RESEARCH ARTICLE

A seasonal study on phytoplankton diversity and dynamics of Lake Chamo, Ethiopia

Addisu Fekadu^{1,2,*} and Solomon Chanie²

¹ Arba Minch University, Biodiversity Research Center, P.O. Box 21, Arba Minch, Ethiopia

² Arba Minch University, Department of Biology, P.O. Box 21, Arba Minch, Ethiopia

Received 17 July 2016 / Accepted 15 September 2017

Handling editor: Véronique Martin-Jezequel

Abstract – Phytoplankton succession in open lakes depends on the availability of nutrients, temperature, light intensity and transparency. Phytoplankton communities usually undergo a fairly predictable annual cycle, but some species may grow exponentially forming the blooms. Accordingly, the seasonal diversity and dynamics of phytoplankton and their correlation with environmental factors were investigated in Lake Chamo, from December, 2013 to November, 2014. Samples were taken from four different sites of the lake; each of these sampling sites had their own unique characteristics. Seasonal plankton samples were collected using nylobolt plankton net (No. 25). pH, water temperature, specific conductivity, saturation, total dissolved solids, salinity and dissolved oxygen were measured in the field. The results showed that there is significant difference in the mean value of pH across the different seasons at the first sampling site, season II having significantly higher value than season I and IV. Water temperature also significantly varied among sampling sites and seasons, site 3 in spring 2014 having significantly higher value (30.4 ± 0.21 °C) than site 2 during summer 2014 (26.0 ± 0.12 °C). Cyanophyta, Chlorophyta and Bacillariophyta accounted 96% of the total phytoplankton abundance during the study period. *Pediastrum*, *Scenedesmus* and *Closterium* species were the predominant Chlorophyta, during the rainy seasons. The average Cyanophyta count was positively and non-significantly correlated with water temperature and turbidity of the lake. Overall, the four seasons exhibit different phytoplankton species composition across different sites. The diversity was high during winter season in all sampling sites.

Keywords: Phytoplankton diversity / physicochemical parameters / species composition / Lake Chamo

1 Introduction

In aquatic ecosystems phytoplankton are the principal primary producers form the first trophic level of the aquatic food chain (Nasser and Sureshkumar, 2014). Hence they play an important role in the food webs as they provide food for zooplankton and other aquatic fauna (Jagadeeshappa and Kumara, 2013). Their presence is also essential to support a healthy aquatic ecosystem, and is frequently used as ecological indicator for the ecological health and the stress effects of chemical contaminants in aquatic ecosystems (Xu et al., 1999).

Phytoplankton diversity and dynamics in open lakes is largely dependent on abiotic factors such as nutrient availability, water temperature, light conditions and transparency, along with biotic interactions such as predation and competition (Siddaraju and Deviprasad, 2012; Jiang et al.,

2014). Light limitation due to high turbidity is another factor that frequently controls phytoplankton growth over both annual and seasonal cycles (Ariyadej et al., 2004). Moreover, when single groups of organisms like algae compete for nutrients within a uniform environment, the diversity may be lower due to competitive exclusion. However, the biotic interactions between diverse freshwater plankton communities and how this influences overall community composition are highly complex (Siddaraju and Deviprasad, 2012).

Phytoplankton typically also undergo a fairly predictable annual and seasonal cycles (Jiang et al., 2014). The spatial and temporal variation highly influenced by the prevailing physicochemical parameters and these determine their abundance, occurrence and seasonal variations (Rothhaupt, 2000). Plankton respond quickly to environmental changes because of their short life cycle, hence, their species composition and dynamics are more likely to indicate the quality of the water which they are found. The relative abundance of chlorophyll is indicative of productive water

*Corresponding author: addisufkd@yahoo.com

(Washington, 1984; Jenkerson and Hickman, 2007). Ecologists have designed a range of indices and models for the measurement of phytoplankton diversity (Warwick, 1992). These diversity indices are applied in water pollution research to evaluate the effects of pollution on species composition (Archibald, 1972; Shashi et al., 2008). The qualitative and quantitative studies of phytoplankton have also been utilized to assess the quality of water (Shashi et al., 2008).

The importance of phytoplankton to trophic systems and overall ecosystem function means that understanding how communities respond to environmental parameters is important. Tropical lakes, particularly those in Africa, are known for their high primary productivity of phytoplankton (Sorokin et al., 2014) and thus present a useful system to study this issue. For example, recent studies on phytoplankton diversity in tropical African lakes, particularly in the soda lakes of East Africa, have come up with reports of exceptionally high diversity and photosynthetic activity (Lemma and Desta, 2016). Similarly, a high diversity of aquatic fauna has also been reported in Lake Chamo (Hailemichael and Raju, 2010; Willén et al., 2011). However, there are no clear reports which show phytoplankton diversity and abundance across different seasons in Lake Chamo. Therefore, the primary objective of this research was to assess phytoplankton diversity, abundance and dynamics with physicochemical parameters of Lake Chamo across different seasons.

2 Materials and methods

2.1 Study area

The study took place at Lake Chamo, a tectonic lake and the southernmost lake of the Ethiopian Rift Valley (5°45' N latitude and 37°30' E longitude), which covers an area of 45,000 ha, at an elevation of 1,233 m. It has a maximum known depth of 12.7 m. It is fed by the perennial *Kulfo* river, *Kulfo* that enters Lake Chamo from the north and by a number of small but non-perennial rivers including the Rivers *Sile* and *Sego*. The lake is characterized by a gently sloping shoreline covered by extensive emergent and submergent vegetation.

