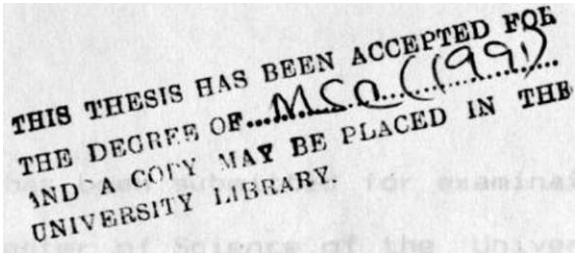
PHYTOPLANKTON PRODUCTIVITY IN LAKE NAIVASHA

By

NZULA KITAKA; B.Ed-Sci. (Hons)



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DECLARATION

I, Nzula Kitaka, hereby declare that this thesis is my own original work and has not been presented for a degree in any other University.

Date: . j ! I \ . ^{v}/M\). . . . . Signed: . . fett^.
Nzula Kitaka

This thesis has been submitted for examination for the degree of Master of Science of the University of Nairobi with our approval as the University Supervisors.

1. Dr. Kenneth M. Mavuti
   Senior Lecturer
   Department of Zoology
   University of Nairobi

Date: . . . . . ILl,^'.!

Signed: ....

2. Dr. UJilliam Kudoja
   Lec turer
   Department of Zoology
   University of Nairobi

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Signed: (J:.

DEDICATION

To my parents

Mrs Ruth Kitaka, lat» Mr. S.B. Kitaka,

and

my son Wanguru.

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ABSTRACT

Lake Naivasha being an endorheic basin, within an intensive agricultural region requires continuous assessment of basic factors controlling phytoplankton productivity, because agricultural activities can contribute to basic ecological changes. Such changes include those attributed to eutrophication, which could be detrimental to the well developed fishery in Lake Naivasha.

Phytopiankton productivity was determined in thres different ecological zones in Lake Naivasha, i.e. littoral, open-water and a semi-enc1osed basin. Near-isothermal conditions were observed in all the stations, with a seasonal change of 3°C. The water was well oxygenated with orthograde curves, however dissolved oxygen stratification was well developed at Crescent Island Lake. Secchi disc transperency, conductivity, alkalinity, and nutrient concentrations were greatest at Crescent Island Lake.

Phytopiankton biornass as chlorophyll a, showed significant differences in concentration between stations and over time, with ranges of 26.5-40.5, 20.6-59.8 and 11.2-41.9 pg/1 at Safariland, Hippopoint and Crescent Island Lake respectively. This could be attributed to differences in species composition: Closterium. Micrpcystis. Ceratium. and Melosira spp.

were abundant at Main Lake stations, while Melosira spp. dominated Crescent Island Lake.

Photosynthetic rates were maximal in sub-surface waters (0.5-1.0 m depth) in all the stations, coinciding with more than the 15 ′/. level o"f incident irradience measured as Secchi depth and PAR light attenuation. Maximum gross photosynthesis (Gpmax) was highest at Safari land between January and March 1990 and Crescent Island Lake took there after. Crescent Island Lake had the highest values of specific photosynthetic rate (Pmax) than the other stations with higher chlorophyll a concentration in January to March.

CHAPTER 1

INTRODUCTION

1.0 General Introductions

Many lake systems have complexities involved in determining the components controlling productivity, due to unequal distribution of physico-chemical factors in the water column. Vertical heterogeneities are reduced in Lake Naivasha, because the lake is shallow and complete mixing occurs almost every day (Melack 1979). Therefore conditions which are often associated with diurnally asymmetric rates of productivity in other lakes are not applicable in Lake Naivasha. Phytoplankton consists of autotrophs which synthesise organic matter from dissolved in-organic and organic substances. They include representatives of several groups of algae, bacteria and some stages of fungi. The subject matter of this thesis is directed largely to planktonic algae in Lake Naivasha.

Lindemann (1942) defined productivity as the rate of flow of energy into the organisms of a given trophic level, amount of carbon or inorganic matter produced per unit volume or area per unit time. The term phytopiankton productivity in this study means "the quantity of newly formed organic matter produced by phytopiankton through the process of photosynthesis per

unit volume or area per unit time, which is directly or indirectly available for maintenance of secondary producers in Lake Naivasha".

Primary production in aquatic ecosystems depends on many factors,such as the quantity of available light, lake stratification, phytop1ankton composition and succession, and the fluctuation and availability of nutrient. (Tailing 8< Tailing 1965, Tailing 1966, Lewis 1970, Hecky & Kling 1901, Njuguna 1982, Reynolds 1984).

Water level fluctuations play an important role in regenerating nutrients to the overlying water mass, especially from the mud of the littoral zone. Water level rises in Lake Naivasha result in inundation of the drawdown region and submerged flora as well as previously oxidised aerated soils, releasing large amounts of nutrients to the overlying water mass,thereby promoting phytop1ankton production and species diversity (Gaudet 1977).

Lake Naivasha, being an endorheic basin within an intensive agricultural region, requires the assessment of basic factors controlling phytopiankton productivity. Agricultural and human activities contribute to basic ecological changes in any lake ecosystem including those attributed to eutrophication. These changes could be detrimental to the developed fishery in Lake

Naivasha.

1.2 Justification

The three commercially exploited fish species in Lake Naivasha are all introductions. Tilapia zi11i (Garvais) was introduced in 1956 from ponds near Kisumu, presumably to establish fish populations for commercial exploitation. Oreochromis 1eucostictus (Trewavas) was unintentionally introduced with T. zi11i. Micropterus sa1moides (Lacepede) was introduced in 1929 from the United States of America to form the basis for a sport fishery (Litterick et aJL- 1979). Due to high species richness of fish eating-birds, Lake Naivasha is one of the most important regions for bird-watching tourism in Kenya.

Preliminary research has shown that all three commercial fish species forage primarily in the littoral zone (Malvestuto 1974, Muchiri pars. comm). Studies on other components of the ecosystem have suggested that neither the phytop1ankton, zooplankton nor the zoobenthos are effectively exploited by fish (Mavuti 1983, 1990, Harper 1987). Studies on Lake Naivasha's plankton from 1975 to 1980 (Mavuti & Litterick 1981, Mavuti 1983) showed that the phytop1ankton community was being cropped by an abundant diverse zooplankton community, but there was no zooplanktivorous predators in the limnetic zone. A

potential opportunity exists to widen the quantity and diversity of the commercial catch by introducing open water zooplanktivorous and benthivorous fish species (Malvestuto 1974, Siddiqui 1977, Mavuti 1983, Harper pers. comm).

To evaluate the ability of proposed introductions it is necessary to determine different levels of the ecosystem productivity, which might sustain the introductions. Several short-term studies have been undertaken in Lake Naivasha (Njuguna 1982, Mavuti 1983, Harper 1987, Harper et al. 1990) but there is a need for monitoring the lake's ecology over a long period of time, because the lake level is not stable and the lake may have dried up as recently as the 1880's (Leakey 1931, Nilsson 1931, 1940, Richardson & Richardson 1972). The impact of these hydrological changes on the ecology of the fauna and flora has been catastrophic, especially on fish (Mavuti 1983) and the lake could face the same problems if new fish species are introduced before a long-term study of the Lake is done.

It is necessary to measure phytoplankton productivity to be able to understand the open water ecosystem, because it comprises the basic portion of primary production and forms the base upon which the aquatic food chain culminating in the fish population

is founded.

Phytopiankton sustains zooplankton via grazing, zoobentfios via detritus, and fish directly in the case of herbivorous Tilapia or indirectly via invertebrate production. It is also important to assess phytopiankton productivity for management of inland waters because excessive algal production presents problems for water industries and can have deleterious effects upon fish. Therefore there are important economic and social reasons for regular monitoring of phytoplankton productivity in Lake Naivasha to give a basic knowledge of the factors controlling productivity. This information will give an idea whether it is ecologically sound to introduce any new fish species in Lake Naivasha.

1.3 Aims and Objectives

The present study was designed to augment studies of phytoplankton production in Lake Naivasha done by Melack (1979), Njuguna (1982) and Harper (1987), to provide long-term information towards the goal of improving and maintaining a high fish population in Lake Naivasha. The major aims of the study are:—

(1) To determine factors affecting phytoplankton productivity in different ecological zones of Lake Naivasha i.e littoral, open water, and a semi-enclosed

basin.

(2) To evaluate the effects of inorganic nutrients on phytopiankton productivity and species composition.

Specific objectives are:-

(a) To determine seasonal variation in phytop1ankton species composition and biomass

(b) To determine the rate of phytopiankton productivity at different depths through time.

1-4 The Study Area: THE LAKE NAIVASHA ECOSYSTEM

1.4.1 Geographical position

Lake Naivasha basin is located in the eastern Rift Valley of Kenya at 0° 45'N - 1°0 S, 36°.20'E, at an elevation of 1890 m above sea level. The basin has tectonic faulting and volcanic boundaries which are associated with the formation of the Rift Valley (Fig.l). The basin is bordered to the East by flanking escarpments including the Aberdare Range (3,960 m) and Kinangop Plateau (2,483 m). Kiambogo Hills form the western boundary and Eburu Hills (2,668 m) to the North separate the Naivasha basin from Lakes Nakuru and Elementaita. Mount Longonot (3,000 m) with its lava sheets and associated volcanic cones forms a barrier to the South, which is breached by the Njorowa Gorge (Hells Gate), a former outlet of the Nakuran - Pleistocene lake which once occupied the Naivasha-Elementeita-Nakuru basin (Richardson «< Richardson 1972).

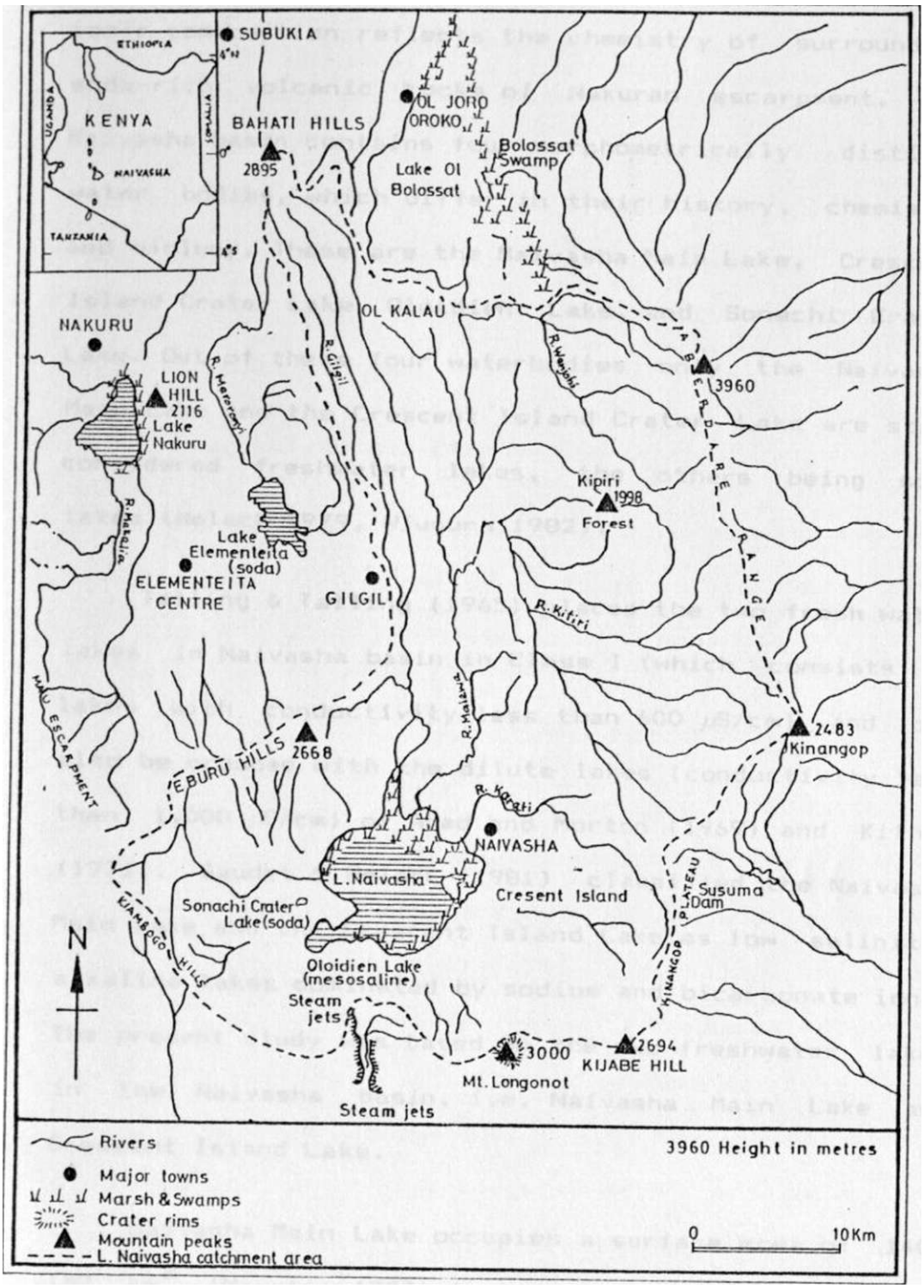


Fig. 1: **A map showing Geographical position of Lake Naivasha**

T L r d o ? t ^ y ° 0t^er lakes in tho K°nyan valley.
The dotted line shows the outer limit of Lake Naivasha catchment area (adopted with permission from Mavuti 1983)

The Naivasha basin has no surface outlet and its ionic composition reflects the chemistry of surrounding soda-rich volcanic rocks of Nakuran escarpment. The Naivasha basin contains four morphometrica11y distinct water bodies, which differ in their history, chemistry and biology. These are the Naivasha Main Lake, Crescent Island Crater Lake, Oloidien Lake, and Sonachi Crater Lake. Out of these four waterbodies only the Naivasha Main Lake and the Crescent Island Crater Lake are still considered freshwater lakes, the others being soda lakes (Melack 1979, Njuguna 1982).

Tailing & Tailing (1965) placed the two fresh water lakes in Naivasha basin in Class I (which consists of lakes with conductivity less than 600 ^jS/cid) and can also be grouped with the dilute lakes (conductivity less than 1,000 /jS/cm) of Arad and Morton (196?) and Kilham (1971). Gaudet & Melack (1981) classified the Naivasha Main Lake and the Crescent Island Lake as low salinity, alkaline lakes dominated by sodium and bicarbonate ions. The present study was based on the two freshwater lakes in the Naivasha basin, i.e. Naivasha Main Lake and Crescent Island Lake.

Naivasha Main Lake occupies a surface area of 140-152 km^2 (Mavuti, 1983) including the fringing swamps, with a mean depth of 4.7 m and a maximum depth of 7-8 m at high water levels. Due to its shallowness, gently

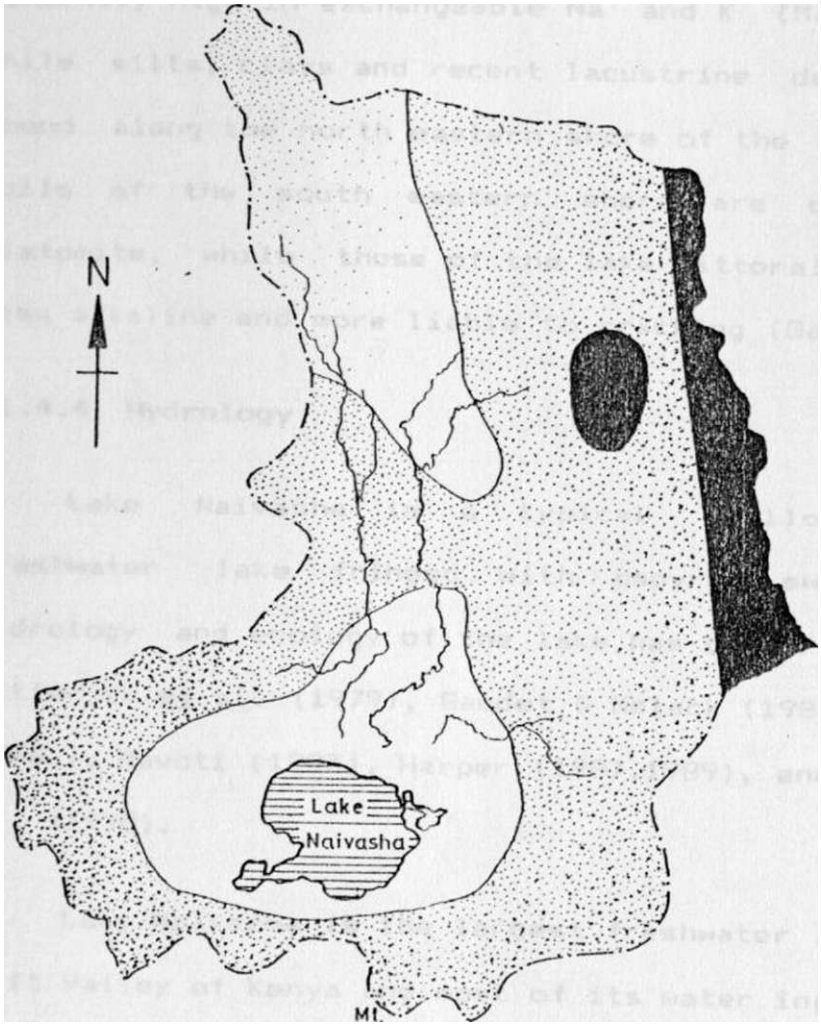
sloping sides and climatic variation, its surface area and that of the fringing papyrus swamps and littoral lagoons are very variable, especially along the northern shore (Gaudet & Melack, 1981). The Crescent Island Lake has an area of 2.1 km^2 (Mavuti 1983) and a maximum depth of 16 m in 1990. It is bordered by Crescent Island, but normally there is a connection with the Main lake especially during high water levels.

1.4.2 Vegetation and Climate

Lake Naivasha lies in a marginal area with woodland savanna vegetation (zone IV of Pratt ejt al_- 1966) which consists of a semi-arid climate with moisture indices of -30 to -40.

1.4.3 Geology and Boils

The geology of the lake basin was described by Gregory (1921), Thompson & Dodson (1963),and reviewed by Richardson & Richardson (1972) and Gaudet ?< Melack (1981). The lake basin region is characterised by faulting especially in the valley floor, with slight folding in the Njorowa Gorge, with the rocks of the basin consist of an assemblage of acidic and basic lavas as shown in Fig. 2. Ongweny (1973) described the soils occupying the floor of the Rift as grey or brown to pinkish non-calcareous soils. Soils surrounding the origin of the River Malewa, Lake Naivasha's major



Basalt, Quart-trachyte Tertiary
Pyroclastics Quartenary
Pyroclastics Tertiary
Lacustrine deposits

0 5 10 15 ?0Km

A map of Lake Naivasha catchment area showing its geology (Adopted from Syren 1986).

inflowing river, are young consisting predominantly of montmorillonite clays (Kilham 1971, Rachillo 1977). The soils along the northern shore of the lake are generally high in exchangeable Na^{+} and K^{+} (Makin 1967), while silts, clays and recent lacustrine deposits are found along the north eastern shore of the Main lake. Soils of the south eastern shore are composed of diatomite, while those of the lake littoral zone are less alkaline and more liable to cracking (Gaudet 1977).

1.1.4 Hydrology

Lake Naivasha is a typical shallow African freshwater lake fringed with papyrus swamps. The hydrology and ecology of the lake has been reviewed by Litterick et aL. (1979), Gaudet & Melack (1981), Njuguna (1982), Mavuti (1983), Harper (1987,1989), and Harper et. al. (1990).

