDA diagram

Axes	**1**	**2**	**3**	**4**
Eigenvalues:	0.597	0.127	0.087	0.044
Species-environment correlations:	0.976	0.961	0.970	0.892
Cumulative percentage variance				
of species data :	59.7	72.4	81.1	85.5
of species-environment relation:	65.3	79.2	88.7	93.6
Sum of all eigenvalues	1.000			
Sum of all canonical eigenvalues	0.914			

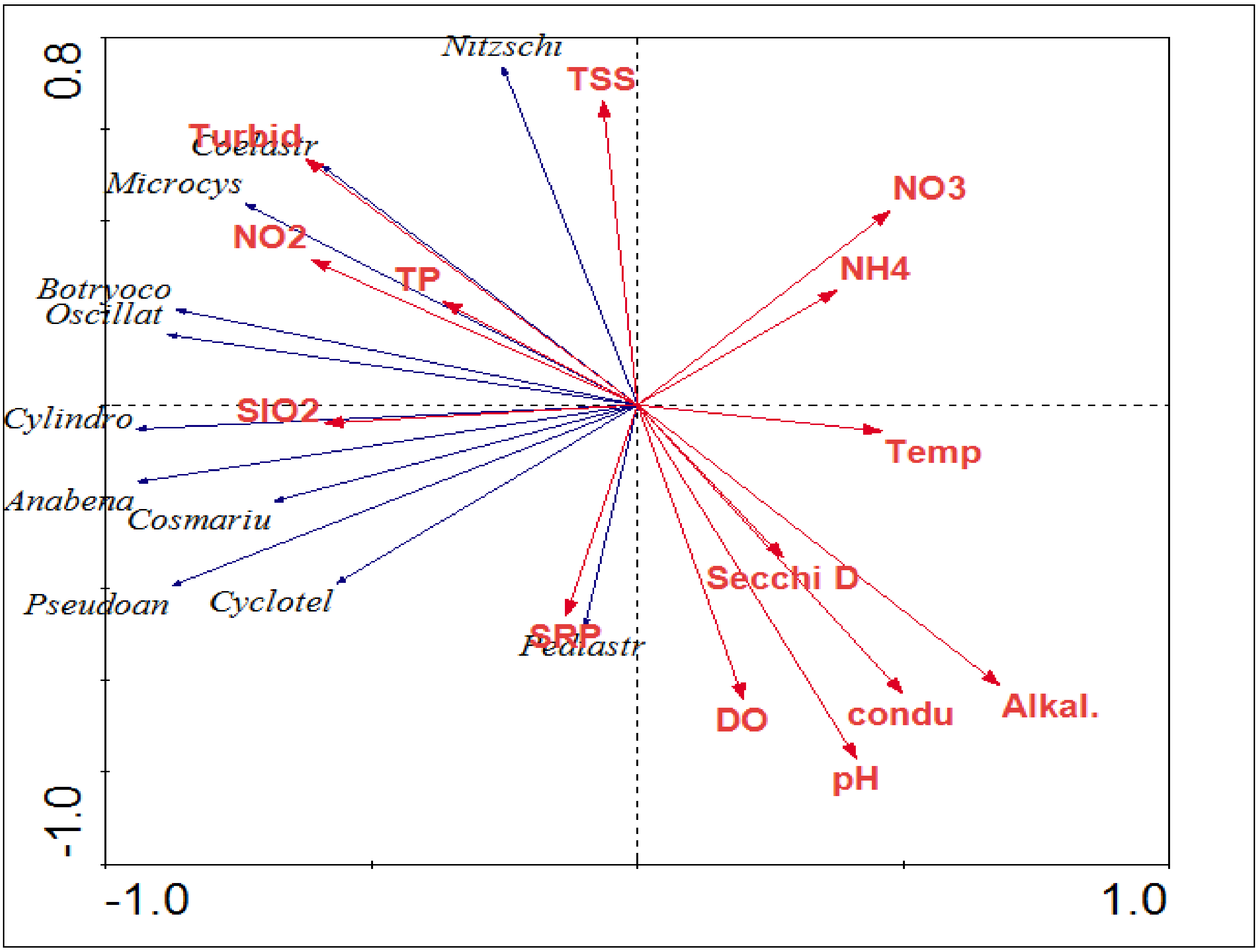


Fig 7: Bi-plot of the constrained Redundancy Analyses (RDA, CANOCO for Windows 4) for dominant phytoplankton specie (blue arrows) and environmental variables(red arrows): *Pediastr-pediastrum simplex, Cyclotel-Cyclotela sp., Pseudoan-Pseudoanabena sp., Cosmariu-Cosmarium sp., Anabena-Anabena sp., Cylindro Cylindrospermopsis africana, Oscillat-Oscillatoria sp., Botrycoco- Botryococcus sp., Microcys-Microcystis aeruginosa, Coelastr- Coelastrum sp, Nitzschi-Nitzschia sp*.**:** Turbid-turbidity, Condu-conductivity, Secchi D-Secchi disk, Temp-temperature, Alkal-Alkalinity

Discussion

Physicochemical features

In the study area, there is a relatively high temperature and dissolved oxygen, which indicated the lake is relatively warm, and well oxygenated. In the study, a considerable temperature fluctuation was observed which could be influenced considerably by meteorological factors such as air temperature, humidity, wind speed, solar radiation and climatic factors. Dissolved oxygen showed temporal variation that might be the result of the variations observed in phytoplankton photosynthetic activity, thermal regime and/or changes in the weather conditions of the lake area. M Calijuri *et al*. (2000)[8] considered that whereas wind is a major oxygenator in large lakes, dissolved oxygen in smaller lakes (a prominent feature of Lake Tinishu Abaya) is largely determined by photosynthetic action of planktons and complete oxygen depletion was not observed, apparently because of significant water movement through the lake as a result of mass water movement due to frequent top-down mixing. A similar fact