2.2 Sample collection sites

Samples were taken from four different sites of the lake, each of which had its own unique characteristics. Site 1 is situated close to the mouth of *Kulfo* river (N°5.55'05.07'', E°37.33'34.8''). Site 2 is considered as the center of the lake (N°5.53'32.1'', E°37.34'33.5''). Site 3 is near the mouth of *Sile* river (N°5.53'45.1'', E°37.31'58.3''). Site 4 is located close to the main gate and is characterized by high disturbance (N°5.55'58.1'', E°37.32'04.9'') (Fig. 1).

2.3 Phytoplankton sampling

Sampling took place between December 2013 and November 2014. Winter 2013/14 was considered as season I, spring 2014 season II, summer 2014 season III, and autumn 2014 season IV. Seasonal plankton, with two sampling times for each season, were collected from 4 sites of Lake Chamo using a nylobolt plankton net (No. 25 µm). To do so, two sampling techniques

Source: Google Earth, 2017

Fig. 1. Study area and sampling sites.

were employed. Firstly, to assess species diversity, phytoplankton were pulled up vertically to the surface. The sample from the net was then placed into a 100 mL bottle. Typically, this process required 2–3 samples to fill the bottle. Secondly, for determining the abundance, phytoplankton were collected using a water sampler (Jagadeeshappa and Kumara, 2013; Jiang et al., 2014). Since the total depth of Lake Chamo is less than 15 m, equal volumes were taken from the surface, mid-depth and bottom regions of the lake (Jagadeeshappa and Kumara, 2013; Jiang et al., 2014). Aliquots from each depth were combined and 1 L of the composite sample was poured into dark plastic bottles and preserved with 2 mL of Lugol's solution per 100 mL of the water for later analysis. For counting, samples were sedimented in glass columns (Welch, 1948) and studied with an inverted microscope. Calculation of phytoplankton abundance (per liter) was based on the cell counts from sub samples. All types of phytoplankton samples were taken to Limnology Laboratory of Addis Ababa University for identification and abundance estimation. Moreover, several special publications from tropical environments and Monographs of Desikachary (1959), (Philipose, 1962; Prescott, 1982), and (Sarode and Kamath, 1984) were consulted.

2.4 Physicochemical parameters measurements

The physicochemical parameters pH, water temperature, specific conductivity, saturation, total dissolved solids, salinity and dissolved oxygen were measured in the field using HQ40D digital multi probes meter (HACH, USA). Chlorophyll-a concentrations and turbidity were measured in the field with a hand-held fluorometer, Aqua Fluor™ (Turner Designs, San Jose, California), and water transparency was also measured using a white and black Secchi disc of 20 cm diameter. All the parameters were measured in three replicates. Water samples were also collected from the surface and stored in a cool box at 4 °C. These samples were later analyzed for total alkalinity (TA), total hardness (TH), total dissolved solid (TDS), chlorides, calcium, magnesium, sulphate, nitrate and total nitrogen (TN) at Arba Minch University Water Quality Laboratory using standard methods (APHA, 2005).

Table 1. The seasonal and spatial variation of physicochemical variables in Lake Chamo during winter 2013/14 (season I), spring 2014 (season II), summer 2014 (season III), and autumn 2014 (season IV).