Lake Naivasha is the largest freshwater lake in the Rift Valley of Kenya and most of its water inputs come from the Aberdare Range and Kinangop Plateau through the River Malewa, which contributes 80 7. of the lake's inflowing water (1730 km^2 catchment) (Fig.3). The River Karati and other streams flowing from the Eburu Hills and Mau Escarpment (1,240 km^2 catchment), and the Gilgil River flowing from the Bahati Highlands (420 km^2 catchment), are either dry or flow intermittently during

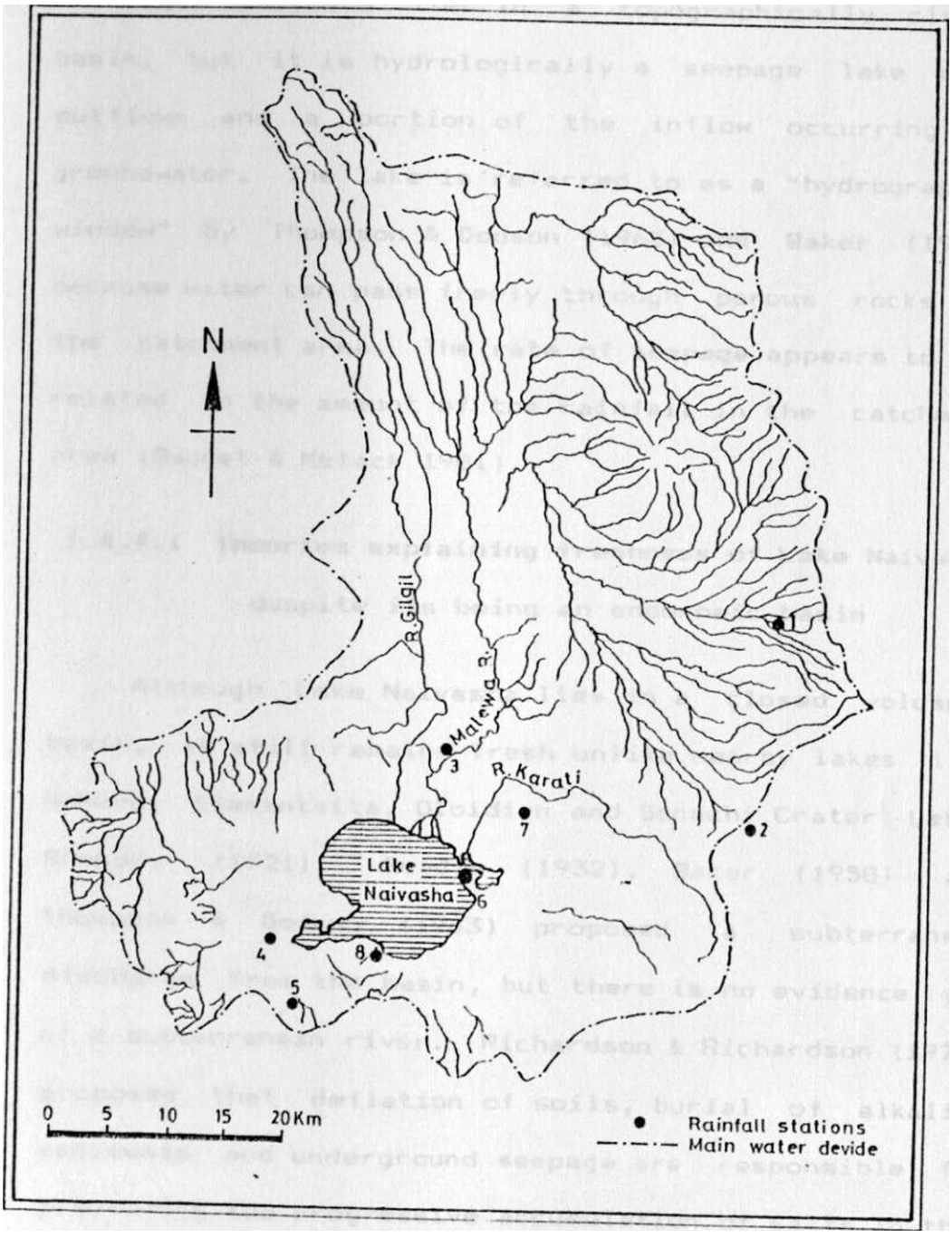


Fig. 3: Map of Lake Naivasha showing drainage patterns and sources of Rivers Malewa, Gilgil and Karati (Adopted from Syren 1986).

the dry season, but may play a substantial role in the lake hydrologica1 equilibrium through seepage inflows.

Lake Naivasha lies in a topographica11y closed basin, but it is hydrologica1 1y a seepage lake with outflows and a portion of the inflow occurring as groundwater. The lake is referred to as a "hydrographic window" by Thompson & Dodson (1963) and Baker (1950) because water can pass freely through porous rocks in the catchment area. The rate of seepage appears to be related to the amount of the rainfall in the catchment area (Gaudet «< Melack 1981).

1.4.4.1 Theories explaining freshness of Lake Naivasha despite its being an endorlteic basin

Although Lake Naivasha lies in a closed volcanic basin, it still remains fresh unlike nearby lakes like Nakuru, Elementaita, Oloidien and Sonachi Crater Lake. Gregory (1921), Beadle (1932), Baker (1950) and Thompson & Dodson (1963) proposed a subterranean discharge from the basin, but there is no evidence yet of a subterranean river. Richardson & Richardson (1972) proposed that deflation of soils, burial of alkaline sediments and underground seepage are responsible for preventing the progressive accumulation of salts in the lake water. Gaudet & Muthuri (1901) suggested that the freshness of the lake is due to removal of nutrients by

aquatic plants in the littoral zone and the dilution effect of the incoming water from the River Malewa (with low total dissolved solutes), thus resulting in low solute input.

CHAPTER 2

LITERATURE REVIEW

2.0 Previous Studies on Nutrients and Phytoplankton Production

The effects of nutrients on phytoplankton production have been widely emphasised, and nutrients are known to play a leading role in regulating the size and composition of phytopiankton populations. Brylinsky & Mann (1973), Likens & Loucks (197B), and Handerson (1978) pointed out that aquatic productivity varied from one place to another, because of variation in nutrient availability. Tailing (1966), Lewis (1978), Hecky & Kling (1981), and Njuguna (1982) noted the importance of nutrients in determining phytopiankton species composition and succession. Njuguna (1982) reported that irradiance and temperatures in tropical systems were sufficient to allow continuous primary production throughout the year, but seasonal fluctuations in nutrient availability and concentration variation have been the principal factors controlling phytopiankton abundance.

Schindler «< Fee (1974, 1975) stressed the importance of rates of supply, rather than the nutrient concentrations, to phytopiankton growth. Investigations have shown that factors influencing the rate of nutrient

supply or loss from natural waters determined the equilibrium levels of primary production per unit phytopiankton biomass (Gaudet 1977, Gaudet & Muthuri 1981).

Mineral elements, such as phosphorus and nitrogen, often occur in micromolar quantities and frequently limit the rate of primary production in lakes (Hutchinson 1975). Phosphorus and nitrogen being important constituents of cell protoplasm with an important role in enzymatic and energy transport systems within cells, which could make them potential limiting nutrients (Reynolds 1984). Bioassays performed in African lakes usually indicate that either nitrogen, phosphorus or both limit phytopiankton growth (Fish 1956, Evans 1961, Moss 1969, Robert & Southhall 1975, Viner 1973, Melack et aJL 1982, Njuguna 1982).

Go1terman (1975) and Reynolds (1984) suggested that although nitrogen was usually quite abundant in temperate regions, it could be a limiting nutrient in a number of tropical lakes. Phytop1ankton production was likely to be limited by inorganic nitrogen (nitrite, nitrate and ammonium). The low nitrate concentrations reported in a variety of African lakes by Tailing & Tailing (1965) also suggested potential nitrate limitation of primary production. This has been supported by various studies, for example Fish (1956)

did algal culture experiments on algae from Lake Victoria and concluded that nitrate was a limiting nutrient in this lake. Tailing (1966) working in the same lake, found a relationship between depletion of nitrate and reduced algal activity. MOBS (1969) found that nitrate limited algal growth in cultures from Lakes Malawi, Chilwa and Malombe. Viner (1973) reported a positive correlation between nitrate and chlorophyll a concentrations in Lake George, Uganda.

Hutchinson (1975) and Wetzel (1983) concluded that phosphorus was more likely to limit primary production in lakes than any other nutrient, because of its major role in biological metabolism and the relatively small amounts being recycled in the biosphere. Phosphorus limitation of primary production was shown for a majority of oligotrophic and mesotrophic lakes in Rhodesia (Zimbabwe) (Roberts & Southhall 1975, 1977). Viner (1973) found that phosphorus concentrations were always low in Lake George, which indicated that phosphorus was a likely limiting nutrient. Melack ei §1- (1982) found that phosphorus was more limiting than any other nutrient in Lakes Sonachi and Elementeita, which are tropical soda lakes and among the world's most productive ecosystems (Likens 1975, Cole 1979). Sakamoto (1966), Vollenweider (1968), Dillon & Rigler <1974), Schindler & Fee (1974), Oglesby & Schaffner

(1978), and McCauley et a]. (1989) found excellent correlations between phytop1ankton standing crop and total or biologically available phosphorus. Rhee (1972) and Carrie «< Kalff (1984) pointed out that not all soluble phosphorus in lake water was available to phytopiankton because bacteria may compete effectively for phosphorus with phytopiankton. This indicates that phosphorus could be a primary limiting nutrient for phytop1ankton growth and productivity in both tropical and temperate regions (Petersen et. al- 1974).

2.1 Nutrient interaction studies in Lake Naivasha

The Lake Naivasha littoral zone has a large stock of nutrients that could be used to replenish low nutrient concentration in the open water (Gaudet 1977), and that is why Gaudet & Muthuri (1981) referred to the littoral zone of Lake Naivasha as the "nutrient kitchen" for the lake. Released nutrients could eventually be transferred from the littoral zone to the open lake by wind, animal migration or drifting of floating macrophytes (plant migration), which enter the limnetic food web resulting in increased open water production especially during high water levels (Gaudet & Muthuri 1981, Njuguna 1982, Mavuti 1983, Harper 1987).

Carbon, nitrogen, phosphorus, and silicon are important constituents of organisms and their supply

has had a major influence on the lake's ecology (Melack 1976). High bicarbonate concentrations reported in Lake Naivasha (Tailing & Tailing 1965, Kilham 1971) provide adequate carbon for algal photosynthesis. The presence of diatoms in the water column, reported in 1973-19BO for both the Main Lake and the Crescent Island Lake, indicates that there is no deficiency in silicates (Table 1). Kilham (1971) also reported that high silicon concentrations in the Naivasha basin (Table 2) may influence the phytopiankton species composition.

The standing stock of dissolved and total nitrogen in the Main Lake was larger than the input concentrations from the River Malewa (Gaudet 1977). Perhaps nitrogen inputs from seepage and nitrogen fixation in the papyrus swamps accounted for the relatively high nitrogen concentrations in the lake (Gaudet 1977, 1979). Seepage accounted for about 70 ′/. of the nitrogen and 40 ′/. of the phosphorus inputs to the open water, even though the North swamp has been significantly identified as a phosphate pump (Gaudet 1978). Atmospheric fall-out contributed 2-8 ′/. of the nitrogen and 7-23 ″/. of the phosphorus inputs to the lake (Njuguna 1982). Kalff (1983) and Peters & MacIntyre (1976) indicated that the nutrients limiting algal

Table 1. Phytop1ankton species composition of Lake Naivasha in 1973-19BO (From Melack 1976, Njuguna 19B2, Mavuti 19B3).

1973 - 1974	1978 - 19BO
Phylum: Cyanophyta	
Lyngbya contorts	*Lyngbya contorts* Lemm.
Aphanocapsa sp.	*Aphanocapsa el achistaM* & G.S.West
Anabaenopsis tanganyi kae	*Anabaenopsis tanganyik*aeG.S. West
Microcystis sp.	*Microcystis aeruginosa* Kutz.
Merismopedia sp.	*Rhizo&olenia* sp.
Chroococcus sp.	*Osci11 a tori a splendidaGrev.*
Spiru1ina 1axisima G.S. West	*Microchaete* sp.
Phylum: Chrysophyta (Bacilliarophyta)	
Synedra acus	*Synedra acus* (Kutz.)Grun.
Surirel1 a linearis W.Smith	*Surirel1 a* sp.
Nitzschia sp.	*Synedra ulna* (Nitz.)Ehr.
Melosira ambigua	*Melosira ambigua* (Grun.)Mull
	Melosira italica (Ehr.)Kutz.
	Navicula sp.
	Cymbel1 a sp.
Phylum: Chlorophyta	
	Scenedesmus diamorphus Kutz.
	Pediastrum sp.
	Ch1amydomonas sp.
	Ankistrodesmus sp.
	Cosmarium sp.
	Haema tococcus sp.
	Coelastrum sp.
	Kirchneriel1 a sp.
	Botryococcus sp.
	Oocystis sp.
	Eudorina sp.
	Chromu1ina sp.
	Mallomonas sp.
	Ac tinastrum sp.
	Staurastrum cornuturn
	*Tetraedron minimum(*A.Br.)Hansg.
	Ec taedron vie torae
	Cryptomonas sp.
	Trac he] omonas sp.

Table 1 cont'd

Rhodomonas **sp.**

Phylum: Euglenophyta

Euglena gracilis **Klebs.**
Phacus **sp.**

Phylum: Pyrrophyta

Peridinium pusillum
Gymnodinium **sp.**

Table 2. Concentration of silica in the waters of Naivasha Main Lake and Crescent Island Lake in 1973 (mg/1) (from Melack 1976).

Date(Months)	Main Lake	Crescent Island Lake
March	29.4	26.4
April	26.4	
May	**28.2**	**28.2**
June	23.4	
July	20.4	31.2
September		
October	37.2	
November		31.2
December	**28.2**	

were similar to those limiting algal biomass in other African lakes, e.g. Lake George in Uganda (Viner 1977) and Lake Victoria (Fish 1956, Tailing 1966). These nutrients had short turnover times and exhibited low concentrations in open waters compared to the littoral zone (Gaudet & Muthuri 1981).

Enrichment experiments with Lake Naivasha water samples suggested that both phosphorus and nitrogen limited algal biomass (Anon 1978). Kalff (1983) found that the relationship between algal biomass (as chlorophyll a) and total phosphorus was the same as that reported for phosphorus-1imited temperate lakes during the summer. Njuguna (1982) found high ratios of N/P which indicated phosphorus deficiency. Peters &

MacIntyre (1976) found rapid turnover rates for P-PO4 and extremely low concentrations of soluble reactive phosphorus in Lake Naivasha, indicating a great biological demand for orthophosphate in the lake, which might be a limiting nutrient for phytoplankton production. There was no difference in total dissolved solids especially Na and bicarbonate ions between the Naivasha Main Lake and Crescent Island Lake (Kilham 1971, Gaudet & Melack 1981).

2.2 Phytoplankton species diversity, biomass and photosynths»tic rate in Naivasha basin lakes.

Lake Naivasha was categorised as a moderately

eutrophic lake because of its algal biomass (Anon 1978, Njuguna 1982, Harper 1987) though the chlorophyll a level recorded was below the maximum for very nutrient -rich lakes (Tailing et aj_. 1973). Njuguna (1982) reported a high algal biomass in the Main Lake which was positively correlated with rainfall and negatively correlated with N/P ratios. Chlorophyll a concent- rations in the open waters of Lake Naivasha steadily increased from 1982 to 1988, paralleling increases in nutrient concentrations and conductivity (Harper 1907, 1989).

There was an even vertical distribution of algal biomass in the water column, both in Naivasha Main Lake and Crescent Island Lake, which was attribut»d to daily mixing of the water column (Anon 1978). The phytopiankton species composition varied little from year to year in Lake Naivasha (Mavuti 1983).

There were distinct differences in maximal photosynthetic rates in the Main Lake and the Crescent Island Lake (Melack 1976, Harper 1987) with higher rates in the Main Lake. Areal photosynthetic rates varied less between these lakes than did volumetric photosynthesis. Melack (1976) reported that variation in photosynthetic rate corresponded with variation in chlorophyll a concpntration. Photosynthetic rate increased with increased rainfall in Lake Naivasha, but this could

have been due to increased nutrients and hence subsequent growth of phytoplankton (Melack 1979). Gaudet 8c Muthuri (1981) indicated that differences in production between the Main Lake and Crescent Island Lake were related to lake area and mean depth of the lake.

2.3 Factors controlling algal biomass and photosynthetic rates in lake systems

Brylinsky & Mann (1973) pointed out that not all tropical lakes are productive, while Hecky & Kling (1987) noted that biomass in African lakes could be low, but associated primary production rates could be high. East African lakes are known for their high photosynthetic rates (Melack 1976). Algal photosynthetic rates were influenced by several factors. It was generally accepted that the quantity of available light was an important determinant of primary production (Ganf 1972, Edmondson 1956, Ryther 1956), which in turn was affected by incident solar radiation, turbidity, depth and light reflection (Owens *et al*. 1969, Youngman *et al*. 1976). Depth of the euphotic zone, mixing depth, light attenuation and solar radiation should all be measured when studying rates of photosynthesis. In some waters photosynthesis was suppressed in surface waters because of photoinhibition of photosynthetic reactions, increased photorespiration,

and sinking of phytopiankton (Steemann-Nielsen 1952, 1962, Ryther 1956, Tailing 1965, Goldman et al_. 1973, Harris & Lot 1973, Viner 1973, Reynolds 1984).

The rate of production can be dependent on temperature, (Harris 1973). Njuguna (1982), however, indicated that temperature was not an important factor in the rate of production in African aquatic ecosystems.

Other external factors such as geochemical processes, vegetation type and cover, groundwater discharge and human activity may greatly influence the productivity of lakes by affecting nutrient inputs into lakes (Livingstone 1977). Viner (1973) reported that increased supplies of nutrients could alter oxygen exchange of algae by increasing respiration rate and not photosynthetic rate.

Phytop1ankton production may also depend on the quantity and species diversity of a phytopiankton assemblage (Jewson & Taylor 1978). Self-shading resulted when phytop1ankton density was high, thus reducing the euphotic zone (Ganf 1972). Therefore changes in algal concentration influenced gross production per unit area by affecting the depth of the euphotic zone and rates of optimum photosynthesis.

CHAPTER 3

MATERIALS AND METHODS

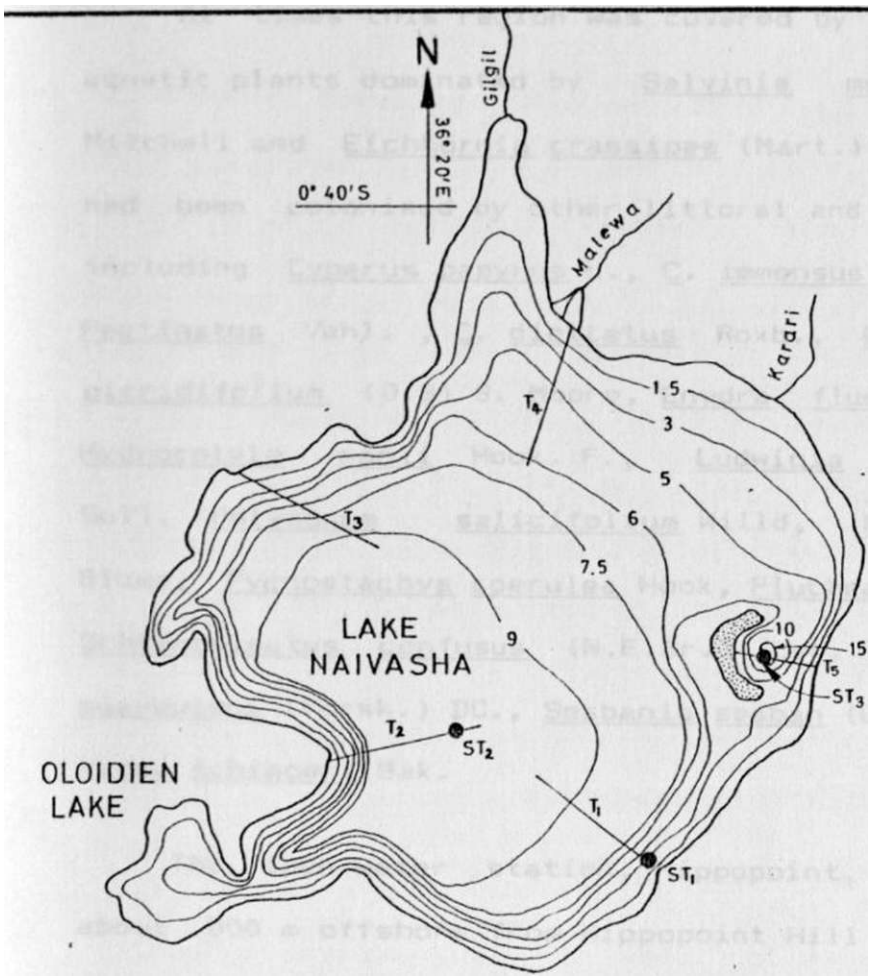
3.1 Preliminary Survey

The general survey of Naivasha Main Lake and Crescent Island Lake was done in October to December 19B9, by collecting surface water samples (0 to 0.5 m depth) from five different transects, running from the littoral zone to the open water (Fig. 4). Five replicates were collected along each transect using a MacVuti volume sampler (Mavuti & Litterick 1781). Chlorophyll a concentrations and algal composition were analysed in the laboratory.

