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SCHOOL OF GRADUATE STUDIES

A SEASONAL STUDY ON THE SPECIES COMPOSITION AND PHYTOPLANKTON BIOMASS IN LAKE ZIWAY, ETHIOPIA

TSEGAYE MIHERET-AB

JUNE, 1988

A SEASONAL STUDY ON THE SPECIES COMPOSITION

AND

PHYTOPLANKTON BIOMASS

IN LAKE ZIWAY, ETHIOPIA

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TSEGAYE MIHERETE-AB

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Abstract

Species composition, seasonal variations in species composition and biomass of phytoplankton in Lake Ziway, a large (ca.442km^2) but shallow (Zm = 2.5m), brown water lake, was studied from 8-III-87 to 26-II-88.

In total 122 phytoplankton species were identified from net and sedimented samples. Identification of phytoplankton species from sedimented samples was done to ensure inclusion of small plankton organisms (<25 m) that may pass though the net(25 m mesh-size) that was used for routine sampling.

There were three major groups of phytoplankton, Cyanophyceae (blue-green algae), Bacillariophyceae (diatoms) and chlorophyceae (green algae).

The Cyanophyceae was represented by 50 species. This was followed by Chlorophyceae with 41 species and the Bacillariophyceae with 31 species.

The community biomass was dominated by blue-green algae which composed 63% of the total mean annual biomass. Diatoms made up about 22% of the mean annual biomass and the green algae contributed only 15% to the total mean annual biomass.

The phytoplankton species of qualitative and quantitative importance were *Lyngbya limnetica* Lemm, *Microcystis, aeruginosa* (kg) G.M. Smith and *Synechococcus elongatus* Nageli (blue green algae), *Melosira granulata*

(Ehr.) Ralfs, *Navicula* spp. and *Surirella* spp. (diatoms), and *Staurastrum leptocladum* Nordst and *Pediastrum b ry num* (Turp.) Menegh (green algae).

The mean monthly total biomass ranged from 79.10^3 to 349.10^3 mg.$^{m-3}$ while chlorophyll a concentration varied between 154 and 212 mg.m^{-3}. There were two peaks in total phytoplankton biomass one occurred in April (329.10^3 mg.m^{-3}) and one in August (349.10^3 mg.m^{-3}).

Peaks of blue-green algae occurred in August (220.10^3 mg m^{-3}) and in November (204.10^3 mg.m^{-3}). Diatom maxima occurred in April (177.10^3 mg.m^{-3}) and in August (73.10^3 mg.m^{-3}), and green algae remained at lower levels in biomass for much of the study period. There were two peaks in green algae which occurred in November and February, at these times green algae biomass was higher than that of diatoms.

The chlorophyll content (ratio between Chl a and biomass.100) was low. It ranged from 0.05 to 0.24%, with higher values in March and July, at which times the biomass was dominated by diatoms. A general trend of decreasing chlorophyll content with increasing blue-green biomass was observed.

Seasonal fluctuations in chlorophyll a and biomass and related chemical-physical parameters were least pronounced. Seasonal variations expressed interms of coefficient of variation (CV, standard deviation/mean-100) were higher for total biomass (cv = 43%) and lower for chlorophyll a (CV = 10.1%).

Amplitude of seasonal variation interms of the $\log_{10}$ of seasonal biomass maxima/minima gave values of 0.14 and 0.67 for chlorophylla & total biomass respectively. These values were lesser than the values for some component species eg. Pediastrum (2.67), Navicula (2.05) and Surirella (2.08).

For the major groups, the amplitude of seasonal variation was the highest for green algae (1.26) followed by diatoms (1.25) and blue green algae (0.81).

CHAPTER 1

INTRODUCTION

Ethiopia has a substantial area ca.7000km^2, of fresh water lakes (Tedla, 1973). The lakes are scattered over a range of altitudes and latitudes.

A review of all the literature (eg. Wood & Talling, 1988; Belay. (in press) reveals that there is fairly a large amount of information on various limnological features of Ethiopian lakes. The current increasing number of limnological contributions by Ethiopian nationals in the Addis Ababa University eg. Getachew Tefera (1980, 1987a,b), Tedla (1973), Belay and Wood (1982), Kassahun Wodajo (1982), Kassahun Wodajo and Amha Belay (1984), Demeke Kifle (1985), Tilahun Kibret (1985), Elizabeth Kebede (1987) are signs of increasing awareness of these and other Ethiopians in this field.

Nevertheless, considering the large number of lakes and variety of conditions, sustained and systematic limnological studies on any of the Ethiopian lakes have not been done except for a few studies limited to a small number of lakes eg. L. Awassa (Demeke Kifle, 1985; Elizabeth Kebede, 1987; Getachew Teferra, 1987) and Lakes Abijata & Langano (Kassahun Wodajo, 1982).

A few other studies lasting about one year on the Ethiopian lakes, include the following on the Bishoftu Crater lakes; seasonal changes in thermal characteristics (Wood et al., 1976), and the aspects of stratification (Baxter *et al.*, 1965).

Because of their proximity to the capital, Addis Ababa, only 45km away, the Bishoftu Crater lakes have become the subject of a number of limnological studies. They have in fact received more attention than any other lakes in the country.

A detailed bathymetric survey of the Bishoftu crater lakes was done by Prosser *et al.* (1968). These authors have also provided basic chemical background information. Phytoplankton photosynthetic productivity (Talling *et al.*, 1973) and geology (Mohr, 1961) of these lakes are available. According to Mohr (1961), the Bishoftu Crater lakes, a group of five lakes, were formed by volcanic explosions about 7000 years ago.

The Rift Valley lakes of Ethiopia in the Ziway-Shalla basin, to which the study lake, L. Ziway belongs, have also been a subject of recent studies related to varying interests, fisheries development (Getaneh & Getaneh, 1979; Getachew Teferra, 1987a; Schroder, 1984), irrigation and agricultural development (Makin *et al.*, 1975), hydroelectric & geothermal development (UN, 1973) and geological and mineralogical explorations (Di Poda, 1972).

The limnological aspects of these studies are of interest to this paper. The earliest records on the northernmost Rift valley lakes of Ethiopia were those for L. Ziway. They were made in 1528 by the missionary Manoel de Almedia. The details of these documentations are found in Grove *et al* (1975).

Limnological investigations on the Ethiopian Rift Valley lakes involving Italian workers (Eg. Loffredo & Maldura, 1941) are some of the earliest documentations and are of paramount importance. These are still considered as the bench-mark descriptions in Ethiopian limnology. Nevertheless, these were limited to descriptions of some aspects of morphometry, bathymetry and some chemical-physical & biological observations.

For Lake Ziway various limnological features are described in the works of Cannicci & Almagin (1947) and Loffredo & Moldura (1941). The bathymetric map of L. Ziway was surveyed by Morandini (1942) and is available with maps of other Rift Valley lakes, L. Abaya (Riedel, 1962), and Lakes Shalla, Abijata & Langano (Baxter et al., 1965).

More recent information is available for L. Ziway concerning its, hydrology (Makin et al, 1975), geology (Mohr, 1962,1971; Di Paola, 1972), former lake level (Grove et al., 1975); Gasse & Street, 1978), Chemistry (Talling & Talling, 1965) & Climatology (Daniel Gamachu, 1977). Belay & Wood (1984) provided data on the primary productivity of L. Ziway with some comments on its light climate. These authors also compared L. Ziway with nearby lakes vis-avis its productivity. Other workers (Wood & Prosser, 1976) dealt with the optical characteristics of L. Ziway, together with the lakes in the Ziway-Shalla basin. These authors made assessments of fish production in these 4 lakes; L. Shalla, L. Langano, L. Abijata & L. Ziway using the morphoedaphic index (MEI, ratio between total dissolved solutes and mean depth, Zm). Their results indicate that L. Ziway has the highest fish stock (MEI = 150) next to L. Abijata (MEI = 900). The lowest value (MEI = 80) was that obtained for L. Langano.