Site	Season	pH	Temp. (°C)	EC (µs/cm)	TA (mg/L)	Chloride (mg/L)	TH (mg/L)	Ca (mg/L)	Mg (mg/L)	Sulfate (mg/L)
1	I	9.12 ± 0.04 ^a	29.8 ± 0.20	1617 ± 2.00 ^{aA}	1490 ± 0.05 ^{aA}	140 ± 0.01 ^{aA}	66 ± 0.02 ^a	14 ± 0.04 ^{aA}	13 ± 0.01 ^{aA}	27 ± 1.25 ^{aA}
	II	9.57 ± 0.01 ^b	28.0 ± 0.31	1934 ± 3.12 ^{bA}	1696 ± 0.08 ^{bA}	117 ± 0.04 ^{ab}	50 ± 0.31 ^{bA}	22 ± 0.01 ^{bA}	7 ± 0.02 ^{bA}	25 ± 3.98 ^{bA}
	III	9.51 ± 0.03 ^{bc}	27.5 ± 0.51	1253 ± 1.24 ^{cA}	1125 ± 0.12 ^c	84 ± 0.03 ^{bc}	57 ± 0.11 ^{cA}	13 ± 0.06 ^{ac}	10 ± 0.02 ^{abc}	74 ± 2.45 ^{cA}
	IV	8.87 ± 0.25 ^d	26.7 ± 0.32	1777 ± 1.32 ^{dA}	1490 ± 0.31 ^{ad}	109.8 ± 0.05 ^{bd}	48 ± 0.23 ^{bA}	16 ± 0.04 ^{adA}	7.8 ± 0.05 ^{bcd}	48 ± 1.65 ^{dA}
2	I	9.43 ± 0.83	29.4 ± 0.22	1600 ± 2.80 ^{aB}	1470 ± 0.22 ^{aB}	140 ± 0.09 ^{aB}	58 ± 0.32 ^a	14.4 ± 0.03 ^{aB}	11 ± 0.02 ^a	40 ± 1.36 ^{aB}
	II	9.72 ± 0.01	27.6 ± 0.40	1921 ± 1.87 ^{aAB}	1486 ± 0.09 ^{bb}	143 ± 0.03 ^{ab}	45 ± 0.05 ^{bb}	18 ± 0.05 ^{bb}	6.5 ± 0.04 ^{AB}	51 ± 1.88 ^{bb}
	III	9.78 ± 0.10	26.0 ± 0.12	1824 ± 2.22 ^b	1725 ± 0.14 ^c	124 ± 0.01 ^{bc}	58 ± 0.04 ^{acAB}	11 ± 0.07 ^c	11 ± 0.01	84 ± 2.33 ^{cb}
	IV	9.07 ± 0.03	26.2 ± 0.08	1751 ± 1.53 ^{dB}	1470 ± 0.26 ^d	121.8 ± 0.06 ^{bcd}	44 ± 0.00 ^{bdAB}	10 ± 0.02 ^{cdB}	8.3 ± 0.06	42 ± 1.61 ^{adB}
3	I	9.41 ± 0.30	29.9 ± 0.12	1606 ± 1.21 ^{aAB}	1530 ± 0.09 ^{aC}	120 ± 0.00 ^c	60 ± 0.09 ^a	14 ± 0.09 ^{aC}	11.2 ± 0.04 ^a	26 ± 1.43 ^{aBC}
	II	9.70 ± 0.10	30.4 ± 0.21 ^a	2127 ± 0.98 ^{bc}	1490 ± 0.21 ^{bbC}	100 ± 0.02 ^a	47 ± 0.07 ^{bbC}	20 ± 0.01 ^{bAC}	6.5 ± 0.02 ^b	52 ± 0.98 ^{bbC}
	III	9.83 ± 0.79	27.1 ± 0.12	1406 ± 1.64 ^{cC}	1360 ± 0.13 ^c	100 ± 0.08	63 ± 0.15 ^{acC}	11 ± 0.07 ^c	12.5 ± 0.03 ^{abc}	57 ± 1.53 ^{bcC}
	IV	9.31 ± 0.06	26.6 ± 0.32 ^b	1754 ± 1.16 ^{dB}	1400 ± 0.16 ^d	114 ± 0.02 ^b	40 ± 0.34 ^{bdC}	8.8 ± 0.03 ^{cdC}	7.6 ± 0.09 ^{bd}	36 ± 2.44 ^{dC}
4	I	9.11 ± 0.50	28.7 ± 0.22	1591 ± 1.64 ^{ad}	1320 ± 0.07 ^{ad}	120 ± 0.05 ^{aBD}	64 ± 0.23 ^a	15.2 ± 0.08 ^{aA}	12 ± 0.05 ^a	36.4 ± 0.79 ^{ad}
	II	9.66 ± 0.13	28.1 ± 0.14	1821 ± 0.91 ^{bd}	1514 ± 0.02 ^{bd}	115 ± 0.04	38 ± 0.47 ^{bd}	21 ± 0.05 ^{bbD}	4 ± 0.00 ^{bc}	52 ± 2.43 ^{bd}
	III	9.77 ± 0.13	29.0 ± 0.91	1822 ± 2.12 ^{beBD}	1510 ± 0.43 ^c	115 ± 0.03	72 ± 0.13 ^{cd}	12 ± 0.03 ^c	14 ± 0.14 ^{ac}	84 ± 1.54 ^{cdD}
	IV	9.19 ± 52	26.6 ± 0.11	1820 ± 1.23 ^{bedD}	1482 ± 0.32 ^{ad}	119 ± 0.06 ^b	32 ± 0.32 ^{dd}	8 ± 0.02 ^{cdD}	5.8 ± 0.05 ^{bd}	36 ± 1.43 ^{adCD}

	Nitrate (mg/l)	Do (mg/L)	Saturation (%)	Transparency (cm)	TDS (mg/L)	Salinity (ppt)	Turbidity (A)	Chl A
1	I 1.6 ± 0.02	7.47 ± 1.11	106.4 ± 2.33 ^{aA}	40 ± 0.71 ^{aA}	713 ± 4.23 ^{aA}	0.93 ± 0.01	42.5 ± 2.11 ^{aA}	206 ± 3.70 ^{aA}
	II 2.6 ± 0.01	7.29 ± 0.91	108.8 ± 3.22 ^{abA}	32 ± 0.92 ^{bA}	905 ± 3.76 ^{bA}	0.92 ± 0.02	33.9 ± 1.98 ^b	222.1 ± 3.15 ^b
	III 3.0 ± 0.01	7.01 ± 0.79	102.0 ± 1.99 ^c	12 ± 0.78 ^c	595 ± 5.10 ^c	0.60 ± 0.01 ^A	103.3 ± 1.43 ^c	350.7 ± 2.97 ^{cA}
	IV 4.8 ± 0.04	7.21 ± 1.08	102.6 ± 3.11 ^{cdA}	25 ± 1.33 ^{dA}	860 ± 3.89 ^d	0.86 ± 0.04	29.8 ± 2.33 ^d	156.6 ± 3.06 ^d
2	I 0.4 ± 0.06	7.85 ± 0.69	102.4 ± 2.76 ^{dB}	55 ± 0.44 ^a	692 ± 3.44 ^{aB}	0.91 ± 0.02	35.2 ± 2.05 ^{aB}	189 ± 2.79 ^{aB}
	II 2.8 ± 0.01	7.31 ± 0.88	106.0 ± 3.01 ^{bb}	60 ± 0.21 ^b	912 ± 4.32 ^{bb}	0.92 ± 0.21	29.2 ± 2.42 ^b	183.3 ± 2.88 ^b
	III 1.8 ± 0.04	7.51 ± 1.32	105.1 ± 2.65 ^{bc}	24 ± 0.14 ^c	895 ± 3.76 ^c	0.90 ± 0.08 ^B	34.0 ± 1.87 ^{ac}	259.7 ± 3.16 ^{cb}
	IV 3.1 ± 0.01	6.83 ± 1.08	96.6 ± 3.66 ^{dAB}	50 ± 0.32 ^{dB}	852 ± 2.77 ^d	0.86 ± 0.04	27.4 ± 2.02 ^{bd}	142.3 ± 1.97 ^d
3	I 1.7 ± 0.05a	7.76 ± 0.22	114.3 ± 4.09 ^{cC}	46 ± 0.23 ^{aB}	716 ± 3.26 ^{aC}	0.92 ± 0.10	41.9 ± 1.77 ^{aAC}	179 ± 2.87 ^{aC}
	II 3.3 ± 0.07ad	7.88 ± 0.98	117.1 ± 1.44 ^{bc}	29 ± 0.09 ^{bb}	924 ± 3.65 ^{bc}	0.93 ± 0.06	30.1 ± 2.31 ^b	157.6 ± 2.72 ^b
	III 4.0 ± 0.06ad	6.98 ± 1.33	100.0 ± 4.11 ^c	14 ± 0.21 ^c	664 ± 4.33 ^c	0.66 ± 0.14 ^C	60.0 ± 1.97 ^{BC}	286.7 ± 3.11 ^{cC}
	IV 4.5 ± 0.00d	6.83 ± 1.45	96.9 ± 2.32 ^{AdC}	35 ± 0.11 ^{dAC}	852 ± 3.22 ^d	0.86 ± 0.05	25.59 ± 2.03 ^d	124.3 ± 2.18 ^d
4	I 1.4 ± 0.02	8.33 ± 0.92 ^a	122.4 ± 1.44 ^{AD}	40 ± 0.78 ^{aACD}	902 ± 3.11 ^{ad}	0.91 ± 0.06	38.61 ± 2.17 ^{ad}	232.7 ± 3.21 ^{ad}
	II 3.1 ± 0.03	8.86 ± 0.77 ^b	132.7 ± 2.22 ^{BD}	32 ± 0.72 ^{bAD}	918 ± 4.13 ^{bd}	0.92 ± 0.07	36.0 ± 1.75 ^b	235 ± 2.99 ^{ab}
	III 3.2 ± 0.01	5.96 ± 1.04 ^c	93.7 ± 3.09 ^c	17 ± 0.32 ^c	787 ± 3.54 ^c	0.80 ± 0.12 ^{AD}	62.0 ± 1.05 ^{cd}	370.1 ± 3.63 ^{cd}
	IV 3.9 ± 0.05	5.24 ± 0.85 ^{cd}	74.5 ± 2.20 ^{db}	20 ± 0.21 ^{dACD}	868 ± 3.47 ^d	0.87 ± 0.09	26.9 ± 1.44 ^d	138.6 ± 1.67 ^d