was observed in Lake Tinishu Abay in which oxygen was not completely depleted throughout the study period owing to its water movement, in turn occurrence of complete mixing. Dissolved oxygen below 5 mg/l adversely affects aquatic live. WHO (2004) [56] (>5 mg/L) standard for the survival of aquatic live. The concentration of DO level for the study lake indicated that it is suitable for the survival of aquatic liife as per WHO prescribed.

In the present investigation, the pH value showed that the water of Lake Tinishu Abaya was alkaline in nature throughout the study period. The alkalinity results suggest that the lake is high productive. BSI (2003) [7] recommendation of pH is 6.5-8.5 for optimal survival of most aquatic live. A lower value of pH below 4 will produce sour taste. The minimum values of pH of the study lake are within the maximum permissible limits of (WHO, 2006) [57] for recreation, agricultural, fish production and other aquatic life water use (6.5-8.5/9). As recorded in this study, Lake Tinisu Abaya is very turbid. This higher turbidity could be the result of rainfall which brought sediment-laden waters from the surface runoff via rivers Bobodo and Dacha, and because of surface run-off water with soil, domestic waste, cattle washing, bathing activity, and etc. The lake had relatively high TDS throughout the study. Water with total ionic concentration <3000 mg/L) is considered fresh. The acceptable range for lifetock drinking is 100-1500mg/l. Thus, Lake Tinishu Abaya is reasonably fresh based on the results of TDS, and it is recommendable for lifetock drinking including fish production.

Lake Tinishu Abaya had low water transparency throughout the study period and, therefore, the lake is generally regarded as a productive lake. The significant lower water transparency is most likely due to wind-induced re-suspension of bottom sediments and this operates the large turbulence and sediment instability which in turn reduces the depth of light penetration.