Studies regarding the fisheries aspect of Ethiopian inland waters are scarse inspite of the mounting demand for protein- foods and the general food shortage in the country. The available studies concerning fisheries development of L. Ziway are those of Getaneh and Getaneh (1979) and Schroder (1984). The latter compared the quantitative and qualitative composition of fish in L. Ziway and L. Abaya. Tedla (1973) has also done some general surveys on the fisheries resources of the Ethiopian inland waters. The most recent studies are those of on the fisheries of Ethiopian lakes are those of Getachew Teferra (1987) on L. Ziway and L. Awassa, Tudorancea et al. (1988) on L. Awassa. They made profound study of the herbivorous fish, Oreochromis niloticus L. and its diet, the phytoplankton.

In spite of the large amount of limnological work done over the last 50 years, studies on phytoplankton composition and seasonal changes in species composition and biomass over an extended period of time in the Ethiopian inland waters are lacking (See Elizabeth Kebede, 1987; Kassahun Wodajo, 1982).

Furthermore in tropical African lakes, seasonal studies of phytoplankton composition, biomass and related chemical-physical & biological processes are few and are also recent. There have, however, been some valuable studies done. Talling (1966,1986),Hecky & Kling (1981), Lind (1968) and Ganf (1974a) have studied seasonal changes in phytoplankton composition & biomass on some east African Rift Valley lakes. Others (Ganf, 1975; Melack, 1979a; Allanson & Hart, 1975; Robarts, 1979) have documented data on seasonal variations in phytoplankton primary Production in some smaller lakes in Kenya & Uganda.

Phytoplankton primary production is the base upon which aquatic food chains, culminating in the natural fish populations exploited by man is founded. Furthermore, phytoplankton generates about 70% of the world's oxygen supply (Reynolds, 1984).

Phytoplankton is the basic diet of many herbivorous fish eg. adult Oreochromis niloticus L. in L. Ziway (Getachew Tefera, 1987; Zenebe Tadesse, pers. comm.). In order to understand better the production of fishes, its essential to know about the composition of their food - the phytoplankton.

In addition, excessive phytoplankton production in lakes, and reservoirs present expensive problems of eutrophication in water industries while deleterious effects upon fisheries and water based recreation are often attributable to over abundance of phytoplankton (Reynolds, 1984).

There is, therefore, a substantial economic and social need for the complete understanding, as far as possible, of the factors which regulate the spatial and temporal variations in phytoplankton composition, biomass distribution & related proximal and distal environmental conditions.

Thus, the aim of this work is to contribute to filling the gap in information in the phytoplankton species composition, seasonal changes in species composition and biomass and related chemical-physical characteristics in tropical African lakes in general and Ethiopian lakes in particular. Furthermore, this work is a contribution to the current effort in the documentation of Ethiopian terrestrial & aquatic flora. This paper may also serve as a base-line reference material for further work in other Ethiopian lakes.

CHAPTER 2

THE STUDY AREA

Location

Lake Ziway is the northernmost of the four main Rift Valley Lakes of Ethiopia (Fig. 1), at ca 7° 52' - 8°8' N latitude and ca. 38°55'E longitude. It lies between Shoa and Arsi Administrative Regions about 145 km due south of Addis Ababa, on the Addis-Awassa highway. Selected morphometric, chemical and physical features of this fresh water lake are given in Table 1.

Geology

The lake is one of the lakes known in the old literature as the "Galla Lakes", a group of lakes which still share the same closed internal drainage. The lakes are: Lake Langano, L. Shalla, L. Abijata and the study lake, L. Ziway. In the late Tertiary (Mohr, 1962, 1971; Grove *et al.*, 1971), the Galla Lakes basin was continuous with the Awash River drainage system in the north and with the L. Awassa and L. Abaya in the South. The system thus formed a single lake, Lake Galla (Gasse & Street, 1978; Grove & Goudie, 1971).

The four lakes were latter separated during the Pleistocene period (Gasse & Street, 1978) by volcanic and tectonic activities, shrinkage in Water levels and by upward and downward faulting (Mohr, 1962, 1971).

Lakes Ziway and Abijata lie on a down faulted basin in the rift valley floor while L. Shalla (266masl) occupies a deep volcanic caldera. Lake Ziway is separated from L. Langano by an outcrop from an extinct volcano, mount Alutu(1850masl) in the south. It is separated from L. Abijata (1578masl),

Table 1. Some morphometric, physical and chemical characteristics of L. Ziway.

Morphometry		Physical	Chemistry	
Altitude(masl)	1848[a]	Surface water	Conductivity 372-42[g]	
Surface area(Km^2)	442[b]	temp(°C)22-27[a]	H_2O	
Volume (Km^3)	1.1[a]	water renewal	Na(mgl^{-1})	64[f]
Max-depth(m)	8.95	time(yr)3[c]	K(mgl^{-1})	14[f]
Mean depth(m)	2.4[c]		Ca(mgl^{-1})	10.2[f]
Max-length(km)	32[d]		Mg(mgl^{-1})	9.8[f]
Max-width(km)	20[d]			
Shoreline length(km)	102[d]		HCO_3 + CO_3 (meql	3.92[f]
Catchment area(km^2)	7025[a]		Cl^- (mgl^{-1})	18[f]
			SO_4(mgl^{-1})	2[f]
			SiO_2(mgl^{-1})	47[f]
			Total P	170[f]
			pH	8.99
			TDS(gl^{-1})	0.329

a = Welcomme (1972)

b = Gasse & street(1978)

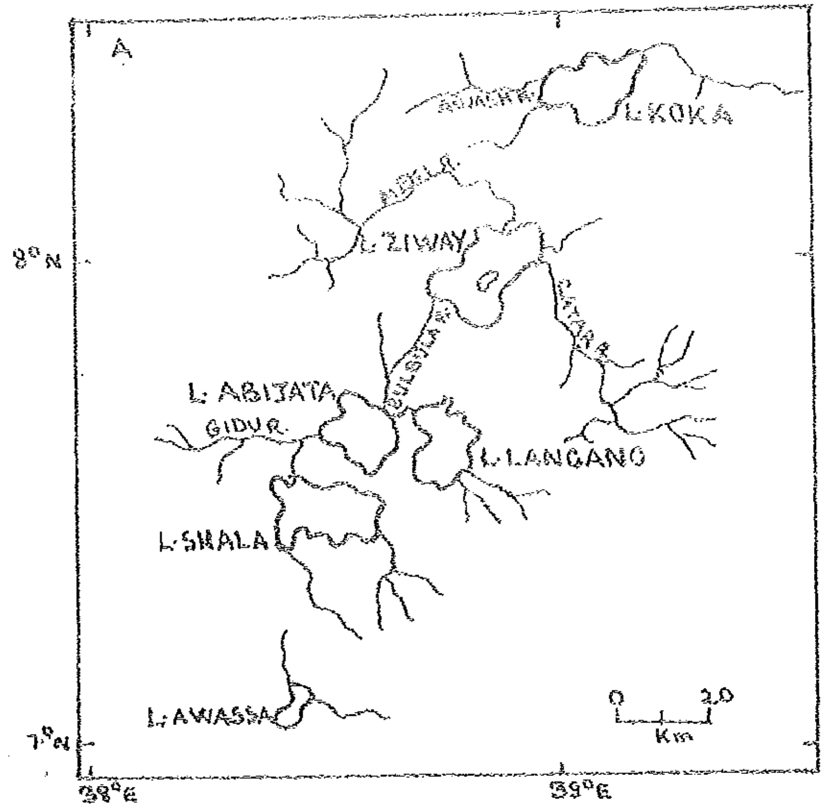
c = Makin et al (1975)

d = Schroder(1984)

e = Loffredo & Moldura(1941)

f = Talling & Talling (1965)

g = Pitwell (1967)