Physicochemical variables represented as arithmetic mean ± standard deviation.

a, b, c, d Means within a column followed by the same superscripts are not significantly different among the sampling sites.

A, B, C, D Means within a column followed by the same superscripts are not significantly different among the sampling seasons.

Fig. 2. Seasonal relative abundance of phytoplankton in Lake Chamo 2013-2014.

2.5 Statistical analysis

One-way ANOVA followed by Tukey's honest significant differences test was used to compare the spatial and temporal variation in phytoplankton diversity and physicochemical parameters, and partial correlation analysis was performed with SPSS (IBM®SPSS Statistics ver. 20, New York, USA). PAST programme, Hammer et al. (2001), was used to run Simpson's index, Shannon equitability index, species diversity (Shannon's index, H'), Margalef's Species Diversity (d) (Magurran, 2004) and evenness (Pileou's index, J) in evaluating phytoplankton community structure.

3 Results

3.1 Physicochemical characteristics of Lake Chamo

Water pH ranged from 8.87 ± 0.25 (Mean $\pm$ SD) in autumn (site 1) to 9.83 ± 0.79 in summer (site 3). Significant differences in pH were observed across different seasons at site 1 (Tab. 1). Water temperature was highest (30.4 ± 0.21 °C) in spring 2014 at site 3 and lowest 26.0 ± 0.12 °C during summer 2014 at site 2. The mean value of transparency ranged from 12 ± 0.78 cm during summer (site 1) to a 60 ± 0.21 cm in spring 2014 (site 2), and significant differences were also observed across the different seasons and sampling sites. Dissolved oxygen concentrations decreased in summer and autumn, while increased in winter and spring. Transparency remained very low during the rainy season due to increased turbidity. The mean value of electrical conductivity ranged from

1253 ± 1.24 ms/cm at site 1 in the summer to 2127 ± 0.98 ms/cm during spring at site 3.

The mean value of TDS ranged from 595 ± 5.10 mg/L at site 1 during summer to 924 ± 3.65 mg/L at site 3 during spring (Tab. 1). There was significant variation in the value of TDS among the sampling sites and between the seasons ($p < 0.05$), site 1 having significantly higher value than site 1 and 3. The mean value of TDS at summer season is significantly lower than all the other seasons. The mean value of salinity ranged from 0.6 ± 0.01 ppt at site 1 during summer to 0.93 ± 0.08 ppt at site 3 during spring season and there was not significant variation in the value of salinity among the sampling sites and seasons ($p < 0.05$).

3.2 Phytoplankton species composition and abundance

A total of 18 genera belonging to four different taxonomic groups were identified (Tab. 4). The three groups, Cyanophyta, Chlorophyta and Bacillariophyta accounted 96% of the total phytoplankton abundance (Fig. 2). Cyanophyta was the most abundant group representing 46.35% of the total abundance, whilst Chlorophyta (blue green algae) had the highest number of genera, and represented 34.06% of the total abundance. Bacillariophyta (Diatoms) represented 18.42% of the total abundance split between genera. Euglenophyta was the least represented group with only 1.17% of the total.

Phytoplankton species composition and abundance in Lake Chamo showed variation across different seasons and sampling sites during the study period (Fig. 3). During the

Fig. 3. Seasonal phytoplankton composition in Lake Chamo 2013-2014.

dry and rainy season, Cyanophyta was the dominant group, followed by Bacillariophyta and Chlorophyta. Dense phytoplankton populations developed during winter and autumn seasons, immediately after the rainy season. *Anabaena*, *Microcystis* and *Scenedesmus* species dominated the lake during autumn and winter seasons. Among the Bacillariophyta, *Cyclotella* and *Amphora* species were the most abundant during the pre and post rainy season in all sites. Of the Chlorophyta, *Pediastrum*, *Scenedesmus* and *Closterium* species showed the highest abundance during the rainy seasons (July to September). Overall, the four seasons exhibit different phytoplankton species composition across different sites.