3.2 Routine Sampling Stations

Three routine sampling stations, representing three ecological zones in Lake Naivasha (Fig. 4), were chosen after the preliminary study, see sections 3.1 and 4.1.

The littoral zone station was located near Safari land about 200 m from the papyrus edge of Safariland Lodge, with a maximum depth of 3 m. Extensive beds of submerged macrophytes are found in this region. Potamoggton octandrus poir dominated shallow waters less than one metre depth, while P. pectinatus L. and Najas pectinata (pari.) Magnus were abundant, especially between one to three metres depth.



T_i-T_5 General survey transects

ST| Safariland - Littoral zone station

STi Hippopoint - Open water station

STj Cresent Island - Enclosed ecosytem station

-7.5- Contours in metres

Fig. 4: Bathymetric map of Lake Naivasha showing the five general survey transects and the three routine sampling stations (Adopted from Mavuti, 1983 with permission).

At times this region was covered by free floating aquatic plants dominated by Sa)vinia molesta (D.S.) Mitchell and Eichhornia crassipes (Mart.) Solms., which had been colonised by other littoral and land plants inc luding Cyperus papyrus L. , C. immensus C.B.CI., C. Pectinatus Vahl. , C. diqitatus Roxb., Crassocephalum picridi folium (D.S) S. Moore, Enydra fluctuans Lour., Hydrocoty1e manii Hook. F., Ludwiqia stoloni fera Gull, Polygonum sal ici fol ium UJilld, P. pulchrum Blume, Pycnostachys coerulea Hook, Pluchea pvalis DC., Schoenoplectus confusus (N.E.Br.) Lye, Sphaeranthus suaveo1ens (Forsk.) DC., Sesbania sesban (L.) Merr. and Viqna schimperi Bak.

The open water station, Hippopoint, was located about 800 m offshore from Hippopoint Hill and had a maximum depth of 8 m. This station was situated in deeper waters with no submerged macrophytes. Occasionally this station was covered by mats of Salvinia molesta and Eichhornia crassipes. also often colonised with other water edge plants. These floating mats around the lake moved in rafts or islands of varying sizes especially during the high water levels.

The semi-enclosed basin (lagoon) station was located in Crescent Island Lake about 500 m from the shore of Crescent Island and had a mean depth of 14 m. This station was free of floating Salvinia mats.

3.3 Routine Sampling

Routine sampling was carried out at the three ecological zones stations in the Main Lake and Crescent Island Lake at monthly intervals from January to September 1990 (Fig. 4). Vertical series of water samples were taken from the surface to the bottom at all stations including surface, 1, 2 and 3 m depths at Safariland Station, surface, 1, 2, 3, 5 and 7 m depths at Hippopoint Station, and surface, 1, 2, 3, 5, 7, 9, 11 and 13 m depths at Crescent Island Lake Station. Triplicate samples were taken at each depth at all three stations using a MacVuti sampler. Water was collected in two litre plastic containers for transport to the laboratory for analysis.

Phytop1ankton samples were collected using a phytopiankton net of 60 fjm mesh hauled vertically through the water column, and placed in 150 ml bottles, preserved in a few drops of Lugol's iodine solution and transported to the laboratory for identification. The phytop1ankton species present were classified as follows: Present: if observed but very rare, common: when consistently observed, dominant: if quite common, pre-dominant: if it represents more than half the total number of species present and algal bloom if highly pre-dominant and almost the only species present. The total number of phytopiankton species present every

month was noted in each station. This information was used to estimate phytopiankton seasonal dynamics and species richness in the lake.

Vertical profiles of water temperature and dissolved oxygen were measured iri situ using a YSI model 57 oxygen meter with a combined oxygen and temperature probe graduated in ppm for oxygen and °C for temperature. The meter was corrected for temperature and calibrated for altitude before measuring dissolved oxygen and occasionally calibrated with the Winkler method (Winkler 18S8). Conductivity samples were collected from different depths (at surface, 1 and 3 *m* depths at Safariland, surface, 2, 5 and 7 m depths at Hippopoint, surface, 4, 9 and 14 m depths at Crescent Island Lake) mixed in a bucket for each station, and conductivity determined using 25°C temperature-corrected conductivity meter, YSI model 33 S-C-T (in pS/cm)

3.4 Analysis of the samples

3.4.1 Alkalinity

On arrival to the laboratory, 50 ml of each sample were used for alkalinity determinations using the 0.02N sulphuric acid titration method with mixed bromocresol green-methyl red, and phenolphthalein as indicators (Golterman 1969). Alkalinity relationships were calculated using the Wetzel and Likens (1979)

formu1e

TA VA_2 x N x 50000/VS

PA VA_X x N x 50000/Vs

CA 2 (PA)

BA TA - 2(PA)

where

TA = Total alkalinity in mg CaCoj/L

PA = Phenolpthalein alkalinity in mg CaCoj

CA = Carbonate alkalinity in mg CaCoj

BA = Bicarbonate alkalinity in mg CaCo3

VAj = Volume of acid used to first end point in ml

VA2 = Total volume of acid in ml

N = Normality of the acid

VS = Volume of sample titrated in ml

50000 is a constant

3.4.2 Phytoplankton biomass

Phytopiankton biomass was estimated as chlorophyll a using 90 7. methanol for extraction after filtration of 250 ml of sample water through a 0.45 pm GFC glass fibre filter (WRC 1973). Absorbance of the extract was measured at wavelengths 665 nm and 750 nm and concentration of chlorophyll a was calculated using the Tailing & Driver (1963) formula:

$$\text{Chi .a} = \frac{Ve.\ E.\ OD^{665}_{750}}{Vf.L}$$

where

Chi. a = Concentration of chlorophyll a in /vg/L

Ve. = Volume of extract in ml

E = Extinction coefficient of chlorophyll a in 90 ⁄. methanol (13.9)

OD^{665}_{750} = Absorbancp of the extract at 665 nm less absorbance at 750 nm

Vf = Volume of water filtered in litres

L = Pathlength of cuvette in cm (2.5)

3-4.3 Inorganic nutrients

Subsamples for nutrient analyses were prepared within four hours after collection by filtering a portion of a well-shaken sample through a Whatman GF/C glass fibre filter, which had been pre-rinsed with de-ionised distilled water. The filtered sub-samples were stored in polyethylene bottles and kept in the refrigerator until analyses were performed.

i I

3.4.3.1 Nitrogen

3.4.3.1.1 Nitrate nitrogen (NO_3-N)

Nitrate nitrogen was determined by reduction to nitrite using the spongy cadmium method of Mackereth et al. (1978) modified from Elliot & Porter (1971). Nitrite before and after reduction was determined using the sulphanilamide method of Strickland and Parsons

(1972), through formation of a pink-azo dye (Mackereth et al. 1978). The concentration of nitrate was determined through calibration with standard nitrate solution and corrected by subtraction of the amount of nitrite present before reduction.

3.4.3.1.2 Ammonium nitrogen **(NH4-N)**

Ammonium nitrogen was determined using the sodium salicylate / sodium diehioroisocyanurate technique modified from Havilan et al_-d<?77). Fifty millilitres of filtered water sample was put in a 100 ml volumetric flask and 10 ml of salicylate reagent added , followed by IO ml cyanurate reagent using Bibbys pressmatic 7.000 dispensers. The bottles were swirled for a few seconds and made into volume using distilled de-ionised water. Bottles were allowed to stand for at least 30 minutes at room temperature for colour development. The optical density of the solutions was determined at wavelength 667 nm in a 2.5 cm cuvette against a compensator cuvette containing distilled de-ionised water. The concentration of ammonium was calculated through calibration with standard solutions of ammonium sulphate.

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3.4.3.1.3 Dissolved Inorganic nitrogen

Dissolved inorganic nitrogen (DIN) was estimated by summing the concentrations of nitrite, nitrate and ammonium.

3.4.3.2 Phosphorus

3.4.3.2.1 Soluble reactive Phosphorus

Soluble reactive phosphorus (orthophosphate) was determined in filtered water samples using Mackereth Ht a1. (1778) high sensitivity extractive method using Ilexan-1-Ol (n—hexanol). The atasorbance of blue hexanol was determined at wavelength 668 nm against blank of hexanol.

3.4.3.2.2 Total Phosphorus

Total phosphorus was determined by converting organic phosphorus into soluble inorganic phosphate by digesting 100 ml of unfiltered water sample in a conical flask with potassium persulphate (0.7 g) and 2 ml of ION sulphuric acid for 30 minutes. After cooling the solution was neutralised by adding 2N sodium hydroxide solution until the colour changed to pink using 0.5 ml of phenolphtha1ein as indicator. The pink colour was discharged by addition of 0.36N sulphuric acid followed by addition of 0.5N sodium hydroxide until the pink colour was just restored. Neutralisation ensured that the pH of the solution was not too low to interfere with t colour development (Mackereth et al. 1978). Inorganic phosphorus was determined by the molybdenum blue method of Strickland and Parsons (1972) and absorbances determined at wavelength 880 nm (Mackereth et al. 1978)

against a blank of distilled water. All absorbances were measured using a Bausch and Lomb Spectronic Mini 20 Spectrophotometer except for total phosphorus were Unicam SP 500 Series 2 Ultraviolent visible spectrophotometer was used.

3.5 **Determination of rates of photosynthesis.**

Measurements of rates of photosynthesis were carried out using the light and dark bottle oxygen technique (Vo11einweider 1969). Water samples from different depths distributed over the water column at each station were taken monthly using the MacVuti sampler, and siphoned into 250 ml pyrex glass bottles. Thr?=;e bottles were then suspended horizontally in pairs (two dark and two light) at the same depths where the samples were collected (Fig.5). The duration of incubation varied between 2 to 4 hours at around midday. The amount of dissolved oxygen before and after-incubation was determined using an iodometric titration technique of Winkler (1BBB). Water samples were processed immediately after incubation by adding 1.5 ml of manganous sulphate solution (MnSO/j^h^O) followed by 1.5 ml of alkaline iodide solution (Winkler reagent) just below the water surface. The bottle was carefully stoppered and shaken vigorously. The resultant precipitate of manganous hydroxide ($Mn(0H)_2$) absorbed the oxygen in the sample water to form manganese

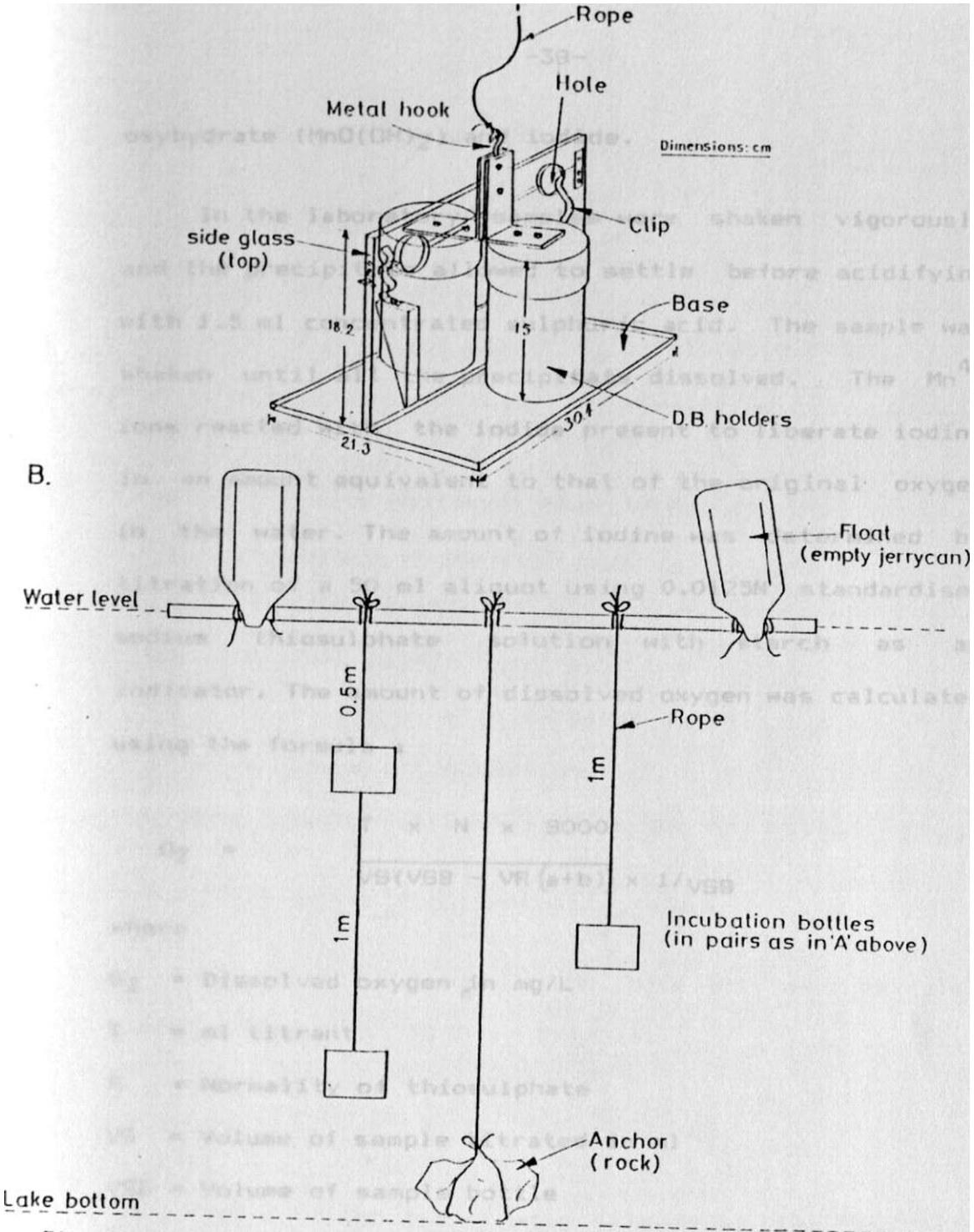


Fig. 5: Diagrammatic plan of the apparatus for photosynthetic rate incubations (modified from Volleinweider 1969).

oxyhydrate (MnO(OH)2> and iodide.

In the laboratory samples were shaken vigorously and the precipitate allowed to settle before acidifying with 1.5 ml concentrated sulphuric acid. The sample was shaken until all the precipitate dissolved. The tin ions reacted with the iodide present to liberate iodine in an amount equivalent to that of the original oxygen in the water. The amount of iodine was determined by titration of a 50 ml aliquot using 0.0125N standardised sodium thiosulphate solution with starch as an indicator. The amount of dissolved oxygen was calculated using the formula :

$$°2 = \frac{T \times N \times 8000}{VS(VSB - VR(a+b)) \times 1/ySB}$$

where

O2 = Dissolved oxygen jn mg/L

T = ml titrant

N = Normality of thiosulphate

VS = Volume of sample titrated in ml

VSB = Volume of sample bottle

VR = Volume of reagents a + b

a = Volume of manganous sulphate solution in ml.

b = Volume of alkaline iodide solution in ml.

Dissolved oxygen concentrations were corrected for altitude of 1870 m. a.s.l by multiplying with a 1.26 correction factor according to Mortimer (1956).

3.5.1 Gross Photosynthesis

Gross photosynthesis was calculated using the formula of Wetzel & Likens (1991) :

$$GP = \frac{(O_2\ LB) - (O_2\ DB)(1000)(0.375)}{(PQ)(t)}$$

where

GP = Gross photosynthesis in mg C/m^/hr

= Oxygen in mg/L

LB = Light bottle

DB = Dark bottle

PQ = Photosynthetic quotient (1.2)

t = Hours of incubation

0.375 = Ratio of moles of carbon to moles of oxygen

3.5.2 Specific Photosynthetic rate

Specific photosynthetic rate (P) was calculated using Reynolds (1984) formula:

$$P = GP/n$$

where

P = Specific photosynthetic rate in mg C(mg Chi. a)/hr

Gp = Gross photosynthesis in mg $C/m^3/hr$

n = Chlorophyll a concentration in mg Chi. a/m^3

3.5.3 Assimilation ratio numbers

Assimilation number (mgC/mg Chi.a) is the ratio at

light saturation region between maximum gross photosynthetic rate (Gpmax (mgC/m^/hr) and plant biomass (mg Chi. a/m^) (Tailing 1965, Curl & Small 1965).

3.5.4. Effect of light on photosynthetic rates

Light attenuation depth was measured using a 25 cm diameter secchi disc with alternating black and white quadrants. The light extinction coefficient was calculated using the formula 1.7/d (Cole 1979), where d = secchi depth in metres. Depth of the euphotic zone was calculated as 2.35 x d where d = secchi depth in metres defined by 1 7. incident energy (Lemoalle 1981).

Radiation wavelengths with depth were measured as a percentage irradiance using a pair of matching photoresistor filters and percentage measured using O_2 percent saturation scale meter Model (Lakes Inst. Co., Windermere, England). This was used in conjunction with a Kipp v. zoner solarimeter with a Delta - T Devices millivolt integrator to estimate the irradiance levels. The photosynthetic efficiency was calculated using the following formula (Lind 1979):

$$PE = \frac{C \times 2 \times 5500}{SE \times 0.5} \times 100$$

where

PE = Phosynthentic efficiency in percent

C = Carbon in $g/m^2/day$

SE = Solar energy in calories/m^2/day

5500 = approximate calorimetric equivalent per gram dry algal tissue

2 = approximate conversion factor of carbon to dry algal tissue

0.5 = factor for the conversion of total solar radiation to the portion of spectrum that is photosynthetically active (PAR)

n

RESULTS AND DISCUSSION

CHAPTER 4

4.0 Physico-chemical characteristics of Lake Naivasha

4.1 Preliminary study

The phytop1ankton composition at the Main Lake transects (Tj - Tq) was dominated by Closterium sp while Melosira spp dominated Crescent Island Lake transect <T_5).

Chlorophyll a concetration was highest along T_2 with a range of 70.0 - 75.6 >jg/l and lowest at T5 (13.5 -27.8 jjg/1). The other transects (Tj , T2 & T3) had mean values of 46.7 - 54.5 >jg/l and were not significantly different from each other. The analysis of variance indicate that T2 and ("5 were significantly different in chlorophyll a concentration from Tj, T3 and T4 ($p < 0.05$). On the above basis, the three routine sampling stations were chosen i.e Safariland station at T^ to represent T3 and T/j , Hippopoint station along T2 and Crescent Island Lake station along T5.

4.2 Rainfall

The monthly rainfall in 1989 to 1990 averaged over 8 stations (Fig. 3) in the Naivasha catchment area is

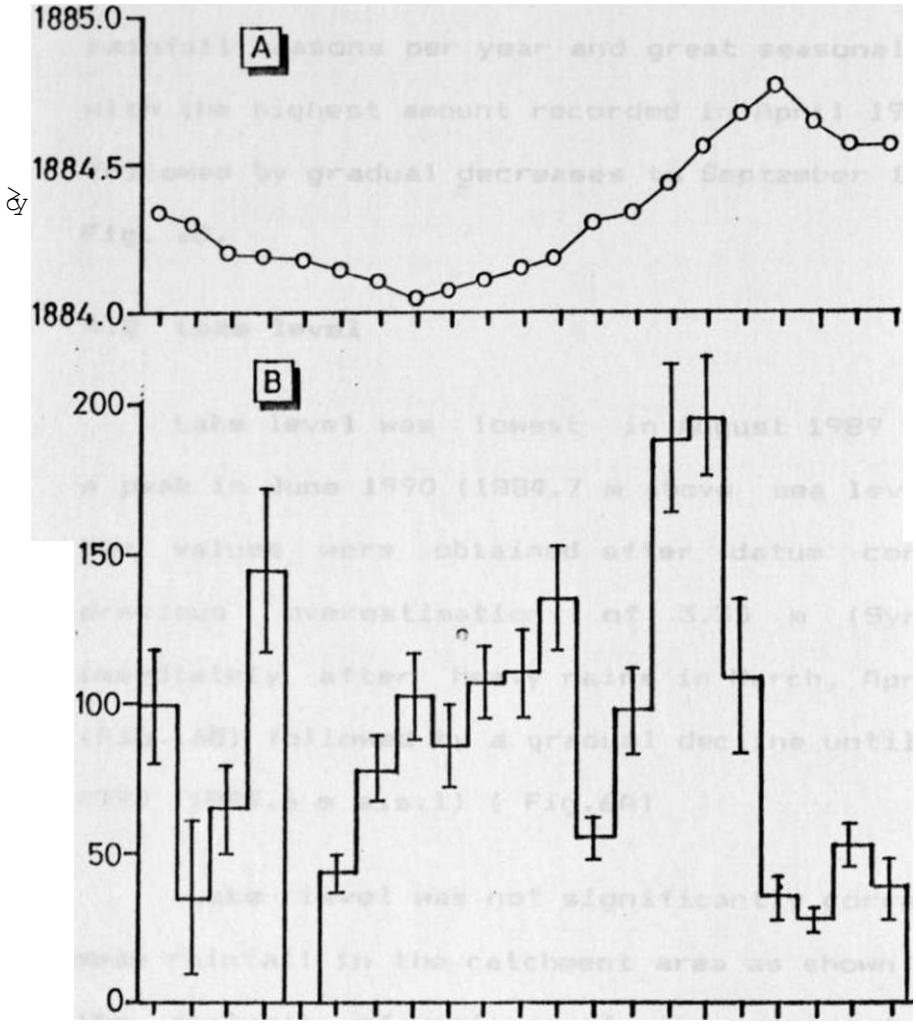


Fig. 6: (A) Mean monthly Lake levels (in metres above sea level) of Lake Naivasha in 1989-1990. Lake level data calculated from 2GDI with Dantum corrective factor of -3.35m from the Ministry of Water Development, Department of the Hydrology.