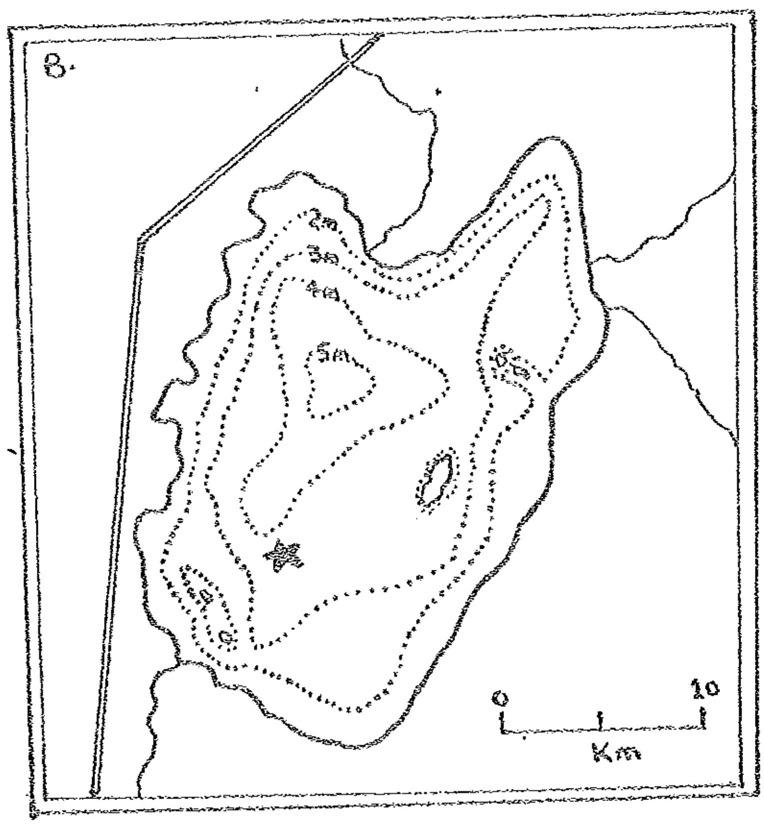


Fig. 1 The drainage system of the northern rift valley lakes [A] and bathymetric map of Lake Ziway [B] (Source: Morandini, 1942) with sampling station indicated by star.

L. Shalla and the Awash River basin by uplifted fault blocks (Makin et al., 1975). Lakes Langano and Abijata are separated from each other by a higher-laying faulted ridge, known as the Wonji faulted belt. There are five volcanic islands in L. Ziway. These are covered with thick vegetation and sparsely inhabited. L. Shalla, similarly has many islands which are home to species of the varied avifauna.

The bottom of Lake Ziway is made up of gravel and pumice or pyroclastic materials of volcanic origin and the water is turbid from silt suspensoid. The lake is unsheltered and thus exposed to frequent agitation by wind.

The Ziway-Shalla basin, otherwise called the Galla Lakes basin, is tectonically the most stable (=inactive) sector of the rift valley and hence has simple morphology (Mohr, 1971; Lloyd, 1977).

Climate and Rainfall

The Lake Ziway basin is arid for much of the year (Daniel Gamachu, 1977) and average evaporation exceeds precipitation in all months. There is a well defined dry season between July and September (see Makin et al., 1975 pp. 18 & 19) but even then the rainfall is unreliable and dry periods exceeding ten months are common.

The mean annual rainfall in the lake basin is generally less than 600mm (UN, 1973). In the northern part of the lake basin rainfall is 700mm. This is due to the increase in elevation around the Meki River delta in the north. The annual rainfall over the lake surface averages little more than

500mm.

The temperature varies little throughout the year. The mean daily maximum and minimum temperature at Ziway are 26.9 and 11.7°C respectively and the extreme ,minimum record in the recent years was 4°C (Makin et al., 1975).

Annual open water evaporation is of the order of 2000mm (Gasse & Street, 1978) which results in an approximate 2m decrease in the lake water level each year. Drastic water level shrinkage was observed during the study period in the months December to March during which was dry except for a few light and intermittent rain showers.

The region around the study lake is windy and clouds of dust from the adjacent land blows over the entire lake surface. This contributes to the allocthonous nutrient enrichment & turbid nature of the lake. The lake is shallow (Zmax = 7.85m, Makin et al., 1975) and wind-induced turbulence is prevalent throughout the year; this again is a significant source of enrichment from the sediments in the lake floor.

Hydrology

Lake Ziway has a total catchment area of ca.7020km^2 and a water storage capacity of 1.1 x 10^9m^3 (see also table 1). It is the only relatively salt-free lake in the rift valley.

The hydrology of L.Ziway is regulated by inflows and rainfall on the

Fauna

The faunal components of L. Ziway consist of a variety of piscivorous birds (avifauna) among which are Pelicans (Pelicanus onocrotalus) lesser flamingoes (Phoeniconaias minor, Ibis and Cormorants of the genus, Phalacorecorax.

Large animals especially hippoptamus (Hippopotamus amphibius) and the Nile monitor are common in the lake.

The fish fauna consist of two native and one introduced species. The mouth brooding, Oreochromis niloticus and Barbus sp. are indigenous while Tilapia zilli is an introduced fish (Schroder, 1984; Getaneh & Getaneh, 1979).

Plankton communities

The common algal communities in the lake are blue-green algae, green algae and diatoms (Cannicci & Almagia 1947). The zooplankton components are made up of Copepods and Rotifers (Semeneh Belay, Pers Comm.).

CHAPTER 3

MATERIALS AND METHODS

4.1. Sampling

A single central station with a depth of ca.3.5m in the pellagic zone of the lake was selected as a representative site of the whole lake throughout the investigation period (Fig. 1). Samples for quantitative and qualitative analyses were collected bimonthly from this station. Samples for quantitative analyses were collected using a Kemmerer sampler of ca.2.5L capacity. Samples of equal volume from equally spaced depths (ca.50cm) covering 0-3m depth were pooled & mixed in a bucket to make a composite sample of the euphotic community. From this pooled samples, subsamples were transferred to 250ml bottles. Samples were fixed in field by adding a few drops of acid Lugol's solution and afterwards 2.3% formalin was added as indicated in Hecky and Kling (1987), Lund *et al.* (1958), Eloranta (1981) and Utermhol (1958)

For pigment analysis, samples were collected from 0-50cm depth using same Kemmerer sampler. These samples were put in polyethelone bottles and transported to the laboratory in an ice box.

For taxonomic investigation, vertical haul samples from 0-3m depth were collected with a phytoplankton net of mesh-size 25 μm and fixed as above. Unpreserved net samples were also transported in an ice box for immediate taxonomic work.

3.2. *In situ* Measurement of Chemical-Physical Parameters

In situ conductivity (K_{25^0c}, $Uscm^{-1}$) was measured with a combined conductivity and salinity meter probe. Surface water temperature was measured with a thermistor temperature sensor (YSI, model 33, S-C-T meter). Temperature corrections to 25°C were made as in Wetzel & Likens (1979) for insitu $Uscm^{-1}$ measurement assuming a mean temperature coefficient of $2.3\%^0c^{-1}$.

In situ pH measurement of lake surface water was done with a portable digital pH meter (YSI, model 607).

Lake water transparency (= vertical visibility) was determined using a standard secchi disc ca.25cm diameter, quartered alternately black & white.

3 .3. Measurement of biological parameters

Phytoplankton identification - was done from both net and sedimented samples in order to include the small single-celled algae that may pass through the 25 m mesh-size sampling net.

Phytoplankton taxa were identified to the genus level and where possible to the species level, with the aid of literature by Huber-pestalozzi (1934-1983), Bourelly (1966, 1968, 1970), Pascher

(1930), Skuja (1948, 1956), Hickel (1976) and Prescott (1971).

Biomass - Phytoplankton biomass was determined based on chlorophyll a concentration and algal counting and conversion of counts to volume

Chlorophyll a concentration - was estimated spectrophotometrically after concentrating the algal samples onto glass fiber filters (Whatman G F/C) and extracting of the pigments in warm 90% methanol, using the abbreviated formula of Talling and Driver (1963) & underlying degradation products.

$$\text{Chl } a = 13.9(0.0_{665}), \text{ (Path length = 1cm)}$$

Counting - algal volume and subsequently algal fresh weight biomass (mgl^{-1} or $mg.m^{-3}$) was estimated by counting algal units using Utermhol's (1958) inverted microscope techniques and phase contrast optics as described in Lund et al. (1958).