3.3 Diversity indices of phytoplankton across different sampling sites of Lake Chamo

The highest Shannon-Wiener's diversity index ($H' = 2.58 \pm 0.14$) was recorded at site 4 during winter 2013/14 season, while the lowest ($H' = 1.79 \pm 0.08$) was recorded at site 2 during autumn 2014 (Tab. 2). Margalefs Species Diversity (d) was highest (2.37 ± 0.27) during autumn at site 1 and lowest at site 2 (1.53 ± 0.01) during winter 2013/14. Highest and lowest Simpsons' index ($1/D$) of 10.44 ± 0.06 and 2.91 ± 0.23 were recorded at site 4 and site 2, during winter and autumn respectively. Species Evenness was lowest (0.58 ± 0.04) at site 2 during autumn and highest (0.83 ± 0.06) was recorded at site 4 during spring season. The diversity was high during winter season in all sites.

3.4 Correlation analysis of phytoplankton group with some environmental factors

The results of the partial correlation analysis showed the average Cyanophyta count was positively and non-significantly ($p > 0.05$) correlated with the water temperature and turbidity of the lake (Tab. 3). However, total nitrogen positively and significantly correlated with Cyanophyta count. Positive and significant correlation was also observed between Chlorophyta count and the water temperature of the lake. A non-significant and negative correlation was found between water temperature and, Euglenophyta and Bacillariophyta counts. Total dissolved solids also showed non-significant and positive correlation with these counts.

4 Discussion

4.1 Physicochemical and phytoplankton conditions

Our current understanding of the seasonal and spatial variation of phytoplankton with environmental factors is insufficient in Lake Chamo. Seasonal variations in phytoplankton are related to a variety of environmental factors in aquatic environments (Cetin and Sen, 2004). Water temperature and transparency are among the most important physical factors affecting the distribution and seasonal variations of phytoplankton (Mosisch et al., 1999). During the study period Lake Chamo water temperature varied between 26.0 ± 0.12 °C to 30.4 ± 0.21 °C. This value is a little higher to the reported

Table 2. Diversity indices measurement of phytoplankton in Lake Chamo during winter 2013/14 (season I), spring 2014 (season II), summer 2014 (season III), and autumn 2014 (season IV).

Season	Site	d	1/D	H1	E
Winter 2013/14	1	2.19 ± 0.13	8.18 ± 0.73A	2.44 ± 0.05	0.78 ± 0.00
	2	1.53 ± 0.01	7.57 ± 0.69A	2.25 ± 0.02	0.81 ± 0.03
	3	2.06 ± 0.23	9.08 ± 0.72A	2.51 ± 0.08	0.81 ± 0.04
	4	2.16 ± 0.24	10.44 ± 0.06A	2.58 ± 0.14	0.82 ± 0.05
Spring 2014	1	1.98 ± 0.04	7.89 ± 0.22aAB	2.35 ± 0.09	0.79 ± 0.00
	2	1.62 ± 0.14	4.83 ± 0.43bB	2.05 ± 0.16	0.74 ± 0.03
	3	2.34 ± 0.26	8.50 ± 0.87acAB	2.48 ± 0.08	0.79 ± 0.07
	4	1.79 ± 0.08	8.18 ± 0.63acdB	2.41 ± 0.07	0.83 ± 0.06
Summer 2014	1	2.09 ± 0.06	6.79 ± 0.11ABC	2.39 ± 0.06	0.78 ± 0.04
	2	2.01 ± 0.04	5.37 ± 0.85BC	2.14 ± 0.04	0.71 ± 0.05
	3	2.06 ± 0.07	7.69 ± 0.73ABC	2.43 ± 0.14	0.79 ± 0.02
	4	2.19 ± 0.11	6.89 ± 0.38BC	2.35 ± 0.09	0.76 ± 0.01
Autumn 2014	1	2.37 ± 0.27	3.28 ± 0.22BD	1.97 ± 0.12	0.62 ± 0.06
	2	2.16 ± 0.31	2.91 ± 0.23CD	1.79 ± 0.08	0.58 ± 0.04
	3	2.25 ± 0.09	3.77 ± 0.21D	2.04 ± 0.13	0.65 ± 0.03
	4	2.14 ± 0.14	4.19 ± 0.13D	2.13 ± 0.91	0.69 ± 0.04

a,b,c,d Means within a column followed by the same superscripts are not significantly different among the sampling sites.

A, B, C, D Means within a column followed by the same superscripts are not significantly different among the sampling seasons.

Table 3. Correlation coefficients found by a partial correlation analysis of phytoplankton group (average count) and various environmental factors in Lake Chamo 2013-2014/15.

	Cyanophyta	Chlorophyta	Euglenophyta	Bacillariophyta
Temp. (°C)	0.89	0.94*	-0.94	-0.95
DO	-0.51	-0.07	0.40	0.36
Transparency	-0.99	-0.81	0.96	0.94
TDS	-0.73	-0.96	0.81	0.83
Turbidity	0.96	0.73	-0.91	-0.89
Total nitrogen	0.99*	0.83	-0.97	-0.96

* Denotes $p < 0.05$ (two-tailed).

values of other Ethiopian Rift Valley Lakes, such as Abijata and Langano 18–27 °C (Kebede et al., 1994; Kumssa and Bekele, 2013); Lakes Ziway 18.5–27.5 °C (Girma, 1988); and Hawassa 20.98–21.33 °C (Abate et al., 2015). The change in water temperature of Lake Chamo affects the phytoplankton diversity and abundance. This result was in agreement with the reports of Richardson et al. (2000) and Lund (1965), in fresh water ecosystem water temperature strongly regulates seasonal variations of phytoplankton. The increase in phytoplankton diversity and abundance during winter and spring seasons in Lake Chamo could also be a result of the increasing water temperature. Similar reports also showed that water temperature of Lake Chamo varied among seasons (Tafa and Assefa, 2014). According to their findings, the water temperature of Lake Chamo increased in January due to the increase in air temperature. Except for site 1 (mouth of *Kulfo river*), the pH values were not significantly different in all seasons. The pH values recorded in this study were comparable with the results obtained by other researchers, (8.53–9.44) in the same lake (Eyasu, 2004; Tafa and Assefa, 2014; Lemma and Desta,

2016). The pH values were relatively low during the rainy seasons, which may be attributed to the decomposition of organic matter (Tafa and Assefa, 2014). However, the pH values increased after the rainy season. This relatively increases the photosynthetic activities of phytoplankton.