(B) Mean monthly rainfall of Lake Naivasha catchment area (By courtesy of the Meterological Department, Dagoretti, Nairobi, Kenya).

shown in Fig. 6B. The coefficient of variation (CV 7.) varies between 25-85, indicating great variation in the amount of rainfall recieved in different stations within the catchment area of Lake Naivasha. More rainfall was recorded at stations on the eastern side than the other sides of the lake (Fig. 3). The data shows two marked rainfall seasons per year and great seasonal variation, with the highest amount recorded in April 1990 (195 mm) followed by gradual decreases to September 1990 (30 mm) Fig. 6B.

4-2 Lake level

Lake level was lowest in August 1989 and reached a peak in June 1990 (1884.7 m above sea level (a.s.l.), the values were obtained after datum correction of previous overestimation of 3.35 m (Syren 1986)), immediately after heavy rains in March, April and May (Fig. 6B) followed by a gradual decline until September 1990 (1884.6 m a.s.l) (Fig.6A)

Lake level was not significantly correlated with mean rainfall in the catchment area as shown in Fig. 7. The analysis of variance of the regression equation shows that the lake level was not directly related to the amount of rainfall in the catchment area in 1989 to 1990 ($P = > 0.05$).

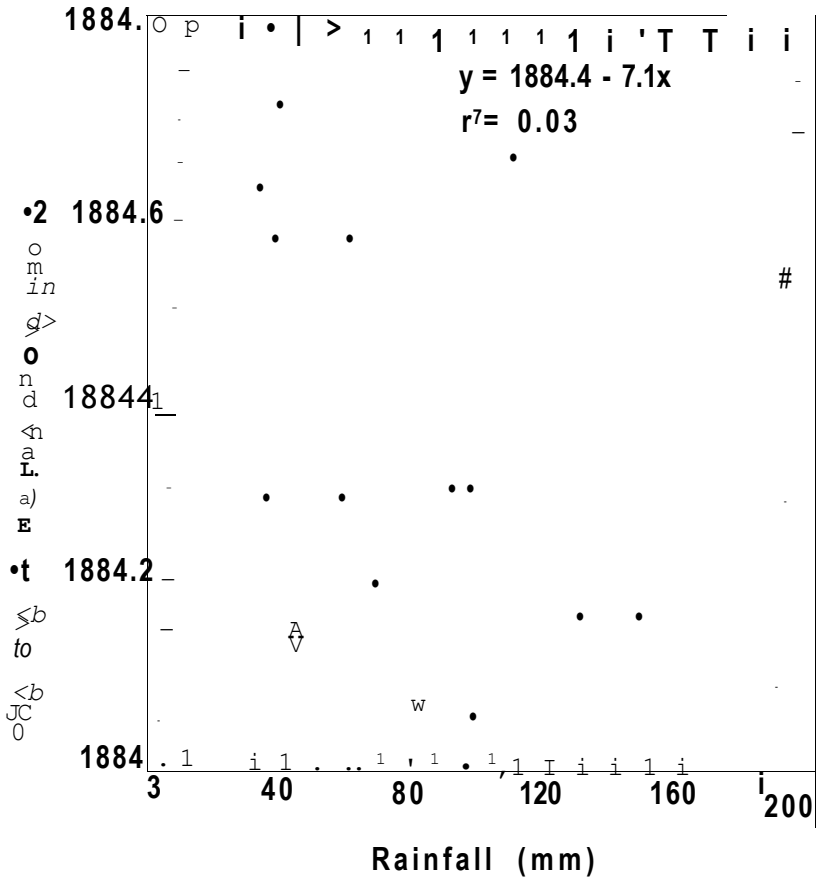


Fig. 7: **Naivasha catchment mean rainfall in 1989-1990**

4.4 Temperature and Oxygen

Maximum temperatures were observed at the surface, with a range of 19 to 24°C. At night surface temperatures can fall as low as 16°C (Harper pers. comm.). The Crescent Island Lake surface waters were warmer than those in the Main Lake by < 1.5°C (Table 3), except in May, July and August with highest temperatures recorded in January and March at Crescent Island Lake. Near isothermal conditions were observed in all the three stati sns most of the time (Fig. B). At times, however there was weak thermal stratification in Crescent Island Lake, with a difference of 2°C between surface and bottom (Fig. Be). The water column was well oxygenated with orthograde curves in all three stations except at times in Crescent Island Lake (Fig.8). Dissolved oxygen values varied from 6.0 in July to 10.6 mg 0_2/L in March (66.0 - 121.6 7. saturation) at Safariland, 2.1 in September at 6m to 9.5 mg O2/L in September (22.6 - 106 ′. saturation) at Hippopoint, and 0.2 at 13 m in January to 7.6 mg O2/L in September (2.3 - 85.3 ". saturation) at Crescent Island Lake. Generally the lowest concentrations of dissolved oxygon were recorded at Crescent Island Lake and highest at Safariland. Weak oxygen stratification was noted at Main Lake stations, however, dissolved oxygen stratification was well developed at Crescent Island Lake most of the

Table 3. Surface water (0-0.5 m depth) temperatures in °C of the three stations between January and September 1990.

Time (Months)	Safariland station	Hippopoint station	Crescent Island Lake
January	22.5	23	24
February	22.5	23	23.5
March	**22**	21.5	24
April	22.5	**22**	23.5
May	20.5	**20**	**20**
June	**20**	**20**	20.5
July	**20**	**21**	**21**
August	**21**	**20**	19.5
September	19	20.5	21.3

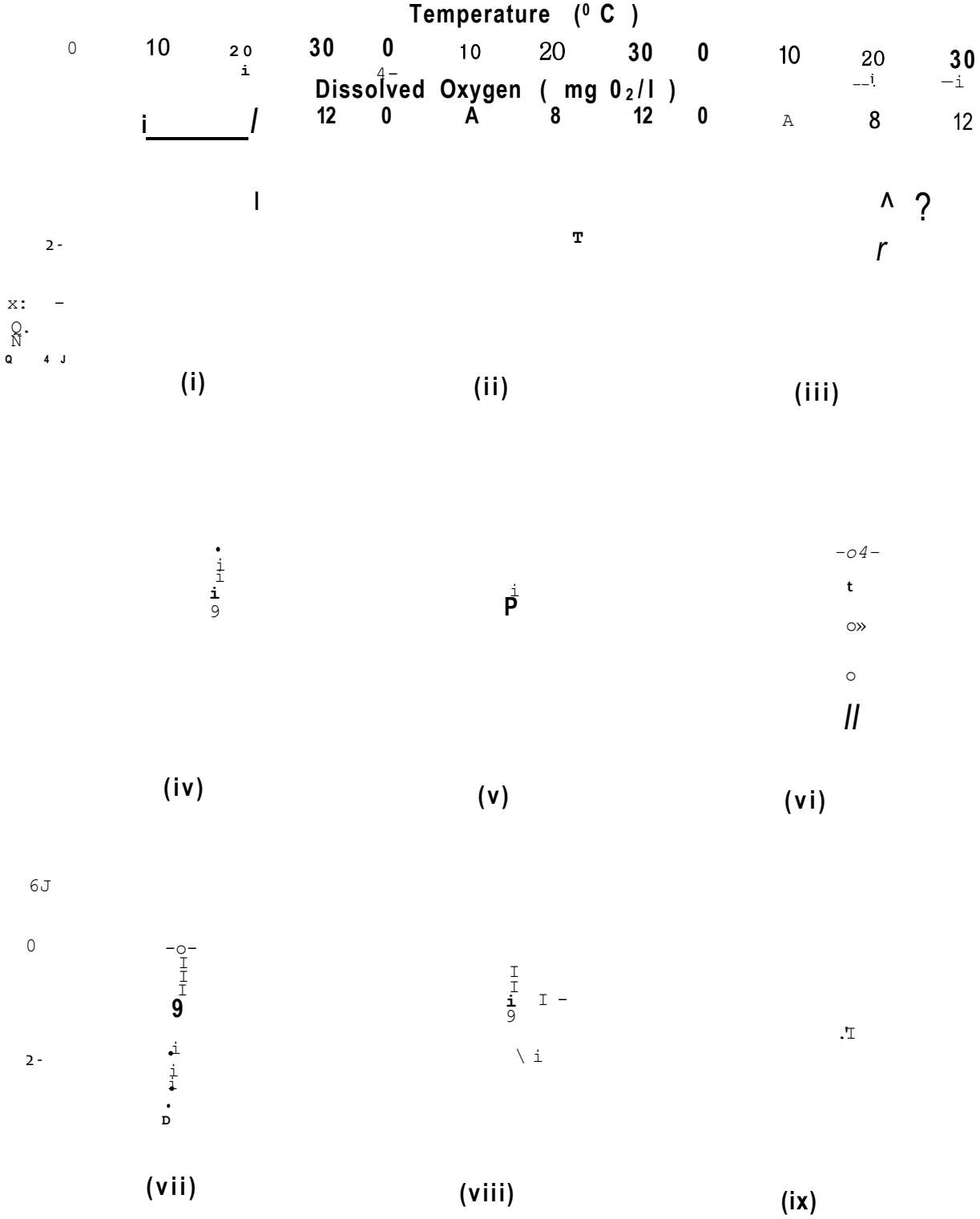


Fig. 8: (A) Temperature and dissolved oxygen profiles between January and September, 1990 (i-ix) at Safari land Station.

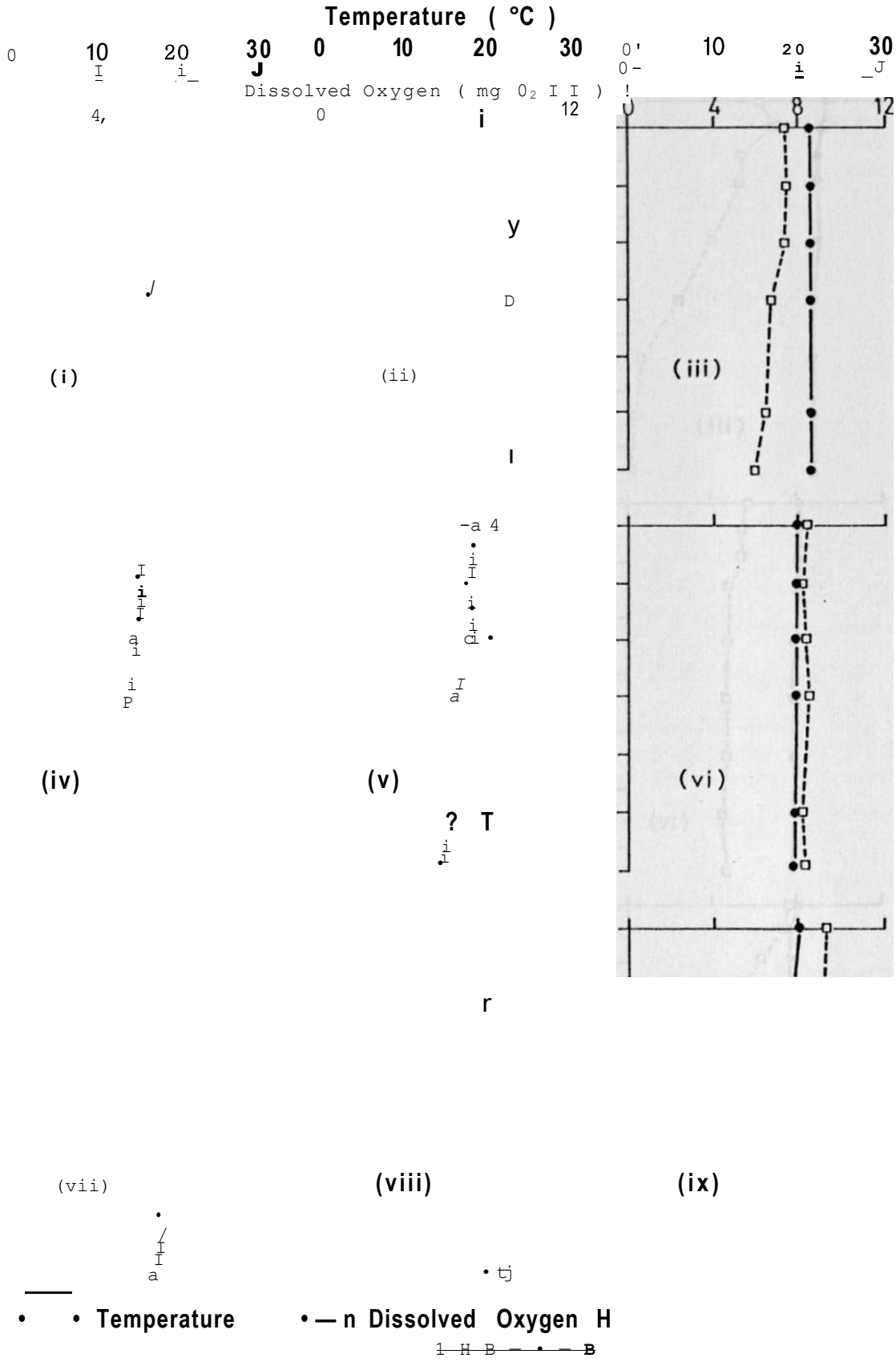


Fig. 8: (B) Temperature and dissolved oxygen profiles between January and September, 1990 (i-ix) **at** Hippopoint **Station.**

C.

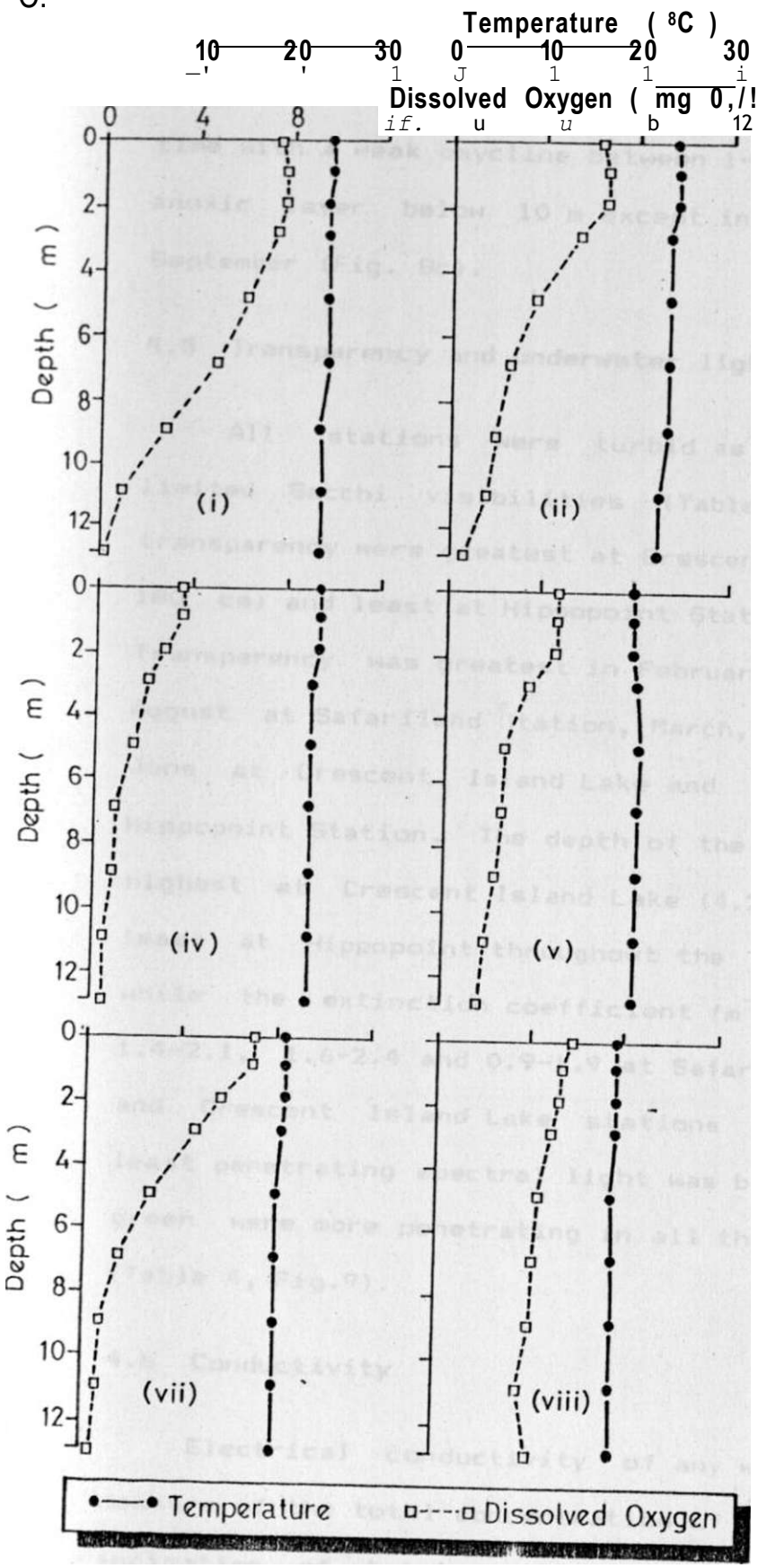


Fig. 8: (C) **Temperature and dissolved oxygen profiles between January and September, 1990 (i-ix) at Crescent Island Lake.**

time with a weak oxycline between 1-2 m depth and almost anoxic layer below 10 m except in June, August and September (Fig. 0c).

4.5 Transparency and underwater light attenuation

All stations were turbid as indicated by the limited Secchi visibilities (Table 4). Serchi disc transparency were greatest at Crescent Island Lake (90 - 10O cm) and least at Hippopoint Station (70 - 115 cm). Transparency was greatest in February-March and July-August at Safariland Station, March, and a sub-peak in June at Crescent Island Lake and in July-August at Hippopoint Station. The depth of the euphotic zone was highest at Crescent Island Lake (4.2 m in March) and least at Hippopoint throughout the study (Table 4), while the extinction coefficient (m ranged between 1.4-2.1, 1.6-2.4 and 0.9-1.9 at Safariland, Hippopoint and Crescent Island Lake stations respectively. The least penetrating spectral light was blue, while red and green were more penetrating in all the three stations (Table 4, Fig.9).

4.6 Conductivity

Electrical conductivity of any water body is a measure of the total concentration of ions and gives an indication of total dissolved salts and a measure of water quality. Conductivity was highest at Crescent

Table 4: Underwater extinction of Light in Lake Naivasha.