Based on results of Preliminary counts of common species, 13 selected species (table 2) which composed of more than 90% the total algal biomass were counted. These 13 species occurred consistently throughout the sampling series.

Counting was done after sedimentation of aliquot samples in sedimentation tubes of ca. 10, 25 and 50ml capacity by adding a few drops of acid Lugol's solution. The volumes of samples sedimented, the number of transects counted, and the level of magnification were adjusted from time to time according to convenience of counting and density of the phytoplankton.

The small and dense species were counted on one transverse strip at a magnification of 600x. Only 0.1ml aliquot samples were sedimented for counting the dense phytoplankton. Large and scarce species were counted by searching the whole chamber floor under 10x objective. The settled sample was 50ml during low algal density and 10ml during high algal density. The sedimentation time for samples was at least 12h.

For filamentous forms (eg. Lyngba & Melosira) counts were taken by measuring the length of each counted specimen and then averaging the lengths within species (Elizabeth Kebede, pers. comm.) The total number of cells in the whole chamber floor was found by multiplying

Table 2, Phytoplankton species counted and measured routinely (biomass determination from L. Ziway).

Species	Volume (μm^3)
Anabaenopsis sp.	109
Chroococcus dispersus	60 (1cell)
Lyngbya limnetica	198 (mean of filaments)
Melosira granulata	1650 (mean of filaments)
Microcystis aeruginosa	14.8 (1cell)
Navicula spp	450
Pediastrum boryanum	160
Scenedesmus spp.	233 (4 cell)
Spirulina platensis	32 (1 coil)
Staurastrum leptocladum	970
Surirella spp.	3680
Synechococcus elongatus	14.0 (1 cell)
Tetraedron minimum	37

the cell numbers in the diameter transect by π n/4 where π n/4 is the ratio of the whole bottom area to that of one diameter transect and n is the ratio between diameter and width of diameter transect (Vollenwider,1974).

Cells per ml was determined from the formula (Wilox *et al.*, 1982):

$$\text{Cell /ml} = \frac{C.TA}{L.W.S.V.}$$

where C = number of cells counted

TA = total area of settling chamber floor

L = length of strips

W = width of strips counted

S = number of strips counted

V = volume of sample settled

Cell counts were transformed to cell volumes (m^3ml^{-1}) by fitting the phytoplankton to appropriate geometric shapes and respective volume formulas (Willen *et al.*, 1985). Cell volumes were latter converted to fresh weight biomass (mgl^{-1} or mgm^{-3}) by assuming a specific density of unity for the phytoplankton.

CHAPTER 4

RESULTS

4.1. Some Chemical-Physical factors of Lake Ziway

The seasonal variations in surface water temperature, secchi disc visibility, pH and conductivity measured over the study period are shown in Fig. 2 and Table 3.

The highest and lowest surface water temperatures recorded for the study period were 27.5 and 18.5°C respectively, with a difference of 9°c. Occasional measurements of bottom temperature indicated a range between 18 and 24°C, differing only by 6°c. Difference between mean monthly surface and bottom temperature did not exceed 2°C. This small difference was indicative of the isothermal condition of the lake water during the sampling periods. The commonly deserved wind-induced mixing was a substantial evidence for this isothermal condition of the lake water.

Lake water transparency (= vertical visibility) varied between 13 and 23.5 cm on a mean monthly basis, with an annual mean value of 18.6 cm. This shallow secchi depth further illustrate the lake's turbid nature which may result from resuspension of silt during turbulent mixing.

The highest secchi disc transparency reading made for the study period occurred in December while the lowest occurred in March. Usually secchi depths were higher when the water was calm notwithstanding algal density.

pH of surface water didnot change very much seasonally (Fig. 2). The difference between the highest and lowest mean monthly pH didnot exceed 0.3. The mean yearly pH for the study period was only 8.54 (Table 3).

The conductivity of the surface water also varied little seasonally. The highest value occurred in January ca.400 μscm^{-1} at $K_{25}{}^{0}$ and the lowest occurred in March ca 333 μscm^{-1}. The annual mean was 372 μscm^{-1}, which was not different from that reported in Talling and Talling (1965).

Table 3. Mean monthly surface temperature, pH, conductivity ($\mu scm^{-1}, K_{25}^{0}$), Secchi depth & (Rainfall of L. Ziway (1987-1988).

	1987										1988		
	M	A	M	J	J	A	S	O	N	D	J	F	Mean
Temperature (°c)	25.1	23.9	27.5	23.5	22	23	25	23.1	24	18.5	20.9	27.2	23.6
pH	8.45	8.75	8.45	6.5	8.5	8.45	8.45	8.6	8.55	8.6	8.67	8.5	8.54
K_{25}^{0} μScm^{-1}	360	340	333	372	363	390	379	386	358	393	400	395	372
Secchi depth (cm)	13	14	16.5	15.5	15.5	14.5	16	19.3	22.3	23.5	22	21	17.8
Rainfall (mm)	59.8	47.7	245.2	16.2	71.6	58.6	54.6	17.7	0.0	0.0	3.41	20.3	

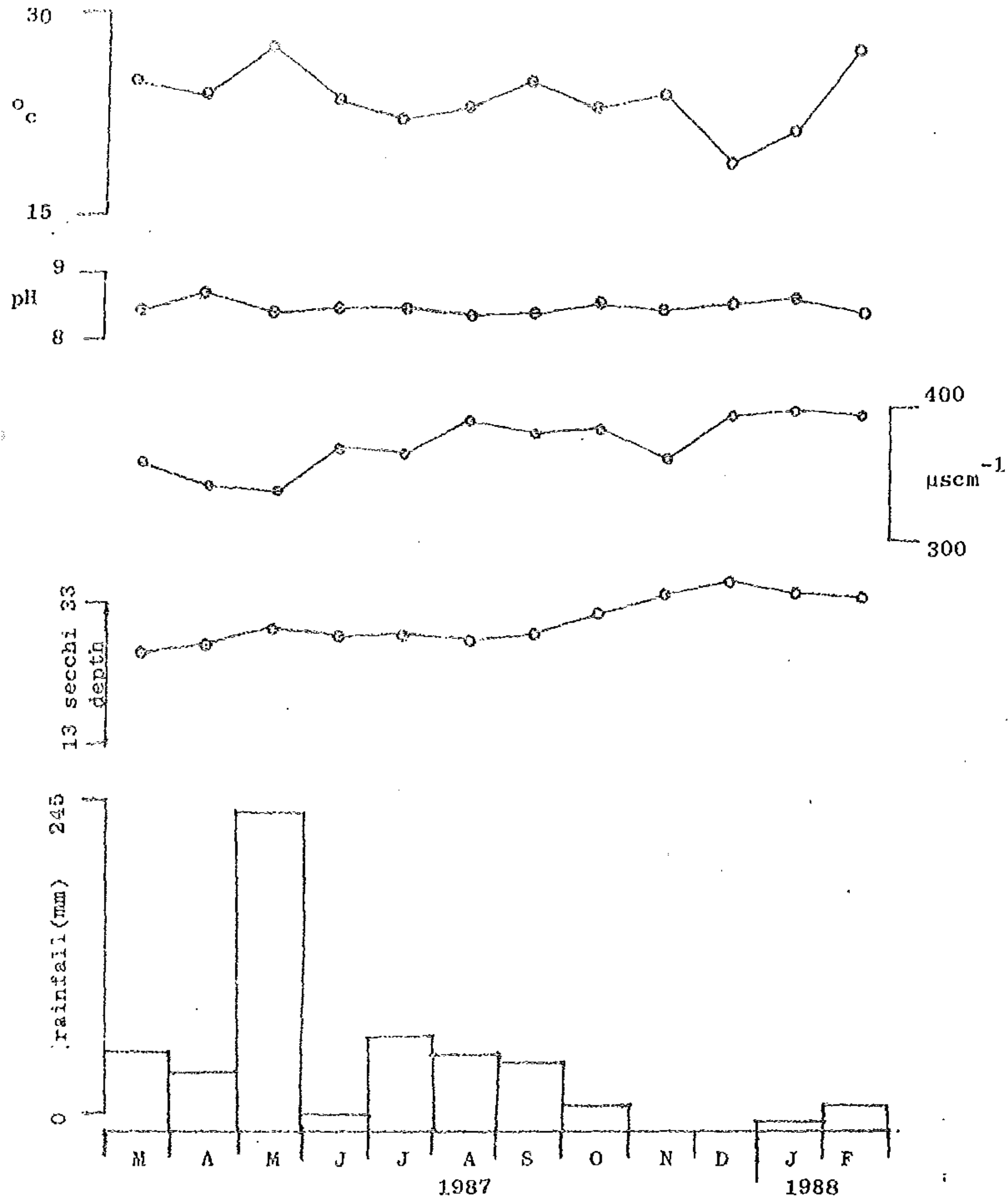


Fig. 2. Seasonal variations in rainfall(mm), Temperature (o_C), Conductivity ($\mu s\ cm^{-1}$), pH and Secchi depth (Z_{SD}, cm) in L. Ziway

4.2. Species Composition

The phytoplankton species found in Lake Ziway are listed in Table 4 and their distribution (by number) among taxonomic groups is given Table 5.