The TDS values of Lake Chamo (924 ± 3.651 to 595 ± 5.10 mg/L) were higher than Lake Hawassa 455.6 mg/L (Abate et al., 2015). But this value is far less than the nearby rift valley lake, Lake Abaya reported a value of 1,522.45 mg/L (Huib and Herco, 2006). This was mainly attributed to the high rate of evaporation and consequent reduction in the water level during spring.

Salinity of Lake Chamo considered to be one of the main factor responsible for the deterioration of the environmental conditions of Lake Chamo and the drop in its phytoplankton and fish diversity (Tafa and Assefa, 2014; Lemma and Desta, 2016). The minimum salinity recorded was 0.6 ± 0.01 ppt at site 1 during summer and the maximum was 0.93 ± 0.08 ppt at site 3 during spring season. The highest salinity during spring season was attributed to the high rate of evaporation in the

region, while the lowest may be due to the effect of dilution arises from drainage water from *Kulfo*, *Sile* and other rivers during the rainy summer season (Tafa and Assefa, 2014).

Phytoplankton species composition in this study showed a decline at the onset of the rainy season (summer) which corresponded to increased dilution and water turbidity. This result is comparable to the study conducted on Lake Tana (Wondie et al., 2007), who reported that phytoplankton biomass declined during the rainy season as a result of increased turbidity. According to this study the phytoplankton community of Lake Chamo consisted of mainly of Cyanophyta, Chlorophyta, Bacillariophyta and Euglenophyta groups. In line with this, (Golubtsov and Habteselassie, 2010), reported Cyanophyta, Chlorophyta and Bacillariophyta being the main phytoplankton groups in Lake Chamo. The seasonal diversity and abundance of phytoplankton in Lake Chamo is mainly related with the range of physicochemical parameters such as temperature, salinity, alkalinity, nitrate-nitrogen and phosphate. The observed variation in plankton species dominance during the study may be attributed to variations in the optimal conditions for the various species (Jiang et al., 2014; Lemma and Desta, 2016). The variations in phytoplankton cell count across different season have also been reported in other Ethiopian rift valley lakes. For example, Kumssa and Bekele (2013) showed that there were marked variations in phytoplankton population in the Abijata Shalla Ethiopian rift valley lake, apparently due to differences in water quality. The finding of this study also showed that Lake Chamo was dominated by Cyanophyta with noticeable changes between seasons. The phytoplankton population changes were characterized by dominance shifts between Cyanophyta and Chlorophyta. The most abundant Cyanophyta was *Anabaena* sp during autumn and winter, while the dominant Chlorophyta during these seasons were *Scenedesmus*, *Cosmarium* and *Pediastrum* species. Of the Bacillariophyta *Cyclotella* and *Amphora* species were the most abundant during the dry winter season. Moreover, the highest Shannon-Wiener's diversity index was recorded during the dry winter season, while the lowest was recorded during autumn. This finding agrees with (Jiang et al., 2014), who reported Lake Chaohu was inhabited by different phytoplankton species and dominated by *Microcystis viridis*, *Microcystis flos-aquae*, and *Anabaena circinalis*. These results are also in agreement with Kumssa and Bekele (2013) and Tewodros and Afework (2014), who reported that *Bacillariophyta* were more dominant during the dry season, especially *Cyclotella* and *Navicula* species dominated Abijata- Shalla Lakes (Tab. 2).

5 Conclusion

In this study, a total of 18 genera belonging to four different taxonomic groups were identified, among which Cyanophyta, Chlorophyta and Bacillariophyta accounted 96% of the total phytoplankton abundance. Cyanophyta was the most abundant group representing 46.35% of the total abundance, whilst Chlorophyta had the highest number of genera, and represented 34.06% of the total abundance. Euglenophyta was the least abundant group in the study period. The four seasons exhibit different phytoplankton species composition across different sites, but the overall species diversity was high during winter season in all sampling sites. Moreover, positive

and significant correlation was observed between Chlorophyta count and water temperature of the lake. The mean Cyanophyta count was also positively and non-significantly correlated with water temperature and turbidity of the lake. A non-significant and negative correlation was found between water temperature and, Euglenophyta and Bacillariophyta counts.