During the period of sampling, a lot of human activities including swimming, washing clothes, watering animals and damping of wastes were observed, and these activities may persuade and cause re-suspension of particles, have probably contributed to the lower water clarity of the study lake. Low water transparency during the rainy season may be because of high flushing rate, inorganic silt turbidity, and high loading of dissolved inorganic matter from the inflowing rivers, which is likely any other tropical lake (Wetzel, 1990) [53].

Most of the inorganic nutrients measured in the study lake were relatively higher and supports most of the aquatic life. Majority of the nutrients were relatively high during the rainy season. This is because of the possible influx of nitrogen-rich flood water into the lake water from the amount of contaminated sewage water. The seasonal changes in NO3+NO2 concentration in Lake Tinishu Abaya seem to be controlled by the introduction of nutrients from external sources through runoff. Ammonium concentrations are lower than nitrate-nitrogen concentrations in most productive lakes after periods of circulation (Wetzel, 2001) [54]. The same results was observed in the study lake. In Lake Tinishu Abaya, the concentration of dissolved silica is very low. Generally over the last two decades, the Ethiopian Rift Valley lakes showed a decline in silicate concentrations (E. Kebede *et al*., 1994; Z. Gebremariam *et al.*, 2002) [30, 15]. The depletion of silica can be related to its removal from solution in diatom-dominated lakes (E. Kebede and E. Willen, 1998) [31] or its slower rate of regeneration resulting from the accumulation of organic matter as was shown for alkaline lakes in Africa (RE. Hecky and P. Kilham, 1973) [22]. Regeneration of phosphorus by zooplankton can be high enough to raise the ambient concentration to a level capable of supporting algal growth (I. Morris, 1980) [36], which is not well studied in African lakes (JA. Thornton *et al*., 1986) [51]. The fairly high level of TP in this lake is probably a result of zooplankton excretion. The release of phosphate from anaerobic sediments (CH. Mortimer, 1971) [37] and its subsequent transport to the epilimnion during mixing contributes to the high level of phosphate in the epilimnion, may results the fairly high phosphate in the study lake. According to R. Ayers and DW. Westcott (1985) [3], the required maximum concentration of NO_3 for lifetock and irrigation were 100 and 30 mg/L respectively and the concentration below 5 mg/l will not affect flora. The concentration of nitrate in Lake Tinishu Abaya was within the permissible limits for flora, lifetock, and irrigation. The maximum allowable concentration of phosphate for irrigation water is 2 mg/l (R. Ayers and DW. Westcot, 1985) [3].

Phytoplankton community structure and abundance

Blue-green algae, diatoms, and green algae are the major taxonomic groups of phytoplankton in the study area whereas, Euglenophyceae and Cryptophyceae are the other minor taxonomic groups, and poorly represented. An observation which is consistent with the generalization that blue-green algae and green algae were a species-rich taxonomic group in most tropical as well as temperate lakes (S. Agusti *et al*. 1990) [1]. Green algae followed by blue-green algae have contributed the most to the total number of species in Rift valley Lakes Ziway, Awasa and Chamo (Ethiopia) (T. Girma and G. Ahlgren 2010) [16], in the present study lake, Bacillariophyceae followed by Chlorophyceae contributed the highest spices richness of phytoplankton.

External inputs from catchments increase through major and minor river discharges (WM. Lewis, 2000) [33]. Rivers Dacha and Bobodo are the main tributary rivers for Lake Tinishu Abaya and these rivers collect nutrient from the catchment during the rainy season may ultimately result in the increment of phytoplankton abundance. As the dilution of the lake when increased water level and nutrient concentration reach their seasonal peaks, all taxa were favored but mainly dominated by blue-green algae. In Lake Tinishu Abaya, blue-green algae dominated the biovolume of phytoplankton. Recent research in some lakes also shows that the dominance of blue-green algae is the result of other phytoplankton groups suffering disproportionably higher losses (S. Agusti *et al*. 1990) [1]. In the study lake, temporality of phytoplankton is more pronounced. The small-sized and shallow lake is polymictic, explaining the absence of significant spatial variations in phytoplankton species composition and biovolume. Biovolume of phytoplankton is high during the rainy seasons. This attributed to the higher concentration of nutrients and the occurrence of complete mixing in which phytoplankton may easily access it for their growth and development. During early dry season (January-April), species of phytoplankton basically, blue-green algae and diatoms (most dominant group) showed a sharp decline following the decrease in water temperature and nutrient depletion. The correlation between the observed decline of phytoplankton with diminishing nutrient concentrations and decreased temperature during the dry season that the relationship appears to be predominantly causal.