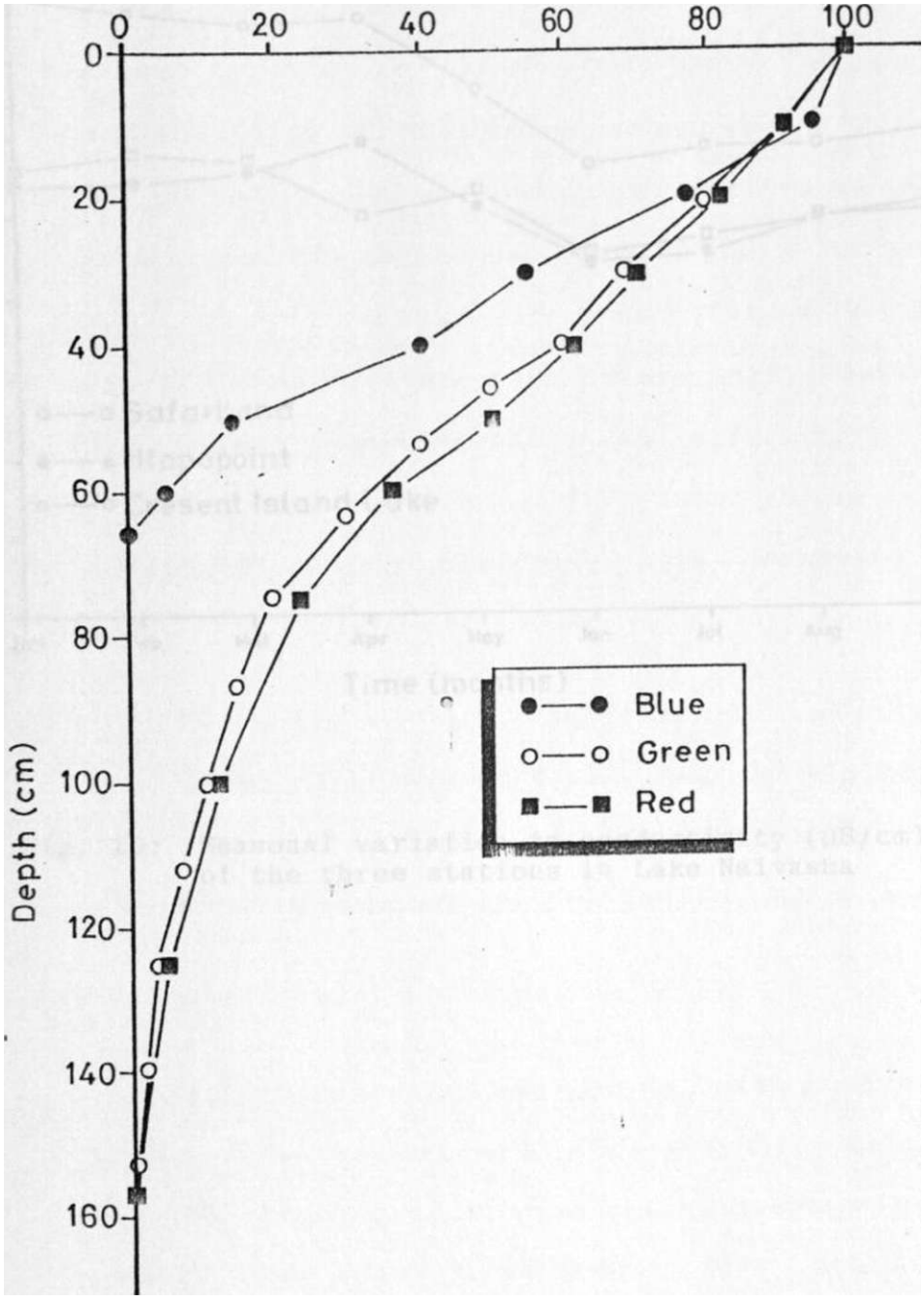
Station	Date	Water Transparency			Light Spectral penetration depth (cm)		
		Secchi Depth (cm)	Extinction Coefficient (m^{-1})	Depth of Euphotic Zone (eu^{n})m	450 nm (Blue)	540 nm (Green)	650 nm (Red)
Safariland	13/1/90	100	1.7	2.35	-	-	-
	2/2/90	115	1.48	2.70	-	-	-
	2/3/90	100	1.7	2.35	-	-	-
	3/4/90	90	1.89	2.12	40	100	125
	5/5/90	85	2.0	1.99	75	125	130
	5/6/90	85	2.0	1.99	50	100	125
	4/7/90	110	1.55	2.59	60	125	150
	6/8/90	120	1.42	2.82	75	125	125
	7/9/90	80	2.13	1.88	60	100	125

Cont. Table 4:

Station	Date	Water Transparency			Light Spectral penetration depth (cm)		
		Secchi Depth (cm)	Extinction Coefficient (nT^{1})	Depth of Euphotic Zone (eu^{m})m	450 nm (Blue)	540 nm (Green)	650 nm (Red)
Hippopoint	16/1/90	70	2.4}	1.65	.	.	.
	9/2/90	70	2.43	1.65	.	.	.
	7/3/90	70	2.43	1.65	.	.	.
	8/4/90	75	2.27	"1.76	40	60	100
	9/5/90	80	2.13	1.88	50	125	125
	8/6/90	85	2.0	1.99	60	100	125
	7/7/90	105	1.62	2.47	60	125	150
	8/8/90	115	1.48	2.70	75	125	150
	8/9/90	90	1.89	2.12	60	125	125

Cont. Table 4.

Station	Date	Water Transparency			Light Spectral penetration depth (cm)		
		Secchi Depth (cm)	Extinction Coefficient (nT^{1})	Depth of Euphotic Zone (eu)m	450 nm (Blue)	540 nm (Green)	650 nm (Red)
Crescent Island Lake	19/1/90	145	1.17	3.41			
	6/2/90	150	1.13	3.53 [c]	.	.	.
	3/3/90	180	0.98	4.23			
	5/4/90	112	1.52	2.63	20	50	75
	6/5/90	95	1.79	2.23	40	75	75
	12/6/90	120	1.42	2.82	75	175	175
	11/7/90	115	1.48	2.70	60	150	150
	10/8/90	103	1.65	2.42	60	150	150
	11/9/90	90	1.89	2.12	50	125	125



g-' Penetration of different light wavelengths in Lake Naivasha.

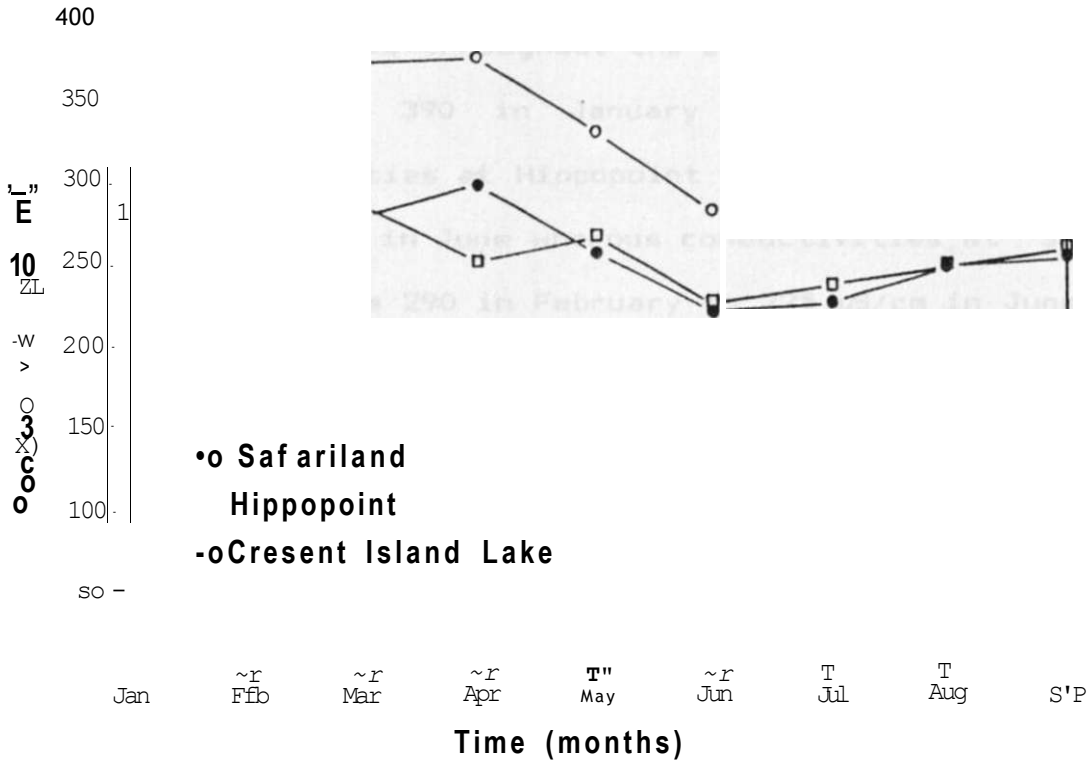


Fig. 10: Seasonal variation in conductivity (uS/cm) of the three stations in Lake Naivasha

Island Lake throughout the study period (Fig. 10) with values of 390 in January to 280 /jS/cm in June. Conductivities at Hippopoint ranged from 297 in April to 220 /jS/cm in June wherous conductivities at Safariland ranged from 290 in February to 225 /vS/cm in June. There was a general decrease of conductivity from January to June followed by a slight increase until September (Fig. 10). Lowest conductivities at all three stations coincided with the highest lake level in June (Fig. 6A), indicating ionic dilution with increases in lake 1eve1.

Conductivity was significantly correlated with lake level at Crescent Island Lake (P = 0.001, r O.93) and Safariland stations (P = 0.001, r = - 0.94 but not at Hippopoint station (P > 0.05, r = - 0.64).

4.7 Alkalinity

Alkalinity varied seasonally with moderate values during January to March (dry season) followed by a decrease from April to June (rainy season) then high values from July to September (dry season) at all stations (Table 5). There were generally higher and more variable values at Crescent Island Lake compared to the other two stations i.e. 42-167.2, 73.3-137 and 64-141.6 mg CaCoj/L at Crescent Island lake, Safariland and Hippopoint stations, respectively (Table 5). Alkalinity

Table 5: Alkalinity values and coefficients of variation (C.VX) with depth, from January to September, 1990.

A: Safarlland Station '

Date	Mean Total alkalinity ($mgC0_3$/L)	CV(%)	Mean bicarbonate alkalinity (mgCOa/L)	CV(%)	Mean carbonate alkalinity ($mgC0_3$/L)	cv(%)
13/1/90	73.3 ± 1.3	6.1	59.3 ± 1.5	8.5	12.4 ± 0.8	21.1
4/2/90	77.0 ± 0.5	2.3	73.3 + 0.5	2.5	4.0 ± 0.0	0
2/3/90	75.3 ± 0.8	3.8	56.7 ± 2.0	12.3	18.7 ± 2.1	38.0
3/4/90	69.9 ± 0.5	1.8	68.9 ± 0.5	1.8	0	0
5/5/90	67.5 ± 2.1	6.1	67.5 ± 2.1	6.1	0	0
5/6/90	68.4 ± 1.3	4.3	68.4 ± 1.3	4.3	0	0
4/7/90	131.6 ± 0.4	0.7	131.6 ± 0.4	0.7	0	0
6/8/90	136.4 ± 1.0	1.6	136.4 ± 0.4	1.6	0	0
7/9/90	137.6 ± 1.0	1.6	128.0 ± 1.3	2.2	9.6 ± 1.0	22.8

Mean i S.E (n = 15)

Cont. Table 5:

B. Hippopoint Station

Date	Mean Total alkalinity (mgCOa/L)	CV(Z)	Mean bicarbonate alkalinity (mgCOa/L)	CV(%)	Mean carbonate alkalinity ($mgC0_3$/L)	CV(%
16/1/90	67.6 ± 4.2	1.5	60.2 ± 0.7	4.8	7.3 ± 0.34	20.9
9/2/90	82.1 ± 0.9	4.6	76.2 ± 1.0	5.5	6.1 ± 0.5	33.6
7/3/90	77.5 ± 0.8	4.4	67.0 ± 1.5	9.6	10.4 ± 1.1	45.8
8/4/90	67.7. ± 0.6	2.2	67.7 ± 0.6	2.2	0	0
9/5/90	64.0 ± 0.6	0	64.0 ± 0.0	0	0	0
8/6/90	68.7 ± 0.8	3.0	68.7 ± 0.8	3.0	0	0
7/7/90	130.0 ± 0.9	1.7	130.0 ± 0.9	1.7	0	0
8/8/90	133.3 ± 0.7	1.2	118.3 ± 1.3	2.7	16.7 ± 0.7	9.8
8/9/90	141.6 ± 2.2	3.7	117.7 ± 1.7	3.6	24.0 ± 1.5	14.9

Mean ± S..E(n = 18)

Corit. Table 5:

C. Crescent Island Lake Station:

Date	Mean Total alkalinlty ($mgC0_3/L$)	CV(%)	Mean bicarbonate alkalinity (mgCOa/L)	CV(%)	Mean Carbonate alkalinity (mgCOa/L)	CV(%)
19/ 1/90	9.9 ± 1.0	5.6	55.1 ± 0.9	5.6	4.9 ± 0.3	34.7
6/2/90	93.3 ± 0.9	4.7	86.7 ± 1.1	6.6	6.6 ± 0.4	31.4
3/3/90	90.9 ± 0.51	2.5	90.9 ± 0.5	2.5	0	0
5/4/90	90.5 ± 1.0	2.1	90.5 ± 1.0	2.1	0	0
6/5/90	42.0 ± 0.0	0	42.0 ± 0.0	0	0	0
12/6/90	83.0 ± 0.8	2.6	83.0 ± 0.8	2.6	0	0
11/7/90	167.2 ± 0.5	0.8	167.2 ± 0.5	0.8	0	0
10/8/90	162.2 ± 0.9	1.1	162.2 ± 0.6	1.1	0	0
11/9/90	161.2 ± 0.9	1.6	156.3 ± 1.8	3.4	4.7 ± 1.2	74.2

Mean ± S.E(n = 27)

was basically due to bicarbonate ions, which gives the lake a high buffering capacity. Low concentrations of carbonate ions were observed in January to March and September, 1990 (Table 5). The presence of carbonate ions coincided with high bicarbonate values during the dry season. This indicates that alkalinity is influenced by rainfall. Alkalinity was negatively correlated with rainfall at Safariland station ($r = -0.56$), Hippopoint station ($r = -0.56$) and Crescent Island Lake ($r = -0.26$) even though not significantly correlated in all the three stations ($P > 0.05$). Total alkalinity is not significantly correlated with conductivity (Fig. 11)

4.B Nutrients

There were higher concentration of all nutrients at Crescent Island Lake compared to Main Lake stations (Fig. 12). There was intermittent nutrient stratification in all the stations (Table 6 and Fig.13) with a maximum either at the surface, middle or bottom waters.

4.8.1 Nitrogen

Concentration and seasonal changes of the three forms of inorganic nitrogen investigated in this study, dissolved inorganic nitrogen (DIN), nitrate nitrogen (NO_3-N), and dissolved ammonium (NH_4-N) at the three stations are shown in Fig. 12.

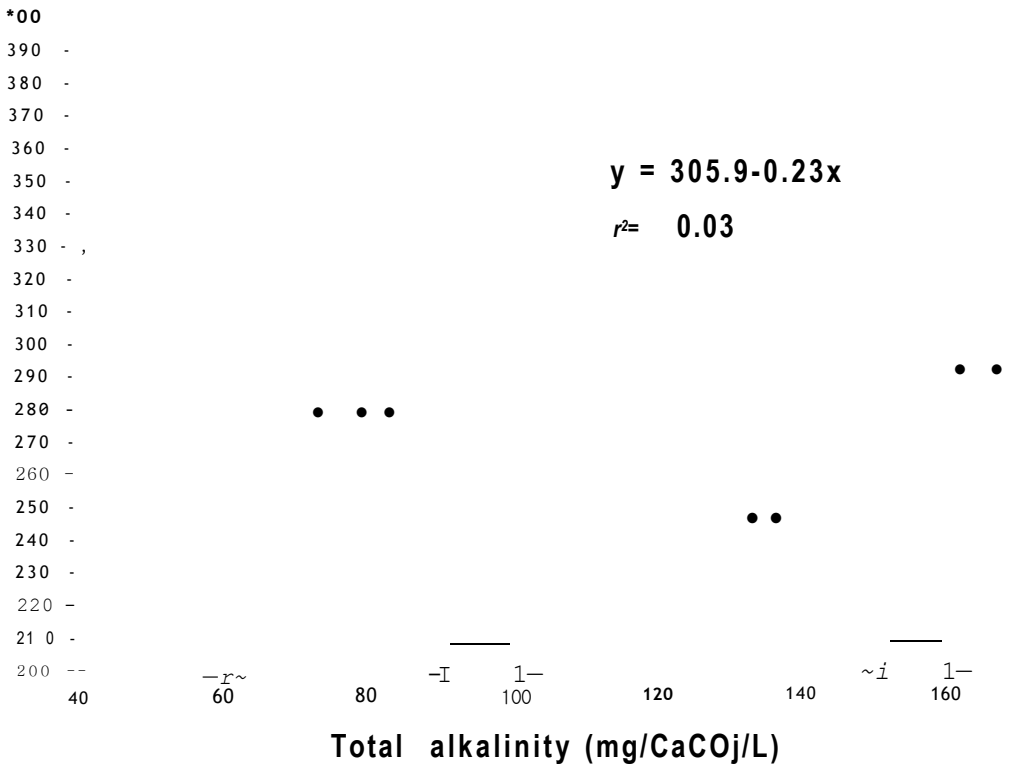
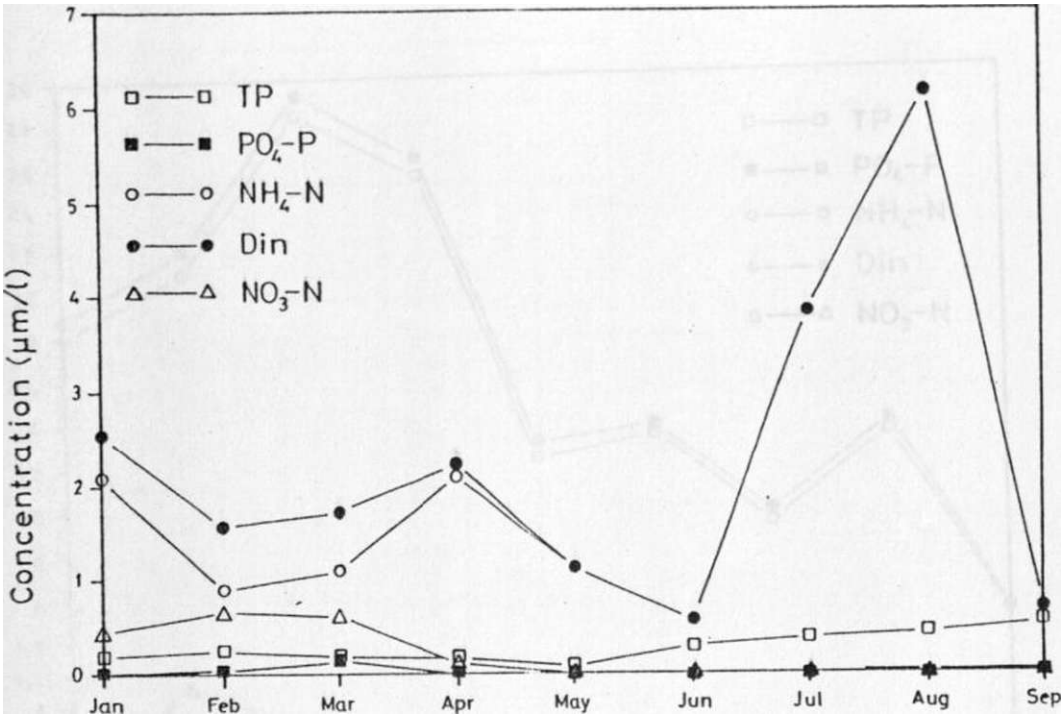


Fig. 11: Regression of Naivasha conductivity on alkalin ity



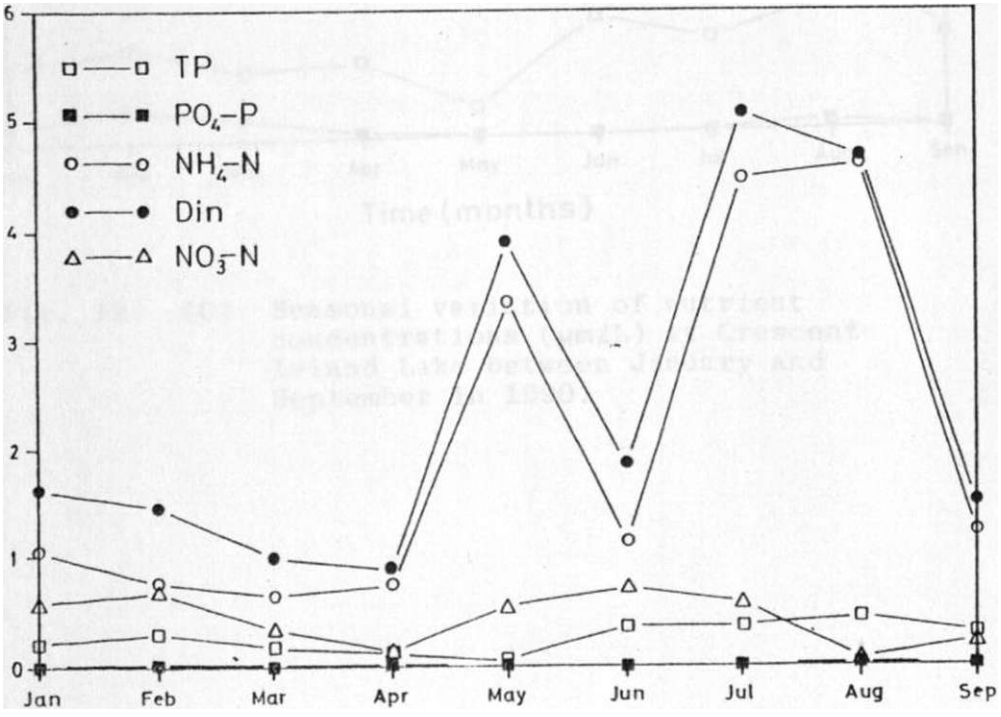


Fig. 12: Seasonal variation of nutrient (N & P) concentrations (um/L) between January and September in 1990. (A) Safariland and (B) Hippopoint Station.