In total 122 phytoplankton species were found during the counting process in the quantitative and net samples from Lake Ziway. These were distributed among three major component groups, blue-green algae (Cyanophyceae), diatoms (Bacillariophyceae), and green algae (chlorophyceae) (Table 4).

Figure 3 shows the seasonal variation of phytoplankton species number and their distribution among taxonomic groups.

Blue-green algae - They are the major group which consisted of 57 species i.e. 41.8% of the total species number (Table 5).

Table 4. List of Phytoplankton Species in Lake Ziway during the Study Period

Cyanophyceae

Anabaenopsis arnoldii Apte Karj

A.Circularis G.S. West.

A.curvata

A.philippinesis Tayor

A.raciborskii Wolo

Aphanocapsa biformis (= Microcystis biformis) (A.Br.)

A.delicatissina W. & G.S. West

A.elachista W. & G.S. West

Aphanothece caldrariorum P. Richt

A.nidulans P.ritcher

A.Richter

A. sp.

A. stagnina (Spreng)

Chroococcus decorticans (A.Br.) Ritcher

C. dispersus (Vokeiss) Lemm.

C. limneticus Lemm.

C. minutus kutz

C. prescotti Dr. & Daily

C. turgidus (Kg.) Naeg.

Coelosphaerium kutzingianum Naeg.

Gloeocapsa arenaria (Hass.) Rabenh.

G. magna (Brib.) Kutz

G. Sp

Gloeothece Confluens Nag.

G. linearis Nag

Lyngbya circumcreta G.S. West

L. contorta Lemm.

L. limnetica Lemm.

Microcystis aeruginosa (kg) G.M. Smith

M. flos-aquae (Wittre) Kirchn.

M. elebaus (Kutz)

M. firma (Bred et Lenorm)

M. incerta (Lemm.)Lemm.

M. marginata (Menegh.) kutz.

M. puluerea (Wood) Forti

M. robusta (Clark) Nygaard

M. wesenbergi (Komarek)

Merismopedia elegans (A.Br.)

M. gluaca (E) Nag

M. tenuissima Lemm.

M. trolleri Bachm.

Pseudoanabaena catenata Skuja

Ps. tennuis koppe

Rhabdoderma linearis Schmidle et Lauterb

Raphidiopsis curvata F.E. Fretsel

Spirulina laxa G.M. Smith

Spirulina major kg.

S. Platensis Nordst

Synechococcus elongatus (Nageli)

S. linearis (= *Rhabdoderma lineare*) G.M. Smith

S. sp.

Bacillariophyceae

Amphora ovalis

Anomoeneis sp.

Cocconeis pediculus

C. placentula Ehr.

C. placentula var. Euglypta Ehrbg.

Cyclotella sp. (centric diatom)

Cymbella sp.

Denticula sp.

Epithemia argus var. longicornis Grunow

E. Zebra (Kutz) Grunow

Fragillaria capucina Desm.

Melosira granulata (Ehr.) Ralfs

Navicula cryptocephalla Kutz.

N. pygmaea

N. radiosa Kutz

N. terians

Nitzschia acicularis var. Major (Kutz. F.T.)

N. luzonensis

N. Pellagica

Pinnularia sp.

Rhopaloida gibberula (Ehrenberg, C.G.) O. Muller

R. gracilis Hantsch.

Surirella celebesiana Hust

S. biserata var. heteropolis Hust

S. engleri O. Mull.

S. linearis W. Sm.

S. robusta Ehr. var. splindida Kutz.

S. turgida

Synedra acus kutz

S. ulna Ehr.

Chlorophyceae

Actinastrum rhaphidoides (Reinsch.) Brunnth

Ankistrodesmus bernardii (kom.)

A. falcatus (Corda) Ralfs

Botryococcus braunii (kutz)

Closterium incuruum Brib.

Closteriopsis longissima

Cosmarium margaritatum (A.Br.) Hansg.

Cosmarium sp.

Coelastrum octaedricum skuja

Crucigenia sp.

Kirchneriella majori (G.S. West) Kon-Legn

Monoraphidium contortum (Thur.) Kom-Legn.

M. minutum Nag.

Oocystis sp.

Pediastrum boryanum (Turp.) Menegh

P. duplex meyen (F.J.F.) Lemm.

P. simplex meyen, F.J.F.) Lemm.

P. tetras (Ehr.) Ralfs

Radiococcus planktonicus Lund

Scenedesmus aramatus Chod.

S. bellospinus Bortob.

S. magnus (= s. maximus) var. Peruviansis Hegew

S. opoliensis P. Richt

S. quadricauda (Turp.) Bre'b

S. setiferus Chod.

S. sp. (small two cells)

Selenastrum sp.

Sorastrum sp.

Staurastrum cerastes Lund.

S. chaetoceros (Shrod.) G.M. Smith

S. gracile Ralfs

S. leptocladum Nordst

S. paradoxum (meyen, F.J.F.) Smith, G.M.

S. spinulosum Ehr.

S. sp.

S. tetracerum Ralfs

Tetradesmus heterocanthum G. M. Smith

Tetraedron triangulare Kors

T. mediocris (Hind)

T. minimum (A.Br.) Hansg

T. regulare Kutz.

The blue green algae dominated the algal community in species number during much of the study period. They were in fact exceeded by green algae only once in May, 1987.

The blue-green algae were represented by a number of coccoid and filamentous forms. The coccoid blue-greens included the species belonging to the genera; Microcystis, Aphanocapsa, Aphanothece, Coelosphaerium and Merismopedia. The genus Microcystis was most notable for its representation by a large number of species (see Table 4) the most important of which was M. aeruginosa(kg) G.M. Smith. These species and genera occurred consistently but their abundance was seasonally variable.

The common filamentous blue-green algae of qualitative importance included the species belonging to the genera; Lyngbya, Spirulina, Anabaenopsis and Aphanizomenon.

The nitrogen fixing genus Anabaena also occurred but it was of less quantitative significance. Other blue-green of less quantitative significance were present but their occurrence was only sporadic.

Green algae - In total 41 species of green algae were identified (Tables 5). Among, these, the genera Staurastrum and Pediastrum were abundant. Scenedesmus and Tetraedron were commonly encountered but their abundance varied seasonally. The species of Scenedesmus eg. S. bellospinus Bortob and S. magnus (= S. maximus) var. Peruviansis Hegew were rarely encountered and these were not reported in any Ethiopian lakes so far studied . Among the genera of green algae, the genera *Staurastrum* and *Scenedesmus* were notable for their large number of species.

Some genera of green algae with sporadic occurrence included, *Ankistrodesmus*, *Cosmarium*, *Kirchneriella*, *Coelosphaerium* and *Monoraphidium*

Table 5. Number of species identified and their distribution (percent of the total) among taxonomic groups in Lake Ziway (Mar., 1987 - Feb., 1988)

Group	Number of species	%
Cyano-phyceae	51	41.8
Bacillario-phyceae	30	24.6
Chloro-phyceae	41	33.6
Total	122	100

Diatoms - The diatom flora of the lake consisted of 30 species - one centric and 29 pinnate diatoms (Table 4&5). The most common diatom genera identified during routine counting included; *Surirella*, *Melosira* and *Navicula*. The most important species of Melosira, *M. granulata* (Ehr.) Ralfs was identified as the sole representative of the genus. It was identified by Dr. J.F. Talling when he visited the laboratory during the study period.