Microcystis aeruginosa was always the most conspicuous populations in the present study lake. However, it contributed relatively low biovolume. The dominance of most of the phytoplankton taxa was high during the rainy months (June, July, August, and September), and the beginning of the dry season (October) might be associated with the availability of nutrients and increasing water turbidity. Similarly, the dominance of *M. aeruginosa* during mixing and rainy period than a period of thermal stability was observed in the nearby rift valley lakes including Lake Awassa, Chamo and Ziway and the tropical high land lake, Lake Hayq (T. Fetahi *et al*. 2010) [14] and other Ethiopia creator lakes, L. Kuriftu and L. Bishoftu.

Increased photosynthetic rates coincided with rainfall (JM. Melack 1979b) [33] due to the fact that the supply of nutrients was increased by rains and subsequently enhanced the growth of phytoplankton. The persistence of fairly high levels of nutrients, particular phosphate in a generally turbid and mixing water column favors the dominance of blue-greens owing to their structural and physiological adaptation for buoyancy regulation (U. Hammer *et al*. 1983) [18]. J. Shapiro (1990) [46] suggested that high temperature helps the dominance of Cyanobacteria. High levels of temperature favor the optimal growth of Cyanobacteria, especially *Microcystis* in lakes and reservoirs of the temperate and tropical regions (RD. Roberts and T. Zohary, 1987) [44]. In general tropical lakes show Cyanobacterial dominance during drought and falling water level (Harris and Baxter, 1996) and this probably explains why the density of Cyanobacteria in Lake Tinishu Abay become high in the beginning of the dry period (October). Cyanobacterial dominance is a common phenomenon in Lakes and Reservoirs in Ethiopia (E. Kebede and E. Willen 1998) [31]. Other investigations also stressed cyanobacterial dominance associated with different factors such as shallow mixing (CH. Reynolds 1990, 1994) [42, 41], low light (VH. Smith 1986) [47], high temperature (J. Shapiro

1990) [45], low CO_2 (N. Carco and R. Miller, 1998; J. Shapiro 1984) [9, 46], high total phosphate (S. Watson *et al*., 1997) [52], luxury consumption of phosphorus (K. Peterson *et al*., 1993) [38], ability to minimize grazing (JF Hanlay, 1987) [19], and buoyancy regulation (CH. Reynolds, 1987) [39].

Bacillariophyceae contributed a comparatively high percentage of phytoplankton biovolume. High concentration of nitrogen and phosphorous nutrients resulting from low of other competing algal groups (apart from cyanobacteria) and biomass most probably favored the dominance of diatoms next to blue-green algae. The higher Baciloriohyceae is reporting during the main rainy season (June-August). Wet period dominance, is probably associated with superficial mixing resulting from nocturnal cooling in spite of the absence of superficial stratification. Diatoms dominate water columns in the presence of strong mixing (JF. Talling, 1986) [49]. Silica was not limiting during the rainy period and it was a peak in August may be contributed the higher density of diatoms during the rainy season. The correlation between the density of diatom and silica in this study lake were positive but not strong (r=0.176). Diatoms commonly dominated the species composition of the plankton during periods of overturn in wind exposed (turbulence) lakes with a sufficient supply of available dissolved silica (M. Diaz and F. Pedrozoa, 1993) [11], a similar situation is observed in the present study lake.