References

- Abate B, Woldeesenbet A, Fitamo D. 2015. Water quality assessment of lake hawassa for multiple designated water uses. *Water Util J* 9: 47–60.
- APHA. 2005. Standard methods nonalcoholic beverages, 18th ed, American Water Works Association and Water Pollution Control Federation, New York.
- Archibald REM. 1972. Diversity in some South African diatom associations and its relation to water quality. *Water Res* 6: 1229–1238, doi:10.1016/0043-1354(72)90023-1.
- Ariyadej C, Tansakul R, Tansakul P, Angsupanich S. 2004. Phytoplankton diversity and its relationships to the physico-chemical environment in the Banglang reservoir, Yala Province. *Songklanakarin J Sci Technol* 26: 596–607.
- Cetin AK, Sen B. 2004. Seasonal distribution of Phytoplankton in Orduzu dam lake. *Turk J Bot* 28: 279–285.
- Desikachary TV. 1959. Cyanophyta. New Delhi, India: ICAR.
- Eyasu S. The temporal and spatial variations in the biomass and photosynthetic production of Phytoplankton in relation to some physico- chemical variables in lake Chamo, Addis Ababa University, Addis Ababa, 2004.
- Girma T. A seasonal study on primary production in relation to light and nutrients in lake Ziway, Addis Ababa University, Ethiopia, 1988.
- Golubtsov AS, Habteselassie R. 2010. Fish faunas of the Chamo-Abaya and Chew Bahir Basins in Southern portion of the Ethiopian Rift Valley: origin and prospects for survival. *Aquat Ecosyst Health Manag* 13: 47–55, doi:10.1080/14634980903578506.
- Hailemicael A, Raju AJS. 2010. Challenges and opportunities of Chamo Lake-Wetland biodiversity, *Ethiopia* 22: 223–233.
- Huib H, Herco J. Ecosystems for water, food and economic development in the Ethiopian Central Rift Valley (BO-10-006-22), Wageningen, The Netherlands, 2006.
- Jagadeeshappa KC, Kumara V. 2013. Influence of physico-chemical parameters on the diversity of Plankton species in Wetlands of Tiptur Taluk, Tumkur Dist, Karnataka State, India. *Carib J Sci Tech* 1: 185–193. <http://caribjscitech.com/>.
- Jenkerson CG, Hickman M. 2007. Interrelationship among the Epipelton, Epiphyton and Phytoplankton in a Entrophic Lake. *Int Reve Dev Gesamten Hydrobiol Hychrograp* 71: 557–579.
- Jiang YJ, He W, Liu WX, Qin N, Ouyang HL, Wang QM, Kong XZ et al., 2014. The seasonal and spatial variations of phytoplankton community and their correlation with environmental factors in a large Eutrophic Chinese Lake (Lake Chaohu). *Ecol Indic* 40: 58–67, doi:10.1016/j.ecolind.2014.01.006.
- Kebede E, Mariam ZG, Ahlgren I. 1994. The Ethiopian Rift Valley Lakes: chemical characteristics of a salinity-alkalinity series. *Hydrobiologia* 288: 1–12, doi:10.1007/BF00006801.
- Kumssa T, Bekele A. 2013. Phytoplankton composition and parameters study in water bodies of Abijata – Shalla Lakes National Park (ASLNP), Ethiopia. *Greener J Biol Sci* 4: 68–76.

- Lemma B, Desta H. 2016. Review of the natural conditions and anthropogenic threats to the Ethiopian rift valley rivers and lakes. *Lakes Reserv: Res Manag* 21: 133–51, doi:[10.1111/lre.12126](https://doi.org/10.1111/lre.12126).
- Lund JWG. 1965. The ecology of the freshwater Phytoplankton. *Biol Rev* 40: 231–293.
- Magurran AE. Ecological diversity and its measurement, Princeton university press, New Jersey, 2004.
- Mosisch TD, Bunn SE, Davies PM, Marshall CJ. 1999. Effects of shade and nutrient manipulation on Periphyton growth in a Subtropical stream. *Aquat Bot* 64: 167–177, doi:[10.1016/S0304-3770\(99\)00014-5](https://doi.org/10.1016/S0304-3770(99)00014-5).
- Nasser KMM, Sureshkumar S. 2014. Seasonal variation and biodiversity of Phytoplankton in Parambikulam Reservoir, Western Ghats, Kerala. *Int Jpure Appl Biosci* 2: 272–280.
- Philipose MT. 1962. Chlorococcales, ICAR, New Delhi.
- Prescott GW. 1982. Algae of the western great lakes area, Otto Kaetz Science publishers, W. German.
- Richardson TL, Gibson CE, Heaney SI. 2000. Temperature, growth and seasonal succession of Phytoplankton in Lake Baikal, Siberia. *Freshw Biol* 44: 431–440, doi:[10.1046/j.1365-2427.2000.00581.x](https://doi.org/10.1046/j.1365-2427.2000.00581.x).
- Rothhaupt KO. 2000. Plankton population dynamics: food web interactions and biotic constraints. *Freshw Biol* 45: 105–109.
- Sarode PT, Kamath ND. Fresh water Diatoms of Maharastra, Saikrupa Prakashan, Aurangabad, 1984.
- Shashi S, Kiran B, Puttaiah E, Shivaraj Y, Mahadevan M. 2008. Phytoplankton as index of water quality with reference to industrial pollution. *J Environ Biol* 29: 233–236.
- Siddaraju, Deviprasad AG. 2012. Distribution and diversity of Phytoplankton in two lakes of Mandya. *Natl Mon Refereed JResSciTechnol* 1: 23. http://www.abhinavjournal.com/images/Science_&_Technology/Jun12/2.pdf.
- Sorokin DY, Berben T, Melton ED, Overmars L, Vavourakis CD, Muyzer G. 2014. Microbial diversity and biogeochemical cycling in Soda lakes. *Extremophiles* 18: 791–809, doi:[10.1007/s00792-014-0670-9](https://doi.org/10.1007/s00792-014-0670-9).
- Tafa B, Assefa E. 2014. Detection of Copper and Zinc (Heavy Metals) in water of Lake Chamo, Arbaminch Ethiopia. *World J Chemical Educ* 2: 42–47, doi:[10.12691/WJCE-2-3-3](https://doi.org/10.12691/WJCE-2-3-3).
- WarwickRM. 1992. Ecological diversity and its measurement, in: Anne E. Magurran (Ed.), Chapman and Hall, London, Second Edition (Paperback), 1991, pp. 179, GBP 13.95; ISBN 0-412-38330-6 (Paperback), Journal of experimental marine biology and ecology 159 (2), Elsevier: 279–80, doi:[10.1016/0022-0981\(92\)90042-9](https://doi.org/10.1016/0022-0981(92)90042-9).
- Washington HG. 1984. Diversity, biotic and similarity indices: a review with special relevance to aquatic ecosystems. *Water Res* 18: 653–694.
- Welch PS. Limnological methods, Revista Europea de Estudios Latinoamericanos Y Del Caribe, Mc hill Book Company, New York, 1948.
- Willén E, Ahlgren G, Tilahun G. 2011. Cyanotoxin production in seven Ethiopian Rift Valley lakes. *Inland Waters* 1 (Steyn 1945): 81–91, doi:[10.5268/IW-1.2.391](https://doi.org/10.5268/IW-1.2.391).
- Wondie A, Seyoum A, Ae M, Vijverberg J, Dejen E. 2007. Seasonal variation in primary production of a large high altitude Tropical lake (lake Tana, Ethiopia): effects of nutrient availability and water transparency. *Aquat Ecol* 41: 195–207, doi:[10.1007/s10452-007-9080-8](https://doi.org/10.1007/s10452-007-9080-8).
- Xu F-L, Jørgensen SE, Tao S. 1999. Ecological indicators for assessing freshwater ecosystem health. *Ecol Model* 116: 77–106.