The common genera of diatoms of less quantitative significance were *Synedra* and *Nitzschia*. Other diatoms which occurred only seasonaly are listed in Table 4.

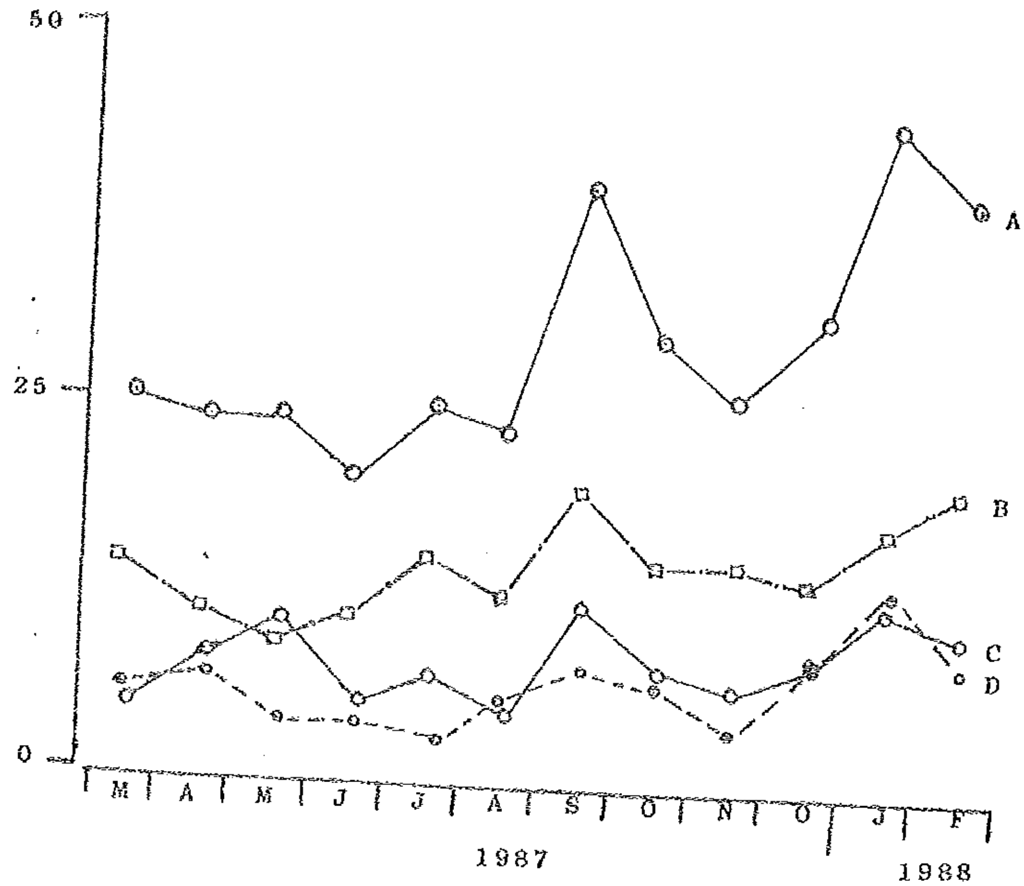


Fig. 3. Seasonal fluctuation in species number and distribution of phytoplankton species (by number) among major taxonomic groups (A=total number of Species, B= blue-greens, C= greens, D=diatoms).

4.3. Phytoplankton Biomass

Chlorophyll a concentration - The seasonal pattern of change in phytoplankton standing crop as indexed by chlorophyll a concentration showed the highest peak in July (212 mg m^{-3}). The lowest chlorophyll a value recorded for the study period was that for the month of November (154 mg.m^{-3}) (Fig. 4 and Table 6).

There was a general tendency for Chlorophyll a to increase with increase in rainfall and water level (Cf Fig. 2 and 4). The mean monthly chlorophyll a values were higher in the months April through July and lower during the months October through February. The water level was higher during the former and lower during the latter months (Pers. observation). The difference between the highest and lowest chlorophyll a values was 58 mg m^{-3}.

The overall pattern of change in chlorophyll a concentration for the study period showed less pronounced seasonal variability.

Biomass(Volume) - The biomass of phytoplankton community in L. Ziway, during the study period was composed of three major taxonomic groups; Cyanophyceae, Bacillaiophyceae and Chlorophyceae.

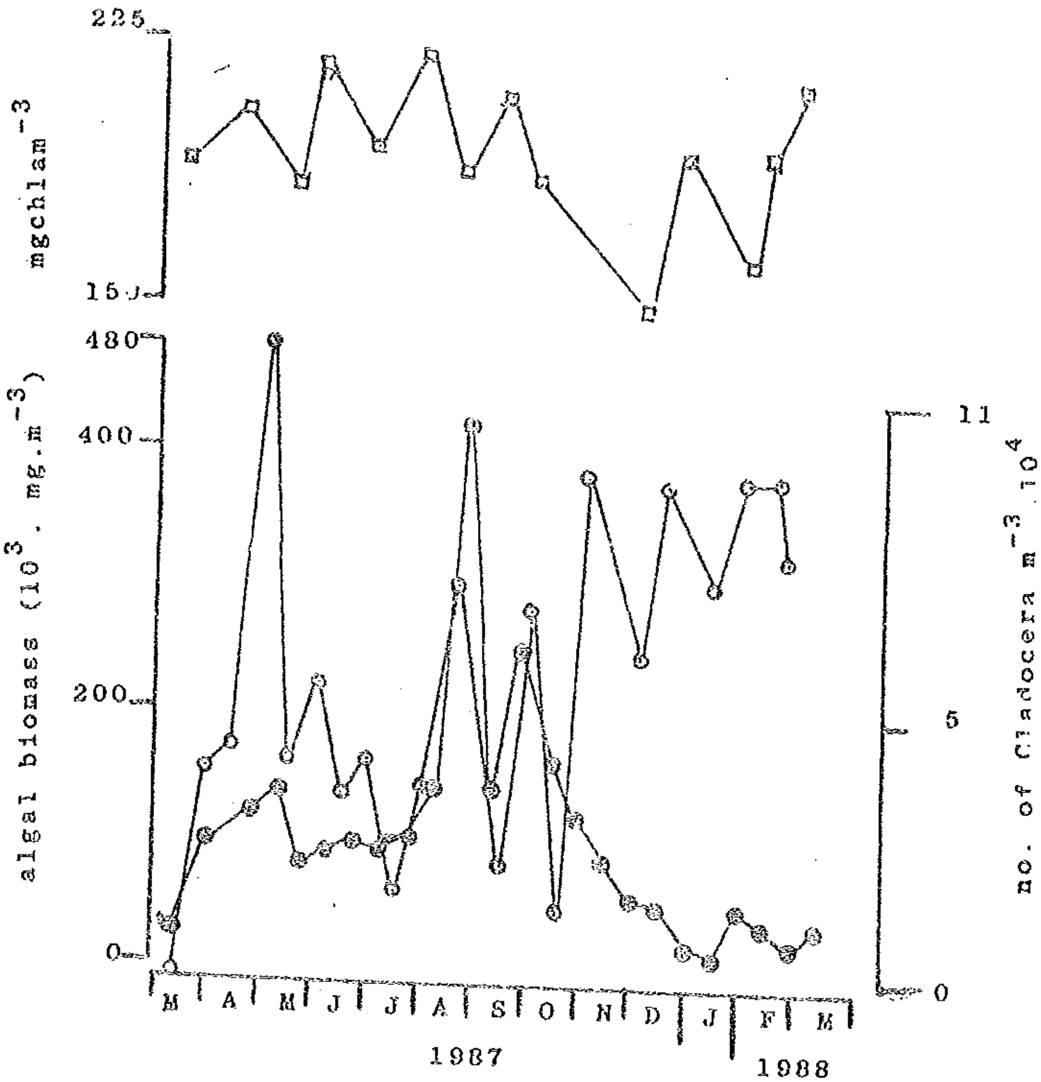


Fig. 4 Seasonal variations in chlorophyll-a(mg m^{-3}), algal biomass (10^3 . mg m^{-3}) and total number of Cladoceran zooplankton (no. 10^4.m^{-3}) in L.Ziway during the study period.