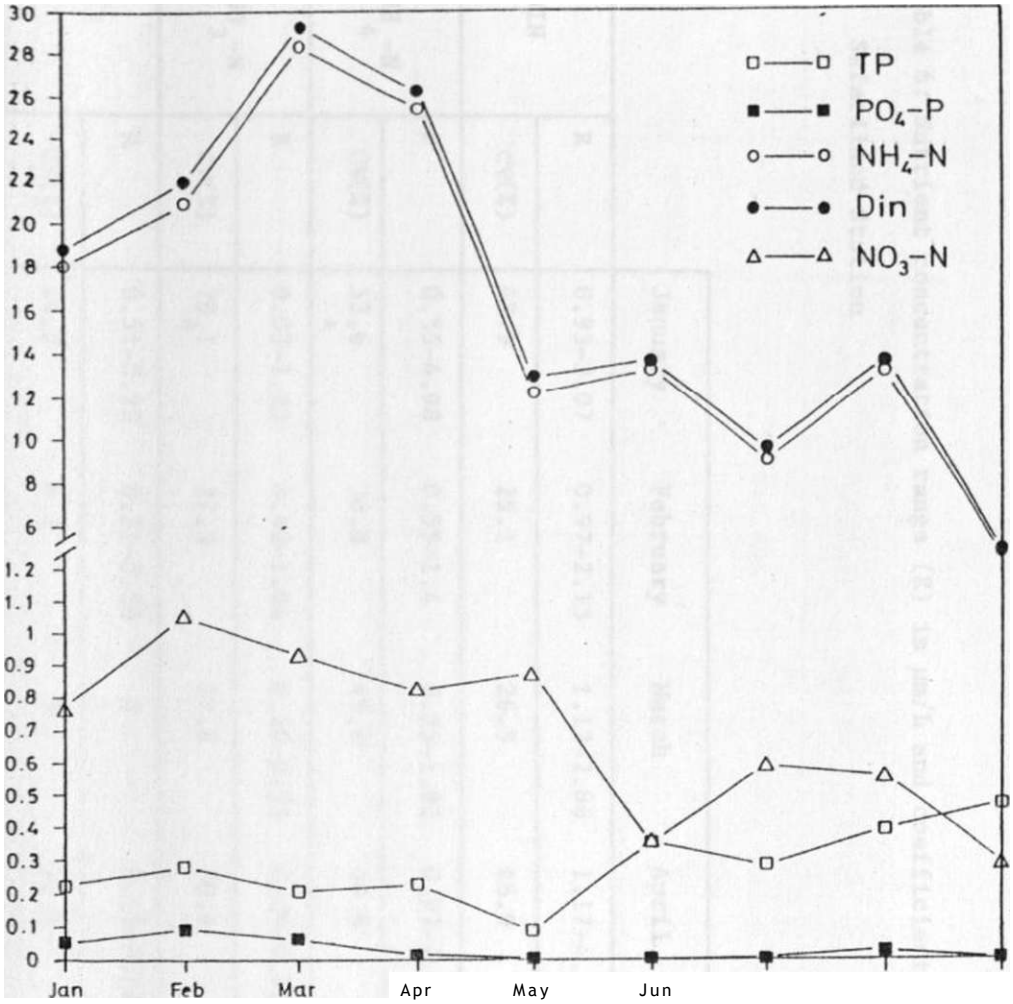


Fig. 12: (C) Seasonal variation of nutrient concentrations (Hm/.L) at Crescent Island Lake between January and September in 1990.

Table 6: Nutrient concentration range (R) in >jm/L and coefficient of variation **((CV%)** over depth in 1990.

A. Safariland Station

		January •	February	March	April	May	June	July	August	September
DIN	R	0.93-3.07	0.97-2.13	1.12-2.86	1.17-4.99	0.13-3.95	0.13-0.97	2.67-4.37	5.22-7.76	0.13-1.19
	CV(%)	43.9	25.1	26.5	46.9	90.3	39.4	22.9	15.1	50.0
NH_4-N	R	0.55-4.98	0.55-1.4	0.55-1.82	0.97-4.79	0.33-3.94	0.33-0.97	2.67-5.64	5.22-7.76	0.13-1.19
	CV(%)	53.6	36.8	45.8	49.6	90.3	39.4	22.9	15.1	50.0
NO_3-N	R	0.03-1.23	0.42-1.04	0.26-0.93	0.04-0.23	0	**0**	0	0	0
	cv(%)	78.1	27.3	37.8	50.8	0	**0**	0	0	0
Tp	R	0.51-0.22	0.25-0.28	0	0.15-0.20	0.07-0.08	0.27-0.32	0.29-0.42	0	0
	CV(Z)	14.5	4.1	0	12.2	7.2	6. 8	14.2	0	0

Cont. Table 6:

		January	February	March	April	May	June	July	August	September
PO -P	**R**	0	0-0.005	0	0.0003-0.006	0	0-0.007	0.003-0.005	0.009-0.001	0.01-0.02
	cvCX)	0	60*.4	0	8.2	0	87*.2	66*.3	7.8	6.9

n - 12

B. Hippopoint Station

		January	February	March	April	May	June	July	August	September
DIN	**R.**	0.69-2.26	0.49-2.43	0.48-2.18	0.69-2.85	2.95-5.04	1.11-2.59	4.16-5.67	2.67-5.76	1.01-1.90
	cv%	28.9	42.4	50.0	48.6	14.8	23.9	9.96	16.4	19.2
NH_4-N	**R.**	0.12-2.26	0-1.19	0-1.61	0.34-2.46	2.89-4.79	0.79-1.61	3.95-5.64	2.67-5.64	0.76-1.82
	cv%	47.6	79*.1	85*.8	69*.3	15.9	25.6	8.8	15.9	24.7
NO_3-N	**R.**	0.17-1.38	0.32-1.04	0.21-1.06	0.21-0.75	0.03-0.48	0.35-0.97	0.21-1.02	0-0.21	0.03-0.35
	CV%	54*.7	28.9	36.7	32.5	76*.8	31.6	36.6	204*.7	48.2

Cone. Table 6:

		January	February	March	April	May	June	July	August	September
TP	R.	0.19-0.23	0.28-0.32	0.13-0.22	0	0.006-0.005	0.32-0.40	0.29-0.40	0	0
	CV%	7.8	4.A	16.6	0	12.3	8.8	13.4	0	0
PO_A-P	R.	0	0.049-0.05	0	0.0009-0.006	0	0-0.0008	0.0003-0.005	0.009-0.001	0.019-0.023
	CV%	0	2.5	0	54.4	0	83.4	62.1	6.2	6.7

n - 18

C. Crescent Island Lake

		January	February	March	April	May	June	July	August	September
i DIN	R.	11.8-41.9	15.41-31.54	19.64-41.6	22.74-	8.94-18.06	13.20-14.94	0.57-31.49	13.02-15.39	0.68-15.49
|	CV%	49.8	27.5	25.9	10.8	20.6	5.4	104.0	5.9	80.7

Cont. Table 6:

		January	February	March	April	May	June	July	August	September
NH -N	R.	11.2-41.28	14.21-3.07	19.4-41.3	21.76-28.98	8.61-16.67	12.85-14.55	0.13-31.1	12.85-14.60	6.55-14.6
	CV%	51.2	28.7	26.7	11.3	18.6	5.4	111.7*	5.3	84.1*
no_3-N	R.	0.24-1.13	0.87-1.42	0.42-1.34	0.59-1.29	0.25-1.54	0.30-0.39	0.26-0.84	0.17-0.91	0.04-0.84
	cv%	36.1	13.8	22.9	17.7	50.3	8.6	29.8	33.5	55.6*
Tp	R.	0.19-0.27	0.27-0.29	0	0.18-0.32	0.0089-0.097	0.33-0.39	0.28-0.29	0	0
	CV%	13.1	3.4	0	28.1	3.9	16.6	2.1	0	00
^{po}a -P	R.	0.03-0.08	0.05-0.12	0.03-0.12	0.0024-0.12	0	0.0003-0.02	0.01-0.02	0.0025-0.36	0
	CV%	30.1	18.3	32.4	57.4*	0	14.6	13.9	15.6	0

n - 27
* Significant (> 52%)

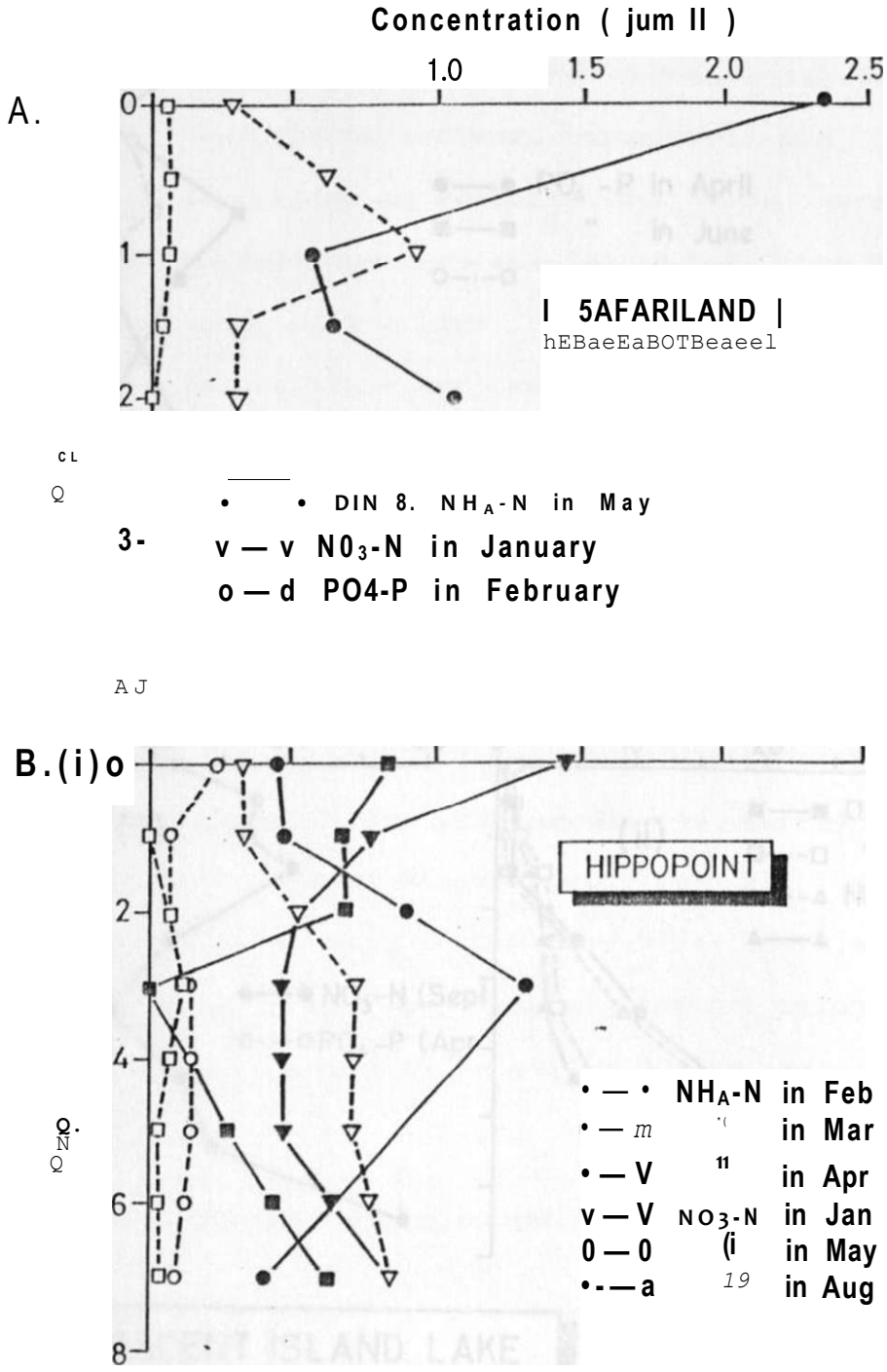


Fig. 13: Nutrient concentration profiles for the months with >52% coefficient of variation with depth at (A) Safariland and (B) Hippopoint Stations.

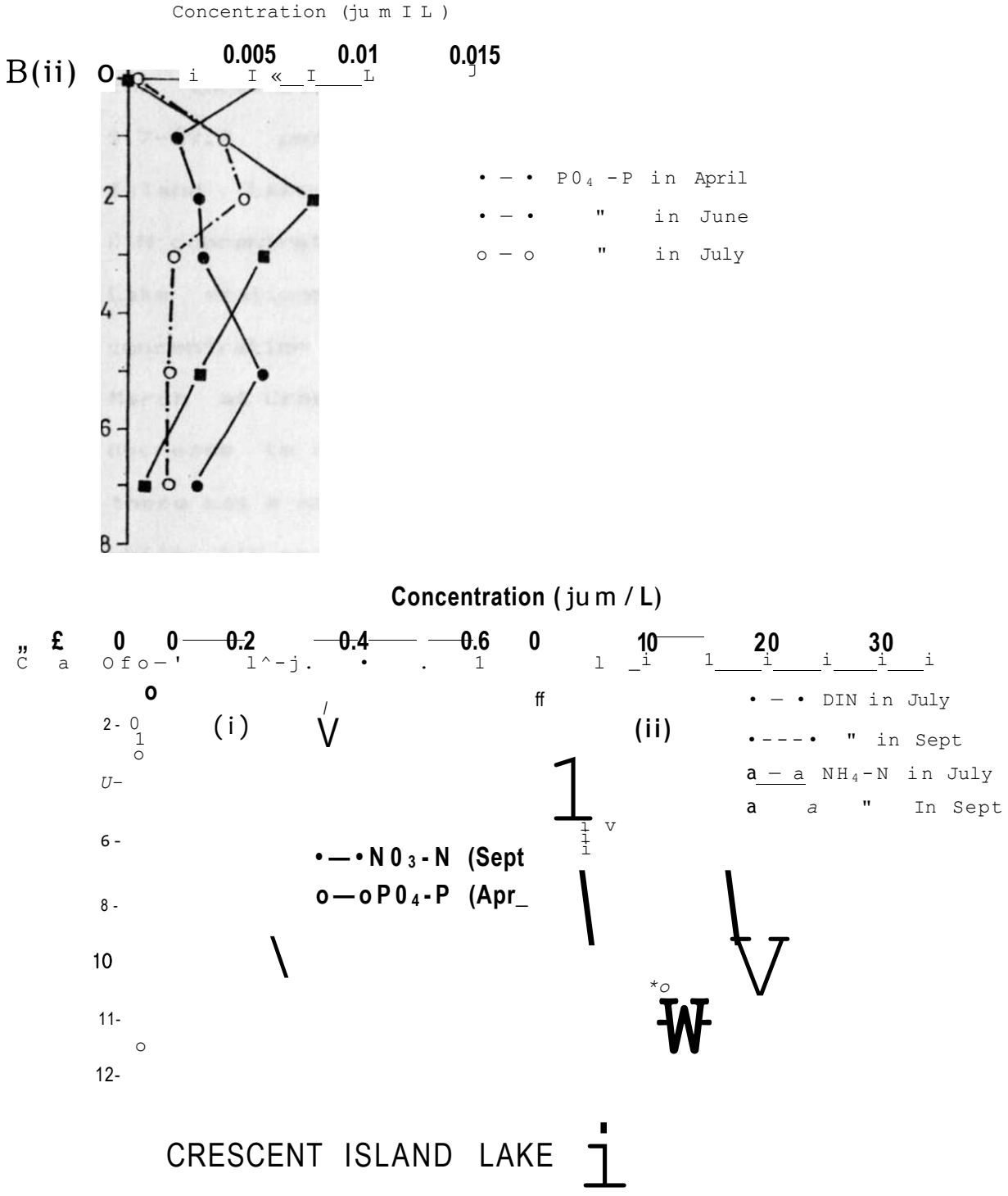


Fig. 13: Nutrient concentrations profiles for the months with >52% coefficient of variation with depth at B(ii) Hippopoint and (C) Crescent Island Lake

4.8.1.1 Dissolved inorganic nitrogen (DIN)

Dissolved inorganic nitrogen values were high at the three stations ranging from 0.6-6.5, 1.1-5.1, and 5.7-29.4 /jm/L at Safariland, Hippopoint and Crescent Island Lake stations, respectively. There were higher DIN concentrations at Crescent Island Lake than at Main Lake stations, with a peak in March almost, 5-fold the concentration in the other two stations. The DIN peak in March at Crescent Island Lake was followed by a gradual decrease to September (Fig.12). At Safariland Station there was a major peak of DIN concentration in August, while DIN peaked in May and July-August at Hippopoint station. Higher concentratioris of DIN coincided with the rainy seasons in all the three stations (March to April and August). DIN was negatively correlated with lake level, except at Hippopoint. (Table 7). There was a significant difference in DIN concentrations with depth at Safariland in May, and July at Crescent Island Lake, with higher concentration at the bottom waters (Fig. 13).

4.8.1.2 Ammonium nitrogen (NH_4-N)

Ammonium nitrogen followed a similar pattern as DIN, and NH4-N formed the major portion of DIN. Ammonium was highest at Crescent Island Lake (5.4-28.5 >um/L) followed by Safariland station (0.6-6.6 pm/L) and

Table 7: Sample Correlation Matrix (r)

A: Safariland Station

	DIN	NH_4-N	NO_3-N	TP	PO_4-P	GP	P
Rainfall	-0.18	-0.23	0.45	-.59	0.56	0.25	-0.03
	0.65	0.55	0.23	0.09	0.12	0.59	0.94
Lake Level	-0.009	0.12	-0.89	0.219	-0.37	-0.65	-0.48
	0.98	0.76	0.001*	0.57	0.33	0.12	0.28
Chi.a	-0.45	0.53	0.65	-0.19	0.47	0.61	0.36
	0.23	0.15	0.05*	0.61	0.21	0.15	0.43
iA(mgC/m^2/hr)	-0.31	-0.48	0.65	-0.43	0.11		
	0.49	0.28	0.12	0.34	0.80		

B: Hippopoint Station

	DIN	NH_4-N	$N0_3$"N	TP	PO_4-P	GP	P
Rainfall	-0.48	-0.43	-0.05	-0.69	0.56	0.59	-0.16
	0.20	0.25	0.89	0.03*	0.12	0.16	0.74
Lake Level	0.49	0.52	-0.35	0.18	-0.40	-0.23	0.91
	0.17	0.15	0.36	0.64	0.28	0.62	0.004*
Chi.a	-0.52	-0.54	0.33	-0.13	0.60	0.49	-0.92
	0.15	0.13	0.37	0.74	0.08	0.08	0.03*
£A(mgC/m^2/hr)	-0.72	-0.69	-0.03	-0.88	0.41		
	0.07	0.08	0.95	0.008*	0.36		

C: Crescent Island Lake Station

	DIN	NH_4-N	NO_3~N	TP	PO_4-P	GP	P
Rainfall	0.87	0.86	0.68	-0.56	0.27	0.25	0.59
	0.00025*	0.003*	0.04*	0.12	0.48	0.59	0.17
Lake Level	-0.56	-0.57	-0.61	0.18	-0.89	0.81	-0.23
	0.11	0.11	0.07	0.64	0.001*	0.03*	0.62
Chi.a	-0.76	-0.76	-0.70	0.32	-0.87	-0.38	-0.07
	0.02*	0.02*	0.03*	0.39	0.0024*	0.39	0.89
(mgC/m^2/hr)	-0.35	-0.34	-0.40	-0.11	-0.74		
	0.44	0.45	0.37	0.81	0.05*		

Coefficient (r),

•Significant at P < 0.05

Hippopoint station (0.5-4.6 /jm/L) (Fig. 12). The NM_4-N was either highest at the surface or bottom waters (Fig. 13) NH^-N is positively correlated with the Lake level unlike DIN (Table 7).