Cite this article as: Fekadu A, Chanie S. 2017. A seasonal study on phytoplankton diversity and dynamics of Lake Chamo, Ethiopia. *Aquat. Living Resour.* 30: 40

Appendix

Table 4. Phytoplankton dynamics across different seasons (number of cells/mL).

Phytoplankton	Winter – 2013/14(Dec, Jan, Feb)				Spring 2014(Mar, Apr, May)				Summer 2014(Jun, Jul, Aug)				Autumn 2014(Sep, Oct, Nov)			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
CYANOPHYTA																
<i>Microcystis Sp.</i>	180	0	140	100	0	0	0	0	432	1765	976	1344	297	1883	1335	1571
<i>Anabaena Sp.</i>	120	500	760	240	72	37	62	44	3245	2745	3372	2431	1322	733	1212	533
<i>Merismopedia sp.</i>	240	0	500	140	42	26	113	78	566	317	623	436	314	148	547	254
<i>Cylindrocapsa sp.</i>	1180	2800	3340	2240	214	0	152	0	0	0	0	0	500	433	100	567
<i>Pseudanabaena sp.</i>	3700	3200	5400	5000	1321	1194	2423	1929	3940	4310	4102	4200	8833	9400	8767	8500
Sub Total	5420	6500	10140	7720	1649	1257	2750	2051	8183	9137	9073	8411	11266	12597	11961	11425
CHLOROPHYTA																
<i>Oocystis Spp.</i>	640	900	2500	1240	154	0	345	163	243	0	177	79	267	0	167	133
<i>Pediastrum sp.</i>	20	200	60	200	15	166	107	142	414	323	437	268	677	459	717	552
<i>Scenedesmus granulatus</i>	240	200	260	740	124	94	175	422	233	184	318	413	512	377	631	948
<i>Scenedesmus quadricauda</i>	1300	700	1860	2400	664	365	775	842	992	243	432	177	940	442	1232	1783
<i>Scenedesmus denticulatus</i>	400	0	940	1040	66	0	176	388	817	234	1342	1540	221	443	342	573
<i>Scenedesmus acuminatus</i>	80	0	140	100	0	0	40	24	444	226	378	456	235	171	236	321
<i>Scenedesmus bicaudatus</i>	280	0	440	40	76	0	213	0	589	789	951	258	274	376	449	213
<i>Scenedesmus platydiscus</i>	0	0	160	100	0	0	24	0	344	287	436	378	74	68	209	265
<i>Scenedesmus armatus</i>	80	0	0	0	34	0	18	0	144	133	244	67	84	21	17	10
<i>Cosmarium Sp.</i>	1880	2200	4260	3200	655	398	816	505	14	0	18	0	33	0	67	33
<i>Pediastrum tetras</i>	80	100	400	340	0	46	126	115	320	462	932	789	288	323	725	611
<i>Ankistrodesmus sp.</i>	80	0	0	0	0	0	0	0	407	256	419	306	67	33	67	0
<i>Closterium sp.</i>	980	700	1700	1900	466	321	720	801	215	174	206	96	442	524	317	322
<i>Dictyosphaerium sp.</i>	180	0	600	500	0	74	83	0	360	216	761	778	213	107	168	233
Sub Total	6240	5000	13320	11800	2254	1464	3618	3402	5536	3527	7051	5605	4327	3344	5344	5997
EUGLENOPHYTA																
<i>Euglena sp.</i>	0	200	0	1400	221	369	178	541	0	0	0	0	67	33	0	0
Sub-total	0	200	0	1400	221	369	178	541	0	0	0	0	67	33	0	0
BACILLARIOPHYTA																
<i>Cyclotella Sp</i>	1600	3700	1740	2300	1987	4230	2482	3456	323	47	26	214	567	67	33	367
<i>Amphora sp.</i>	1002	1700	460	3000	514	720	356	1230	69	0	0	24	0	0	0	0
<i>Navicula sp.</i>	20	100	60	240	619	694	857	714	0	27	14	42	17	117	87	312
<i>Melosira Sp.</i>	240	124	500	140	1623	870	1442	1249	98	76	212	45	169	221	317	111
<i>Nitzschia Sp.</i>	0	500	260	400	122	757	438	866	0	26	0	44	56	166	73	231
Sub total	2862	6124	3020	6080	4865	7271	5575	7515	490	176	252	369	809	571	510	1021
Total No of individuals	14,522	17824	26480	27000	8989	10361	12121	13,509	14209	12840	16,376	14385	16469	16545	17,815	18443