Data on the phytoplankton biomass, determined by algal counting, indicated the mean monthly values varied between 79.10^3 and 349.10^3 $mg.m^{-3}$ (Table 6). The highest values recorded for the study period were for the months April and August, during which times the biomass maxima occurred. The lowest values were recorded for the months March and October.

The contribution of taxonomic groups to the mean monthly and yearly biomass is evident from Tables 6 and 7.

The blue-green algae formed the bulk of the biomass for much of the study period comprising about 63% of the biomass on a mean yearly basis while the diatoms followed making up to 22%. The green-algae occupied a third rank in the community biomass, forming only 15% of the biomass. The biomass showed little relationship to chlorophyll a concentration (Fig. 4) and the chlorophyll content of the biomass, determined from the ratio, 100. Chla: biomass was generally low, ranging from 0.05 to 0.24%.

4.4. Seasonal Fluctuations in Phytoplankton Biomass

The seasonal assemblage of phytoplankton biomass of the study lake was dominated by blue-green algae for much of the study period (See Fig. 5 & 6, Tables 6 & 7). There were brief periods in April and October during which times diatoms predominated in biomass. Except during these periods, prolonged dominance of seasonally variable blue-green algal flora was a feature commonly observed.

Table 6. Mean monthly phytoplankton biomass ($10^3.mg.m^{-3}$) of major taxonomic groups, chlorophyll a concentration in the euphotic zone of L. Ziway, with annual total and percentage proportions indicated (monthly means are the mean of two monthly samples.)

	1987										1988		Total	%
	M	A	M	J	J	A	S	O	N	D	J	F		Biomass
Cyano-phyceae	64	117	164	99	69	[illegible]	134	34	204	189	214	183	1691	63
Bacillario-phyceae	10	177	37	34	15	89	[illegible]	73	25	9	49	36	579	22
Chloro-phyceae	5	35	13	22	25	40	24	23	77	10	44	92	410	15
Total	79	320	214	155	110	[illegible]	182	[illegible]	[illegible]	[illegible]	307	311	2680	100
Chla(mgm^{-3})	192	205	[illegible]	[illegible]	212	189	195	174	154	177	179	160		

Table 7. Mean monthly percentage contribution of phytoplankton groups to the total biomass in Lake Ziway (1987-1988)

	1987									1988	
Group	M	A	M	J	J	A	S	O	N	D	J	F
Cyanophyceae	81	36	77	64	62	49	74	26	64	91	70	57
Bacillario-phyceae	13	54	17	22	14	35	13	56	9	4	16	7
Chloro-phyceae	6	10	6	14	23	16	13	18	27	5	14	36

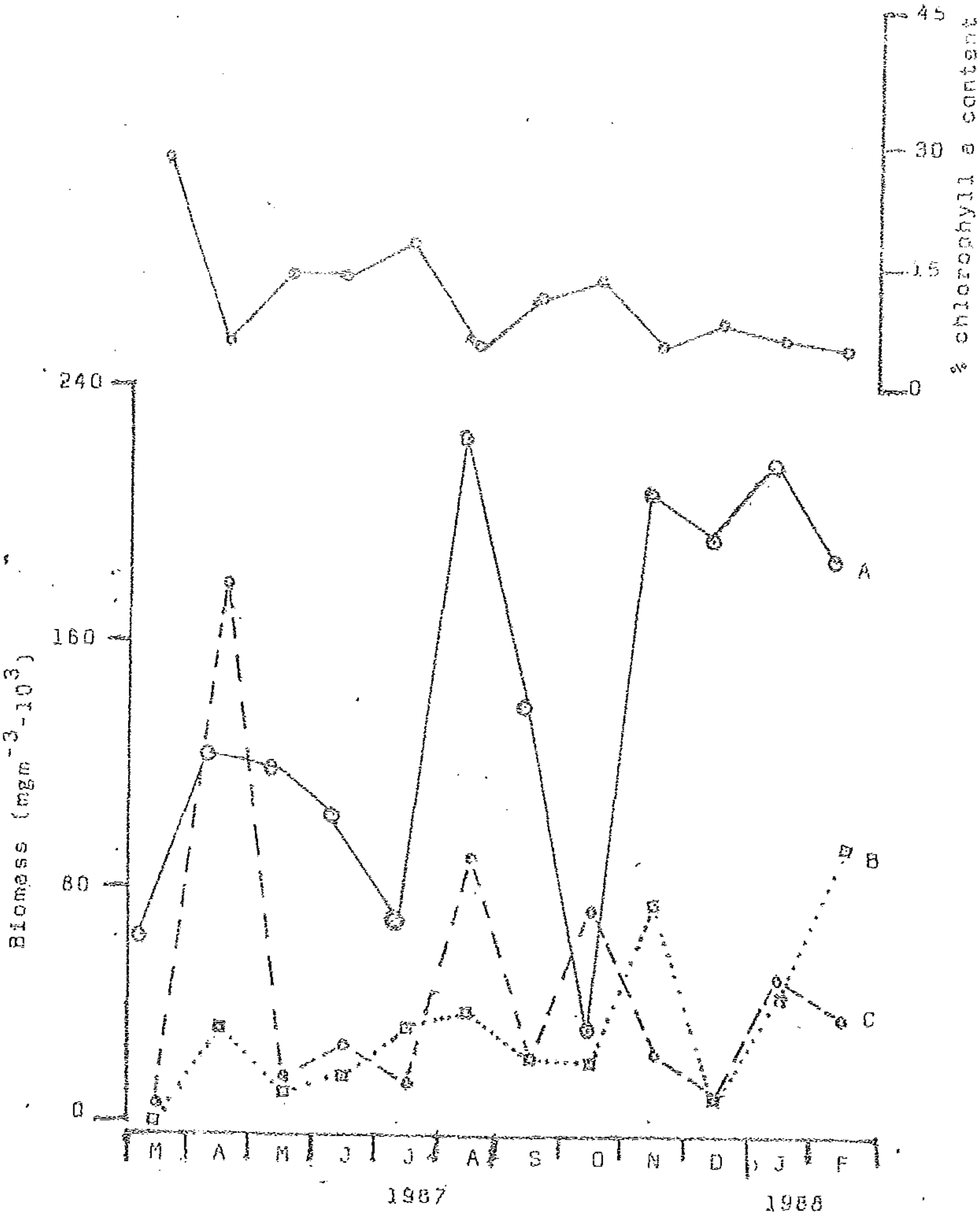


Fig. 5 Seasonal fluctuations in phytoplankton biomass (mg m^{-3}.10^{3}) in different phytoplankton groups and chlorophylla content in L.Ziway (A=Blue - greens, B= Greenalgae, C=diatoms)

Among the blue-green algae, the species of *Lyngbya* (mainly, *L. limnetica*), *Microcystis* (mainly, *M. aeruginosa*) and *Synechococcus* (mainly *S. elongatus*) were important components of the community biomass. These three, contributed about 60% of the community biomass in a mean yearly basis.

Other blue-green algal species such as *Spirulina*, *Anabaenopsis* and *Chroococcus* were occasionally important components of the community biomass.

The diatom population, especially, the species of *Navicula*, *surirella* and *Melosira*, were important components of the phytoplankton biomass, nevertheless, they showed tremendous seasonal variability in abundance. The diatoms remained subdominant in biomass during most of the study period, except in April and October when they predominated in biomass, exceeding blue-green algae. These periods were when the diatom maxima occurred. The diatoms showed minima in March and December (See Fig. 5 and 6).