Nitzschia sp. widely dominated the diatom biovolume. *Cyclotella sp.* and *Synedra ulna.* are mostly co-dominant with *Nitzschia.* There was a seasonal pattern in the biovolume of the dominant species of diatom. The higher *Nitzschia sp.* was reported in July and August, while the peak *Cyclotella* and *Synedra ulna*s. observed in September and December respectively. Studies on the seasonality of phytoplankton in Lake Tana, the largest lake in Ethiopia, showed that diatoms (*Nitzschia sp.* and *Melosira sp.)* are important elements in the seasonal pattern. In Lake Tinishu Abaya, *Nitzschia* and *Cyclotella* shows a similar pattern. Unlike Lake Malawi (R. Hecky and H. Kling, 1981) [20] where there was no well-established co-dominance of diatoms and blue-green algae have seen, in Lake Tinishu Abaya, there is a positive yet not strong relationship between the diatom and blue-green algae indicated the two major algae of the study lake are found co-dominantly. However, the predominance of diatoms generally occurred in periods of strong vertical mixing (June-August) and that of blue-green algae under relatively less mixing water column (October). In addition, the fact that the lake is small-sized and very shallow which results absence of marked thermal stratification has enable it to have its own pattern of seasonality compared with other large lakes.

In studies of African phytoplankton dynamics, Livingstone and Melack (1984) have described large inter-annual changes in the soda lakes involving multiple shifts of dominant algal species against a background of changing salinity, zooplankton density, and nutrient dynamics. A number of soda lakes, such as Lake Arenguadie (Wood 1986) and Rift Valley Lakes in Ethiopia and Lake Simbi in Kena (Melack 1997b) exhibited year long-dominance by single blue-green algae species, *Spirulina platensis.* In the present study of phytoplankton community in Lake Tinishu Abaya, *Microcystis aeruginosa* dominated year round. Euglenoid, Peridinium, and Phacus sp occurred rarely relative to other taxonomic groups. However, Peridinium comprised relatively high biovolume.

Conclusion

The phytoplankton community composition of Lake Tinishu Abaya comprised six major taxa including Bacillarophyta, Chllorophyta, Cyanobacteria, Euglenophyta, Chryptophyta, and Dianophyta. Majority of the phytoplankton biovolume, or abandance, constituted in the Pediastrum, Anabaena, Cylindrospermosis, Nitzchia and Perdinium species. *Microcystis aeruginosa* is the most conspicuous phytoplankton, however, this species comprised low value of the total biovolume of phytoplankton. The phytoplankton showed seasonality with high bio-volume during rainy season concurrently with high ambient inorganic nutrients from runoff the watershed via rivers whilst low biovolume reported during the dry season with high water transparency. Various physicochemical parameters including major inorganic nutrients of water analyzed depicted a positive correlation with diversity and distribution of phytoplankton and support most of the phytoplankton development and growth. The diversity and abundance of phytoplankton in the study lake was comparatively high. Due to the high species composition and biovolume, the lake can be said to be productive. The various physico-chemical factors responsible for the observed temporal variations in the physical, chemical and biological features of the lake are discussed and generalized that the lake water was well oxygenated, slightly warm, alkaline, contained more TSS, TDS, and EC, very turbid, low transparency and with relatively high inorganic nutrients which support most of the aquatic life. Generally, based on the results of the diversity and abundance/biovolume of phytoplankton communities, and the nutrient condition, the authors concluded that Lake Tinishu Abaya is reasonably a productive inland freshwater ecosystems in the Ethiopian rift valley basin.

Acknowledgements

The authors would like to thank the Department of Zoological Sciences of Addis Ababa University for assisting us in laboratory facilities. Our acknowledgment also went Bureau of Culture and Tourism (Selttie District, Ethiopia) for permission to carry out the study in the area.

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