The green algae were too low for adequate enumeration in the standard sedimentation technique, however, the species of *Staurastrum* mainly (*S. leptocladium*) and *Pediastrum* (mainly *P. boryanum*) were fairly abundant and were routinely counted. The green algae were represented in the biomass by these two species and their small contribution to the biomass was mainly the result of this low representation.

The peaks for green algae occurred in July and February (Fig. 6) during which times their biomass exceeded only that of the diatoms. There was not a single occasion, during the course of the study when the green algae exceeded the blue-greens in abundance. Low biomass values for green algae were recorded for the months of March and December.

The overall seasonal trend of phytoplankton biomass followed the order; Cyanophyceae > Bacillariophyceae > Chlorophyceae.

are numerous in fresh waters of low total ionic content. Furthermore, Talling and Talling (1965) stated that desmids are numerous in class I lakes (k_{20} < 600 μscm^{-1}) but are less common in Class II (K_{20} 600 - 6000 μscm^{-1}). This observation was consistent with the present chemical status of the lake water, for measured conductivity values over the study period were far below the limit value (600 μs cm^{-1}) (see Table 3).

Another characteristic feature of the lake water was the occurrence of many species of Spirulina (mainly, S. platensis) in significantly countable numbers. These species were considered to be characteristic population of highly alkaline-saline lakes (Melack and Kilham, 1974; Vareschi, 1982).

Seasonal periodicity in the environmental and biological processes during the study period were weak. Lack of seasonality in environmental-biological processes are common characteristics of shallow, frequently mixing (Polymictic) tropical lakes (Ganf, 1974a; Melack, 1979b).

Various factors that affect the seasonality in lake ecosystems have been studied by many workers (eg. Talling, 1986; Roden et al., 1987; Harbot, 1982) who distinguished between hydrological & hydrographic regulations of seasonality and others stressed the importance of nutrients and light in regulating seasonality of phytoplankton (eg. Hecky and Kling, 1981; Talling, 1966; Lewis, 1978a) . Although, no measured hydrological and hydrographic data that can qualify our visual observations are available, it is suggested the observed lake level changes may have a profound effect on the phytoplankton periodicity.

Light and nutrients are determinant factors in regulating seasonality in deep, stratifying lakes (Willen, 1980). However, in the case of the shallow, frequently circulating lake, L. Ziway, light and nutrients were most unlikely to regulate the observed weak phytoplankton seasonality. One reason for this is that due to the tropical location of the lake light climate is invariable. Another reason is that nutrients were constantly being replenished from the sediments by diurnal mixing. This was shown by analyzing for major nutrients from samples taken during turbulent mixing (Zafar, 1980; Girma Tilahun, unpubl. data), where results showed that nutrients didnot reach levels of complete depletion even under conditions of high phytoplankton development.

Several measures of seasonal variability have been proposed to compare phytoplankton dynamics. For example, Melack (1979b) applied the coefficient of variation to measure seasonal variations in phytoplankton abundance and seasonal changes in photosynthesis. Kalff and Watson (1986) used the ratio of seasonal maxima to minima to measure the total population abundance. Talling (1986) used, the annual amplitude of population density, expressed in orders of magnitude (= $\log_{10}$ units) as a measure of seasonal variability.

Applying Melack's (1979b) coefficient of variation (cv) to measure the degree of seasonal variability in algal abundance for L. Ziway gave a value of 43% for volume. This puts the lake in pattern A, a pattern which shows pronounced seasonal fluctuation (by Melack's criteria, cv greater than 25% shows pronounced seasonal variability). However, the cv for chlorophyll *a* (10.1%) puts the lake in pattern B, a pattern which depicts a muted or nearly a constant seasonality.

For Lake Ziway, the ratio of seasonal maxima to minima gave values 4.42 and 1.38 for volume and chlorophyll a respectively, with corresponding $\log_{10}$ units, .65 and .14.

The amplitude of seasonal variation in total community (assessed as chla), in L. Ziway (.14) resembled the amplitude for the total community in L. George (0.2 - 0.4) (Ganf, 1974a) but was lower than that for L. Sibaya (0.42) (Hart and Hart, 1977).

Among taxonomic classes the amplitude of seasonal variation, assessed as volume, (diatoms = 1.25, green = 1.26, and blue-green = 0.81) fall within the range for the same taxonomic classes in L. Victoria (see Talling, 1986, pp 154). However, in all cases the amplitude among component species was much higher than the amplitude in total community and taxonomic classes. For example, in L. Ziway, the amplitude of seasonal variation was about 2 (10^2) orders of magnitude for the species of Pediastrum (2.67), Surirella (2.08) and Navicula (2.05). The total community in the lake, however, showed less than 1 order of magnitude, i.e. 0.65.

In Lake Victoria (Talling, 1986), an amplitude of seasonal variation as high as 5 orders of magnitude was reported for a single blue-green algae species, Anabaena flos-aquae, while Hart and Hart (1977) has reported that all component species counted had much higher values of seasonal amplitude than the total community.

Grazing by herbivorous fish and zooplankton, coupled with the effects of hydrological changes may have had profound effects in influencing phytoplankton distribution and seasonal variation in the study lake.

The phytoplanktivorous fish, Oreochromis niloticus L. (Lowe, 1958; Getachew T., 1987 a,b; Zenebe T. pers. comm.) and the grazing populations of zooplankton eg. Mesocyclops spp., Microcyclop spp. Diaphanosoma sp., Brachionus angularis and Keratella tropica (Semeneh Belay , pers comm.) were suspected to have modifying effects on the seasonality of phytoplankton in L. Ziway (see fig. 4).

Seasonal variations in species composition, biomass and associated environmental factors, during the study period were not pronounced. The weak variations that did occur remain un explained in this study,however, it is possible that hydrological changes observed may have had an over-riding role in regulating seasonality in Lake Ziway.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

The phytoplankton of L. Ziway was largely made up of three taxonomic groups - Cyanophyceae, Bacillariophyceae and Chlorophyceae.

The blue-green algae dominated the algal community of the lake both, quantitatively and qualitatively. The blue-green algal species *Lyngbya limnetica* and *Microcystis aeruginosa* were dominant components of the algal biomass.

Although not well pronounced, there was seasonal periodicity in algal biomass and the accompanying physico-chemical environmental factors, there was no, however, strong relationship between the environmental factors and the measured biological changes.

The magnitude of seasonal variation in total biomass was higher than that of the algal standing crop (chl*a*). The seasonal amplitude of variability in component species was much higher than the amplitude in total community.

The seasonal amplitude of variations in phytoplankton species composition and biomass in L. Ziway, as in other shallow tropical lakes, is dependent upon the coupled effects of hydrologic (Water input-output) and hydrographic (water-column structure and circulation) factors. However, the observed frequent wind-induced mixing of the lake water makes the hydrographic factor play the over-riding role in the seasonality of biological processes in the lake.

As trends in the time series indicate, L. Ziway is on the process of progressive eutrophication (Chl<u>a</u> determinations show that in 1938 the lake was "clear water", in 1966 = 7 μ g chla l^{-1}, in 1980 = 91 μ g chla l^{-1} and in 1987-1988 = 187 μg chla l^{-1} the caused of which are unknown.

Eutrophication, resulting in dense blooms of phytoplankton, becomes obstacle in fisheries development, in filtration processes for making drinking water and create problems in water-based recreation. Some algae even pose formidable health problems by having potentially toxic substances in their cells.

In spite of all these, phytoplankton is an important diet for the commercial food fish, <u>Oreochromis</u> <u>niloticus</u> L. and other algivorous fish populations which are essential protein food supplements.

There is, therefore, a substantial economic and social need to understand the factors which regulate the growth and development of this phytoplankton. Furthermore, knowledge of the species composition and seasonality of its change becomes a prime importance in different management routines.

The current increasing human settlement in the lake basin and the subsequent activities in the diversion and pumping of water from its tributaries is threatening the lakes very existence per se and its ecosystem. Similarly, the unplanned over-zealous exploitation of the lakes fisheries resources may lead to destructive consequences in the lake's natural balance.

There is, therefore, a pressing need for an integrated ecological study of the lake over extended period of time for further understanding of the lake's natural ecosystem before exploitation of its resources begins.

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