4.0.1.3 Nitrate nitrogen **(NO3**-N)

Nitrate nitrogen concentrations were highest at Crescent Island Lake->0.4 /jm/L throughout the study with a peak in February. At Safariland the range was 0-0.7 /jm/L, being highest between January to March and undetectable after April. NO3-N had a clear seasonal variation in concentration highest between January-Apri1 in the three stations. This gives a negative correlation relationship with the lake level and have a positive correlation with rainfall in Safariland and Crescent Island Lake stations (Table 7). Coefficient of variation over depth exceed 52 7. in January at Safariland, January, May and August at Hippopoint and September at Crescent Island Lake (Table 6, Fig. 13).

4.8.2 Phosphorus

Concentration and seasonal variation of the two forms of phosphorus investigated (Fig. 12) are total phosphorus (TP) and soluble reactive phosphorus (PO4-P).

4.8.2.1 Total phosphorus (TP)

Total phosphorus concentrations were very low at

all three stations (< 0.8 fjm/L) but highest at Crescent Island Lake (0.09-0.8 pm/L), in June to September. Concentration of TP was lowest at Hippopoint station (0.07-0.4 >jm/L) with a peak in August while Safariland station lies in the middle (0.08-0.5 /jm/L), highest in August to September and lowest in April-May (Fig. 12). This gives a positive correlation relationship with the lake level and negatively correlated with rainfall (Table 7).

4.8.2.2 Soluble reactive phosphorus (PO^-P)

Soluble reactive phosphorus was extremely low (below detection) most of the time except at Safariland station which had a slightly higher concentration, only measurable in February fo March (0.08-0.2 /jm/L) with a peak in March. Crescent Island Lake had a peak in February and extremely low throughout the study at Hippopoint station (Fig. 12). PO_4-P concentration is negatively correlated with lake level and positively correlated with rainfall unlike total phosphorus (Table 7).

4.9 Discussion

4.9.1 Limnological factors of Lake Naivasha in relation to previous work.

The water temperatures recorded during this study

(20—24°C) with a seasonal change of 3°C are not significantly different from 22.5 - 26.7°C recorded in 1978 (Melack 1978), 19.5 - 23 °C recorded in 1979 (Litterick et al - 1979) and 19.0 - 25.C°C recorded in 1982 (Njuguna 1982). Crescent Island Lake surface waters were warmer than the Main Lake stations with 2°C difference between surface and bottom waters. These patterns of thermal variation are similar to those reported by Beadle (1932), Melack (1976), Litterick et al. (1979), Njuguna (1982), and Harper (1987) as typical for Lake Naivasha. Similar results have been observed at Winam Gulf (Melack 1976), Lakes Albert, Edward and Kivu (Hecky & Kling 1981). Near isothermal conditions observed in all the stations agrees with Tailing (1966) and Melack (1979) who suggested that shallow tropical lakes are warm at all depths with only slight thermal differences with depth (2-3°C) indicating frequent mixing, as a result of afternoon winds, evaporation, nocturnal cooling, and decrease in rate of heating as a function of extinction of light during calm days. This agrees with Njuguna (1982) idea that temperatures in tropical systems are always high to allow continuous production throughout the year.

Further evidence of frequent mixing is given by well-oxygenated water from surface to bottom at Main Lake stations, where lowest oxygen levels recorded were

2.1 mg 0_2/L (22.5 %. saturated) at Hippopoint, 5.1 mg 0_2/L (50.0 7. saturated) at Safariland and 0.2 mg 0_2/L (2.3 7. saturated) at Crescent Island Lake compared with 3.8 mg 0_2/L (52 %. saturated) and 5.6 mg 0_2/L (79 %. saturated) at Crescent Island Lake and Naivasha respectively, in 1973 (Melack 1976, 1979), 3.5 mg 0_2/L (52 %. saturated) at Naivasha Main Lake (Njuguna 1982) and 3.0 mg 0_2/L at Safariland in 1984 (Harper 1987). The deeper waters maximal concentration at Crescent Island Lake in this study was 4.7 mg 8_2/L (51 7. saturated) compared to 6.4 mg O2/L (Melack 1979) and, 2.3 mg 0_2/L in 1984 (Harper 1987). The surface range of 5.9-6.0 (66.0-68.9 7. saturated) at Main Lake stations are not greater than 6.9-7.4 mg0_2/L (93-107 7. saturated) in 1973 (Melack 1976), and 6.7-7.7 mg 0_2/L (94-108 7. saturated) of the Winam Gulf in Lake Victoria which is deeper than Lake Naivasha (Melack 1979). Generally there was higher oxygen concentrations at Safariland station most of the time compared to the other two stations, which could have been a result of photosynthesis by the high density of submerged macrophytes. Biswass (1966), Adeniji (1973) in Lake Volta (Ghana) and Kainji (Nigeria) also observed similar results, where higher dissolved oxygen content was obtained in areas with high density of submerged macrophytes.

The weak thermal stratification observed and well-

oxygenated waters agrees with Tailing et §1,. (1973), Melack & Kilham (1974), Melack (1976), Vareschi (1981), and Njuguna (1982) who stated that tropical shallow lakes stratify slightly and mix everyday. Slight intermittent thermal and oxygen stratification is common and usually develops in the morning during periods of calm and sunny weather, however afternoon winds soon mix the "later column (Melack 1976 , Litterick et ai. 1979 , Mavuti 1983). Tailing (1966) also pointed out that most tropical lakes do exhibit thermal cycles though of low amplitude depending on the depth.

Conductivity is widely used as an index of ionic concentration in the water as well as an approximation of total dissolved solids (APHA 1971). The conductivity range observed (220 to 297 /jS/cm) at Main Lake stations compares with 250 *jS/cm in 1965 (Lind 1965), 20B *pS/cm* in 1969 (Hecky & Kilham 1973) and 259 in 1982 (Harper 1987) which were measured when water levels were high. By contrast, conductivity values when Naivasha's water levels was low were 311-353 */jS/cm* in 1973 (Melack 1976), 300-350 pS/cm in (Njuguna 1982), 350 pS/cm in 1984 (Harper 1987), 400 */jS/cm* in 1952, and 445 pS/cm in 1975 (Millbrink 1977). Crescent Island Lake had higher conductivity values (280-390 /jS/cm) compared to the Main Lake stations. These results

are slightly lower than 3B9-438 /jS/cm in 1973 (Melack 1976), but are not significantly different from 359 /yS/cm recorded in 1982 (Harper 1987) although higher than the 250 uS/cm recorded in 1965 (Lind 1965).

Conductivities recorded at Crescent Island Lake and the Main Lake Naivasha lie within the range recorded for other tropical lakes, e.g. 288-533 yuS/cm of Lakes Fort Portal and Kagenda (Melack 1978), and 335 /jS/cm of Lake George (Tailing 8< Tailing 1965). This compares with 768-892 ;uS/cm of Oloidien in 1973 (Melack 1976), 645-750 /iS/cm in 1982 (Njuguna 1982) and 1300 j/S/cm in 1990 (Harper pers. comm). In general, seasonal changes of conductivity shows an increase during the dry seasons and low water levels and decrease during the wet seasons and high water levels. This shows that conductivity is affected by dilution during high water levels owing to an influx of dilute water from the Rivers Malewa (88-179 *pS/cm* in 1973 (Melack 1976), Gilgil (72-167 /jS/cm (Melack 1976) and Karati, direct rainfall, and seepage. Conversely solutes are concentrated by evaporation in low water levels (Lind 1965, Gaudet 1977).

Alkalinity showed a similar pattern as conductivity, with a range of 42-167 mg CaCOj/L (1.7-3.5 meq/L) which compares with 2.9-4.3 meq/L in 1973 (Melack 1976), < 2 meq/L in 1982 and 3 meq/L in 1984 (Harper

1987). The lowest value of alkalinity previously recorded was 2.2 meq/L (Hecky & Kilham 1973) at high water levels and the highest values recorded were 4.5 meq/L in 1952 and 4.3 meq/L in i'">75 (Millbrink 1977) at low water levels. Alkalinity in Oloidien was 4.3 meq/L at high water levels in 1930 (Beadle 1932) increasing to 5.4 meq/L in 1984 (Harper 1987). Lake Naivasha has slightly higher concentrations of bicarbonate and carbonate ions compared to Lake George (Tailing & Tailing 1965).

Despite the fact that bicarbonate dominated at all stations, similar to result obtained by Lind (1965), Melack (1976), Njuguna (1982) and Harper (1987, 1989) the relationship between alkalinity and conductivity obtained during this study was very weak, in contrast to strong relationship documented as common in East Africa rift valley lakes, which depends upon the predominance of bicarbonate and carbonate ions (Tailing & Tailing 1965, Kilham 1971).

The extinction of light owing to absorbance by plankton, water, suspended and dissolved particles varied between 0.7-1.8 m at the three stations. This compares with Secchi depth of 0.5-1.5 m in 1979 (Melack 1979), 0.8-2.3 m in 1982 (Njuguna 1982) and O.5-1.1 m in 1984 (Harper 1987). This indicates that Lake Naivasha is turbid with low Secchi disc transparencies (< 2 m).The relative extinction of photosynthetica11y active

radiation (PAR) of less than 1.5 m depth with blue light being the least penetrating, coinciding with maximum gross photosynthesis (Gpmax) indicating a possibility that different light wavelength were all being used in photosynthesis. Similar results were obtained by Melack 1973 to 74 (Melack 1976), Harper (1987, 19B9 and per. comm.) unlike those in 1979 when Melack observed red light least penetrating at Crescent Island Lake. This results agrees with Rhode (1958) idea that blue light was the most efficient component of insolation because maximum photosynthesis was measured at 50 %. blue irradiance.

4.9.2 Nutrient interaction

Concentration of nitrogen and phosphorus can have a major influence on the ecology of freshwater lakes Hutchinson (1975), pointed out that mineral elements often occur in micromolar quantities therefore frequently limit the rate of production in lakes

High concentrations of dissolved inorganic nitrogen (DIN) at the three stations indicate that there is a large stock of nitrogen in Lake Naivasha. Similar results were obtained by Gaudet (1977), Njuguna (1982), and Harper (1987). Gaudet (1977,1979) pointed out that the concentration of dissolved nutrients represents the excess of supply over demand, and that particulate

matter is more important as a nutrient reservoir than dissolved nutrients. There was no clear seasonal variation in nutrient concentrations in this study as observed by Njuguna (1982).

The high levels of ammonium observed at the three stations are similar to previous results recorded by Jenkin (1932) (0.1 fjm/L), Millbrink (1977) (1.1-2.0 /jm/L), Harper (1987) (0-3.5 ;um/L) . This compares with 4.0 /um/L in 1979 (Gaudet 1979) and 0.6 pm/L in 1984 (Harper, 1987) reported for the [1] River Malewa. These concentrations lie within the range found in unpolluted surface waters (< 56 pm/L) (Reynolds 1984) although greater concentrations are known to develop in smal 1 eutrophic and anoxic lakes. A similar situation was observed during this study were high concentration of ammonium were obtained at bottom waters of Crescent Island Lake with low or no oxygen. This possibly indicates that, there was a high rate of nitrate reduction and the dissolved oxygen was being used for decomposition of organic matter in the sediment. Similar results have been reported for various water bodies in Africa (Prossor et. al_- 1968, and Biney 1990). High concentrations of ammonium in Main Lake Naivasha could have resulted from nitrogen fixation (Gaudet & Muthuri 1981) within the papyrus swamps or by blue green algae. Zooplankton and fish excretion are also known to

contribute to elevated levels of ammonium in waters (Banf & Viner 1973).

Nitrate nitrogen was extremely low with little difference between stations. Similar results were obtained by Harper (1987) (0-0.3, and 0-0.2 /jm/L at Main Lake and Crescent Island Lake, respectively). Previous workers recorded nitrate levels of 1.0 //m/L (Tailing & Tailing 1965) and O.l /jm/L (Millbrink, 1977) in Lake Naivasha. It has been reported that Naivasha inflowing rivers contain higher values of nitrate-nitrogen (1.0 *pm/L* by Harper (1987), 0.6 */jm/L* by Gaudet (1979) in River Malewa and 0.2 fjm/L (Harper 1987) in Gilgil river) than the lake water. These results lie at the low end of nitrate concentration reported for a variety of African lakes (Tailing & Tailing 1965), Lake Victoria (Fish, 1956, Tailing 1966) Lakes Malawi, Chilwa, Malombe (Moss 1969), and Lake George (Viner 1973).

Low concentrations of nitrate in Naivasha waters does not mean that nitrate is limiting production because nitrate can be made available through nitrification of large quantities of ammonium present. On the other hand ammonium is readily utilised by most algae and is a favourable source of combined inorganic nitrogen of some algae in preference to nitrate (Reynolds 1984).

Evidence obtained here indicate that phosphorus occurs in extremely low concentrations in Lake Naivasha, which is reflected by low levels of phosphorus in the sediments (Gaudet & rluthuri 1981). Low phosphorus could be due to adsorbtion of phosphorus by hydrosoils on the other hand, Peters & Maclntyre (1976) pointed out that utilisation of phosphorus by phytop1ankton could, reduce the levels of phosphorus in the water column to low values. Rigler (1966) showed that phosphorus can be taken up by phytopiankton until only < 0.03 /jm/L ^{32} remains in the water. The rapid turnover rates of P—PO_4 reactive phosphorus also indicates a great biological demand for phosphorus in Lake Naivasha (Peters & Maclntyre 1976)

Tailing (1966) postulated that estimates of total phosphorus give an indication of maximal or potential supply of this element irrespective of it's biological utilisation. The low concentration of total phosphorus and soluble reactive phosphorus in this study is similar to previous work by Tailing & Tailing (1965) (1.7-3.7 /jm Tp/L), Mill brink (1977) (1.7pm Tp/L), and Njuguna (1982) (2.7 fjm Tp/L). Soluble reactive phosphorus values of <0.3 *p*m PO_4-P/L were recorded in 1973 (Melack 1976), 0.8 LIM PO_4-P/L in 1982 (Njuguna 1982) and < 0.3 fm PO4-P/L in 1984 (Harper 1987) in Lake Naivasha. Values of 0.009 ;.«n PO4-P/L and 0.2 /jm Tp/L in 1979

(Gaudet 1979) and 0.3 pm PO^-p/L and 2.1 pm Tp/L in 1984 (Harper 1987) were recorded for the River Malewa. The soluble reactive phosphorus (PO/j-p) values for Lake Naivasha observed in this study lie between the low •fertility <0.2 pn PO4/L) level, and high eutrophication ranges (> 0.8 *fj*m PO4/L) of Dillon (1975). Similar results were observed by Viner in (1973), (1977) in Lake George, Melack (1978) in Lake Nyamusingire in western Uganda and Melack e_t al_. (1982) in two Kenyan soda lakes (Sonachi and E1ementeita).

CHAPTER 5

5.0 Phytoplankton production in lake Naivasha

5.1 Phytoplankton species composition.

The species composition of phytoplankton in a water body is an indication of the character and environmental state of that body of water. For example, high species diversity of green algae and diatoms is known to occur in unpolluted waters (Patrick 1950).

Phytoplankton species were dominated by the Chlorophyta, Cyanophyta, and Bacillariophyta (Table 8). Chlorophyta included such genera as Pediastrum, where three species were encountered Pediastrum simplex Meyen, P. duplex Meyen and P. tetras (Ehr.) Ralfs, Ankistrodesmus. (A. fusjformis. A. falcatus (Corda.) Ralfs, A. graci1is), Scenedesmus (S. acuminatus, S. quadricauda (Turp.) Breb., S. maqnus and S. dispair). Selenastrum and Tetrastrum sp. In the order Zygematales, three genera were observed, namely Closterium, Cosmarium and Staurastrum where two species were present S. tetracerum Ralfs and S. paradoxum Meyen. Cyanophyta consists of order Chroococcales and Nostocales (Table 8) while Bacillariophyta consists of order Bacillariales (Table 8).

The most prevalent species found at the three

Table 8: Taxonoraic check list of Phytoplankton species collected in Main Lake Naivasha and Crescent Island Lake (2,3 respectively) between January and September, 1990.

	January		February		March		April		May		June		July		August		September	
	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
DIVISION: CHL0R0PHYTA CLASS: Chlorophyceae ORDER: Chlorococcales																		
Pediastrum so.									2x	x	2x	x	2x	x	2x	x	2x	2x
Ankistrodesmus spp.									x	x	x	x	x			x		
'Tetraedron sp.									x	x	x		x			x		
Selenastrum sp.										x	x		x	x		x		x
Scenedesmus spp.					2x		2x		2x	x	2x	x	2x		2x	2x	2x	2x
Tetrastrum sp.									x		x		x			x		x
Crucigenia sp.									x	x	x	x	x					
Codastrum sp.									x	x	x	x	x	x	x	x	x	x

Cont. Table 8:•

	January		February		March		April		May		June		July		August		September	
	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
Kirchineriella sp.											x						x	
ORDER: Zygnematales																		
Closterium sp.	3x	x	3x	x	3x	x	3x	x	3x	x	3x	x	3x	x	2x		x	
Cosmarium sp.		x		x		x		x		x	x		x	x	x	x		x
Staurastrum sp.	3x		3x		2x		x	x	x	x	x	x	x			x		x
DIVISION: CYANOPHYTA CLASS: Cyanophyceae ORDER: Chroococcales																		
Microcystis sp.	x	x	x	x	x		x		x		x	x	2x	2x	5x	5x	5x	5x
Merismopedia sp.					x		x	x	x	x	x	x	x			x		2x
Gloeotrichia sp.											x					x	x	x

Cone. Table 8:

	January		February		March		April		May		June		July		August		September	
	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
Chroococcus sp.											x					x	x	x
Gloeocapsa sp.																		
ORDER: Nostocales																		
Lyngbya sp.							·		x	x	x	x	x		x	x	x	x
Anabaenopsis sp.			·								x	x	x		x	x	x	x
Spirulina sp.																x		2x
DIVISION: BACILLARIOPHYTA CLASS: Bacillariophyceae ORDER: Bacillariales																		
Melosira sp.	x	3x	x	3x	x	3x	x	3x	3x	3x	3x	3x	2x	x	2x	2x	2x	2x
Synedra sp.									x	x	x	2x	x	x	x	x	x	x

Cont. Table 8:

.	January		February		March		April		May		June		July		August		September	
	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
Navicula sp.									X	X	**x**	**2x**	X	X	X	X	X	X
Surirella sp.											X		X					X
Nitzschia sp.									X		**x**	**2x**	X	X	X	X	X	X
DIVISION: EUGLENOPHYTA **ORDER: Euglenales**						.												
Euglena sp.					X		X		X	X	X	X	X	X	X	X		X
Phacus sp.										X	X					X	X	
DIVISION: PYRROPHYTA **CLASS: Dinophyceae** **ORDER: Peridiniales**																		
Ceratium sp.					X		X		X	**2x**	**x**	**2x**	**2x**	**3x**	**3x**	**3x**	**3x**	**3x**

x Present 3x dominant
2x Common 4x Pre-dominant
5x Algal bloom

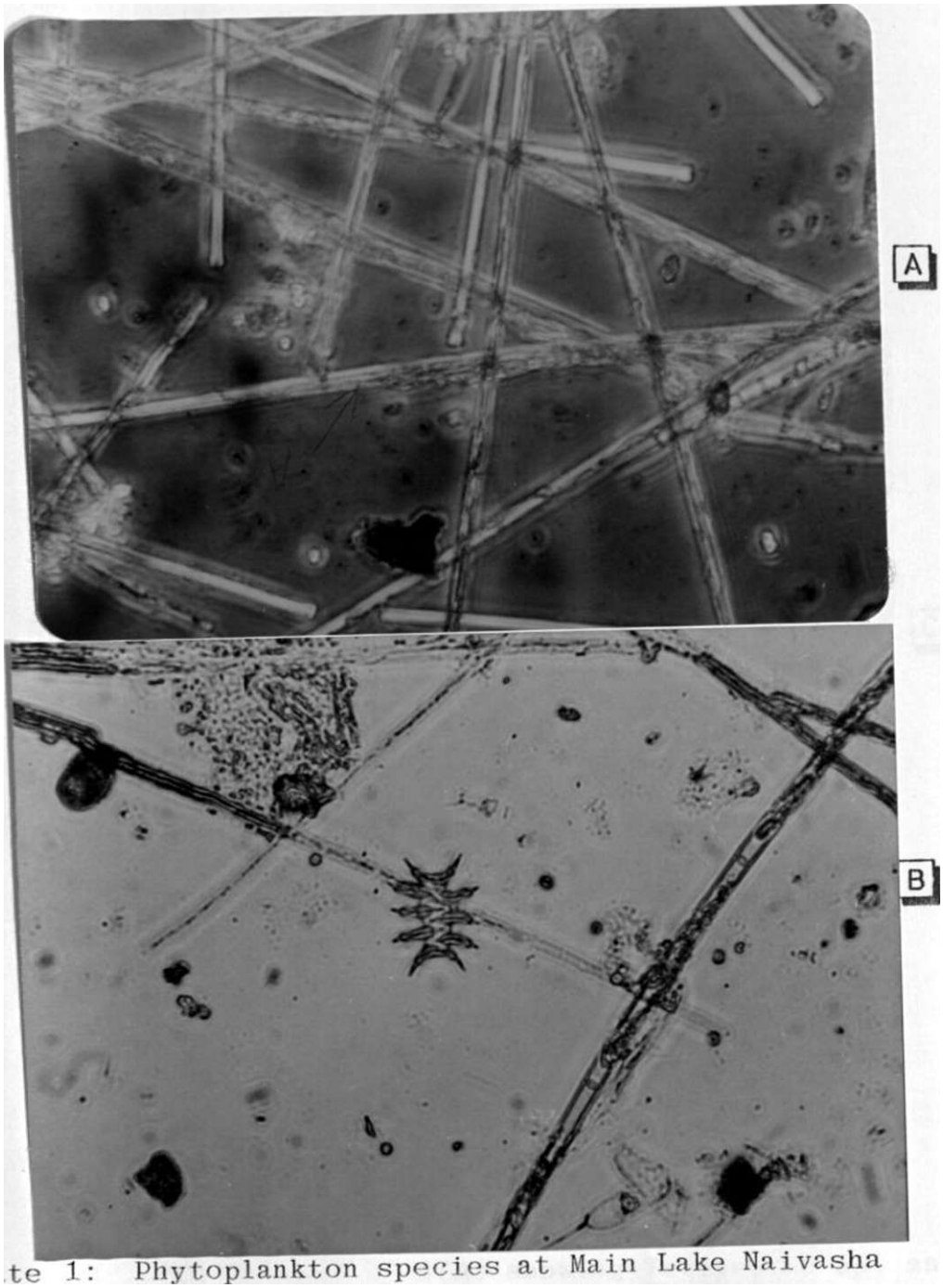
Total number of species 34.

stations belonged to the genera Closterium. Melosira Microcystis and Ceratium. while Pediastrum and Scenedesmus were consistently common. There was no difference in phytoplankton species composition between Safariland and Hippopoint, therefore these two stations were averaged as Main Lake. In the Main Lake Closterium sp. was most abundant between January to July, then succeeded by Microcystis sp. and Melosira spp., while Melosira spp. dominated at Crescent Island Lake throughout the study (Plate 1, 2). Two Melosira species were encountered M. italica (Ehr.) Kutz. and M. ambiqua (Grun) Mull. Low species richness was observed at all the stations between January and April during the low water level, whereas species richness was high between May and September which coincided with high water levels. The number of species present was significantly correlated with water level ($P = 0.01$, where $r = 0.86$ at Safariland, and Hippopoint (Main-lake) and $r = 0.89$ at Crescent Island Lake).

Cochran Q-test (Cochran 1950) indicated that species richness varies with season ($P < 0.01$) in both Main Lake Naivasha and Crescent Island Lake.

5.2 Phytopiankton biomass as Chlorophyll a

Chlorophyll a concentration ranged between 26.5-54.7, 20.6-59.8 and 11.2-41.9 /jg/L at Safariland ,



te 1: Phytoplankton species at Main Lake Naivasha

(A) In January 1990, wilh Closterium sp. (Longrods) being the most abundant species.

(B) A detail of 1A above showing Scenedesmus acuminatus in the centre

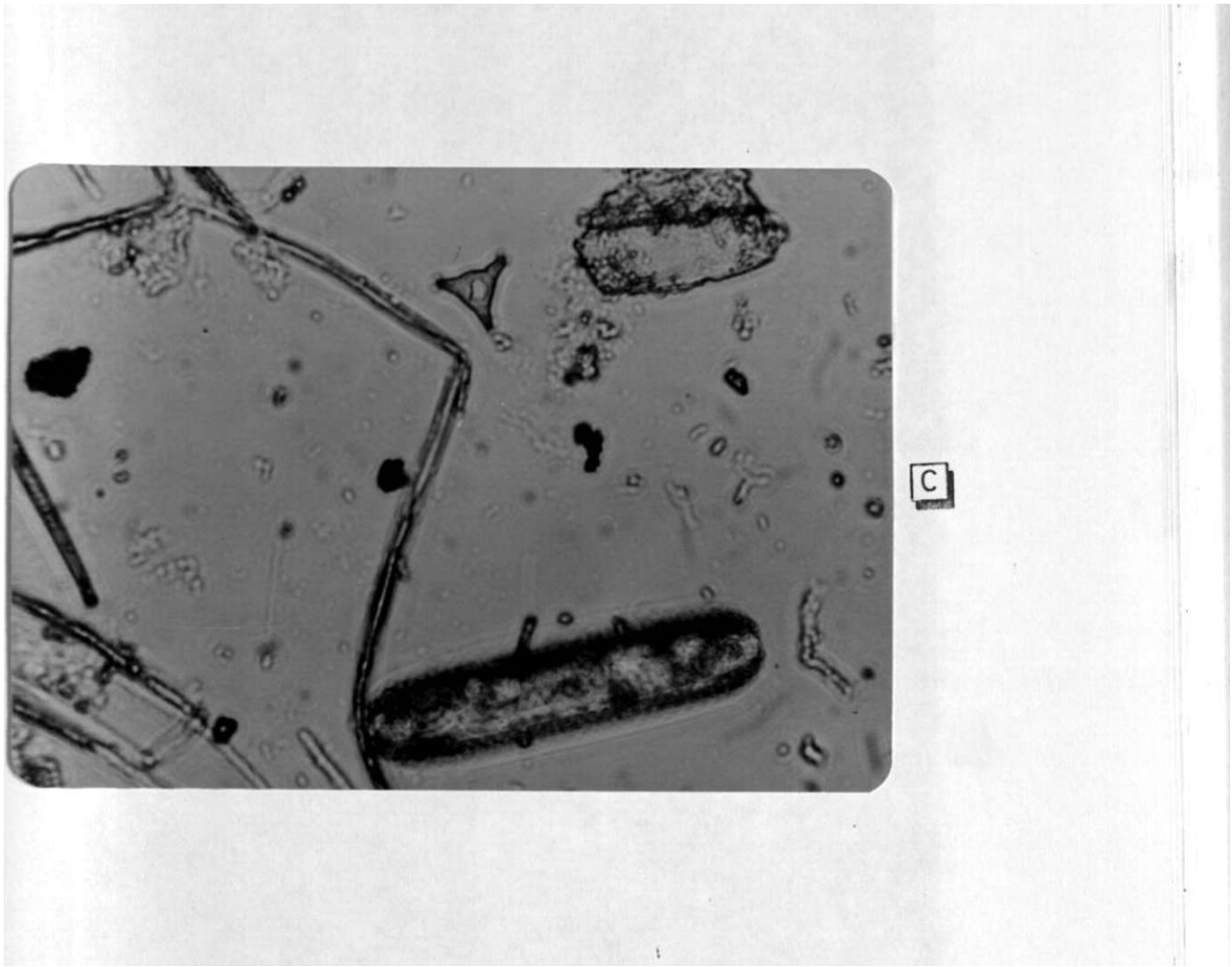


Plate 1: (C) Detail of 1(A) showing Tetraedron sp. and Euglena sp.

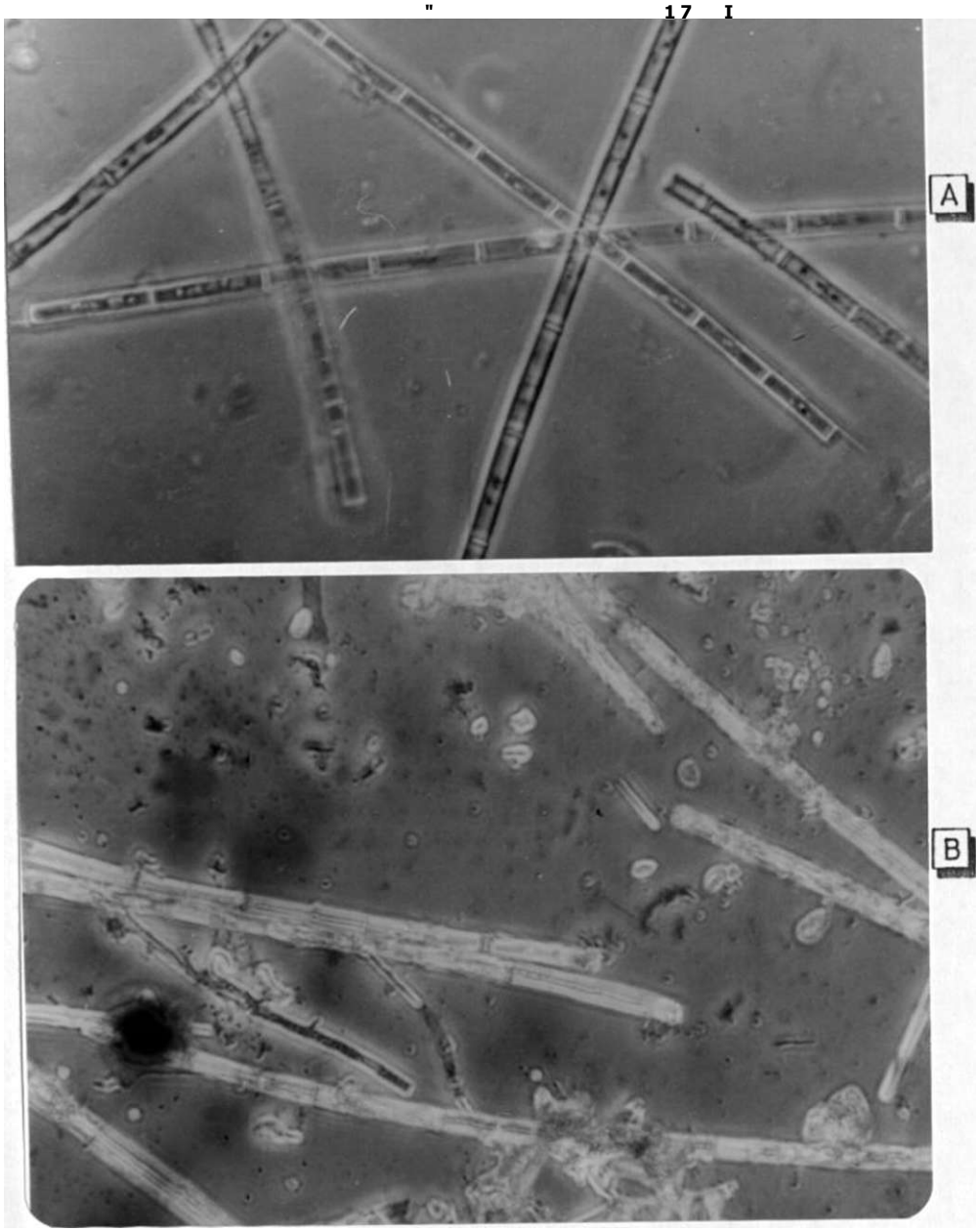


Plate 2: Phytoplankton species at Crescent Island Lake.

(A) In January 1990, with Melosira sp. being the most abundant species

(B) In June 1990, showing more species richness.

Hippopoint and Crescent Island Lake, respectively. The seasonal variation of chlorophyll a in the three stations is shown in Fig. 14, where Hippopoint station had the highest concentration between January and March (almost 3-fold the Crescent Island Lake concentrations) followed by Safariland station with a peak in February (Fig.14). There was a sharp decline of biomass in April at both Hippopoint and Safariland stations but a concomitant increase at Crescent Island Lake with a peak in May—June. Thereafter, biomass remained similar and relatively constant at the three stations. Different stations vary in different ways over time (Fig.14). Chlorophyll a concentration is negatively correlated with lake level at Hippopoint $r = -0.92$ ($p = 0.001$) but there are no significant correlations at the other stations. Chlorophyll a was not significantly correlated with rainfall ($r = 0.49$, 0.32, 0.11 at Safariland, Hippopoint and Crescent Island Lake, respectively) in the three stations.

The coefficient of variation of chlorophyll a concentrations with depth ranged between 7.3-52.7, 7.4-26.3 and 9.1-50.2 7. at Safariland, Hippopoint and Crescent Island Lake, respectively (Table 9). These intermediate values indicate that there is no significant difference in chlorophyll a concentration with depth at all the three stations ($p > 0.05$).

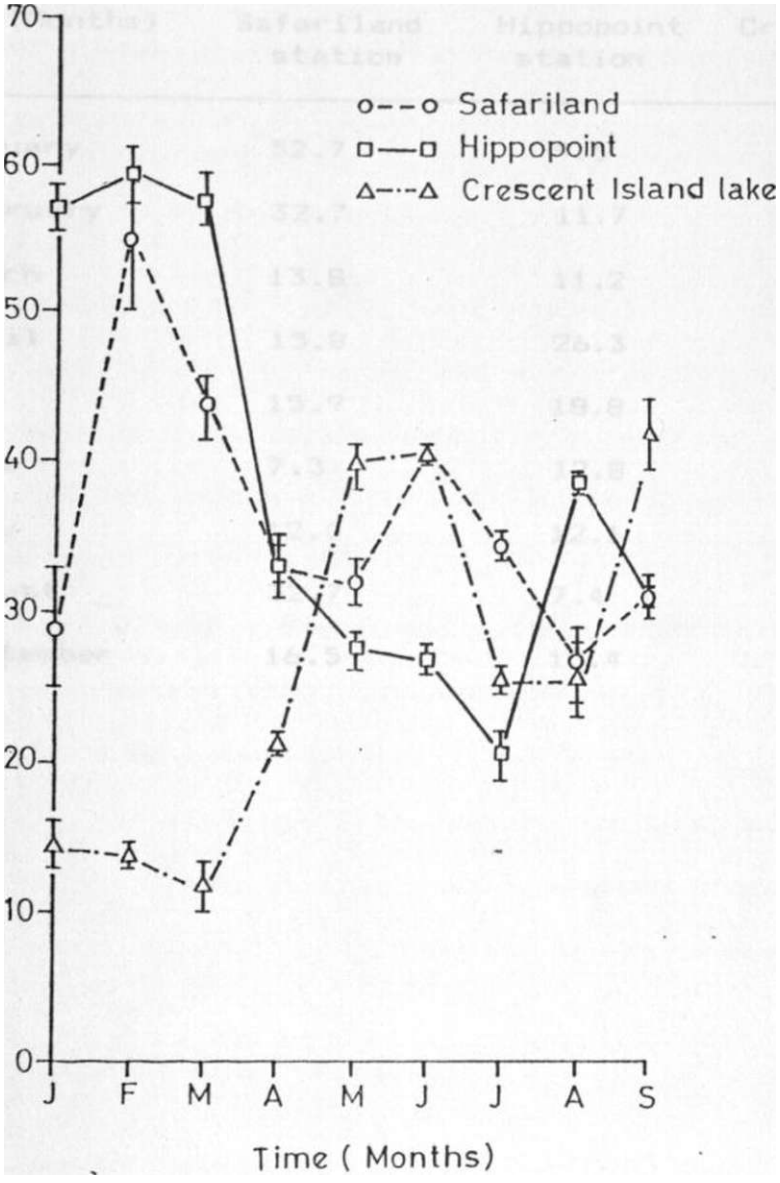


Fig. 14: Seasonal variation of chlorophyll £ concentration at Safariland, Hippopoint and Crescent Island Lake Stations in 1990.

Table 9. Coefficients of variation <CV %) of chlorophyll a concentration with depth in 1990.

Time(Months)	Safariland station	Hippopoint station	Crescent Island Lake station
January	52.7	9.5	45.1
February	32.7	11.7	29.B
March	13.8	11.2	50.2
April	15.8	26.3	16.2
May	15.9	18.B	15.9
June	7.3	12.8	9.1
July	12.O	12.1	15.6
August	32.7	7.4	26.3
September	16.5	10.4	31.1

Chlorophyll a which is an indicator of algal biomass showed a weak negative correlation with dissolved inorganic nitrogen (DIN), dissolved ammonium (NH_4-N) and total phosphorus (TP) but positively correlated with nitrate-nitrogen (NO_3-N) and soluble reactive phosphorus (PO4-P) (Table 7) with the following regression equations as shown in Table 10.

5.3 Rates of Photosynthesis

Photosynthetic rates were maximal in sub-surface water usually at 1 m depth, and with regular decline in the lower portion of the euphotic zone (Fig. 15). All the profiles had a single sub-surface maximum which corresponded with >15 V. level of incident irradiance measured as Secchi depth and attenuation of different light wavelengths (450, 540 and 650 nm) (Fig 9). Maximal rates of gross photosynthesis was higher at Safariland than at other stations from January to March with a peak in February. Crescent Island Lake maximum photosynthetic rates were higher than those at other stations from April to June. Hippopoint had the lowest maximal photosynthetic rates (Fig. 16).

Specific photosynthetic rates (p) showed the same pattern as gross photosynthesis (GP) with sub-surface maxima, which ranged between 0.4-11.4, 0-7.4 and 0-11.1 (mg C) (mg Chi. a)/hr at Safariland, Hippopoint and

Table 10. Summary of regression equations of nutrient interaction with algal biomass as Chiorophy11 a

(A) Safari land station

Chi. a = 40.35 - 2.02DIN	t = 1.09 (df 106)	P > 0.05
Chi. a = 40.49 - 2.29NH_4~N	t = 1.55	P > 0.05
Chi. a = 32.23 +• 1£>.01$N0_3$-N	t = 1.92	P > 0.05
Chi. a = 40.04 - 15.47Tp	t = 0.31	P > 0.05
Chi. a = 33.70 + 75.9Po_4-p	t = 0.86	P > 0.05

(B) Hippopoint station

Chi. a = 49.38 - 4.29DIN	t = 2.83 (df 160)	P = 0.02#
Chi. a = 47.42 - 4.23NH_4-N	t = 3.15	P = 0.002*
Chi. a = 33.84 + 12.02$N0_3$-N	t = 0.70	P > 0.05
Chi. a = 41.98 - 11.45Tp	t = 0.10	P>0.05
Chi. a = 34.1 + 181.97$P0_4$-P	t =* 4.72	P = 0.001*

(C) Crescent Island Lake

Chi. a = 41.55 - 0.92DIN	t = 8.81 (df 241)	P > 0.001*
Chi. a = 40.97 - 0.93NH_4~N	t = 8.56	P < 0.001*
Chi. a = 38.70 - 18.63$N0_3$-N	t = 3.87	P < 0.001*
Chi. a = 16.70 + 31.51Tp	t = 1.13	P > 0.05
Chi. a = 35.09 - 2B8.94$P0_4$-P	t = 13.11	P = O.OOl*

• Significant

t test (for coefficients)

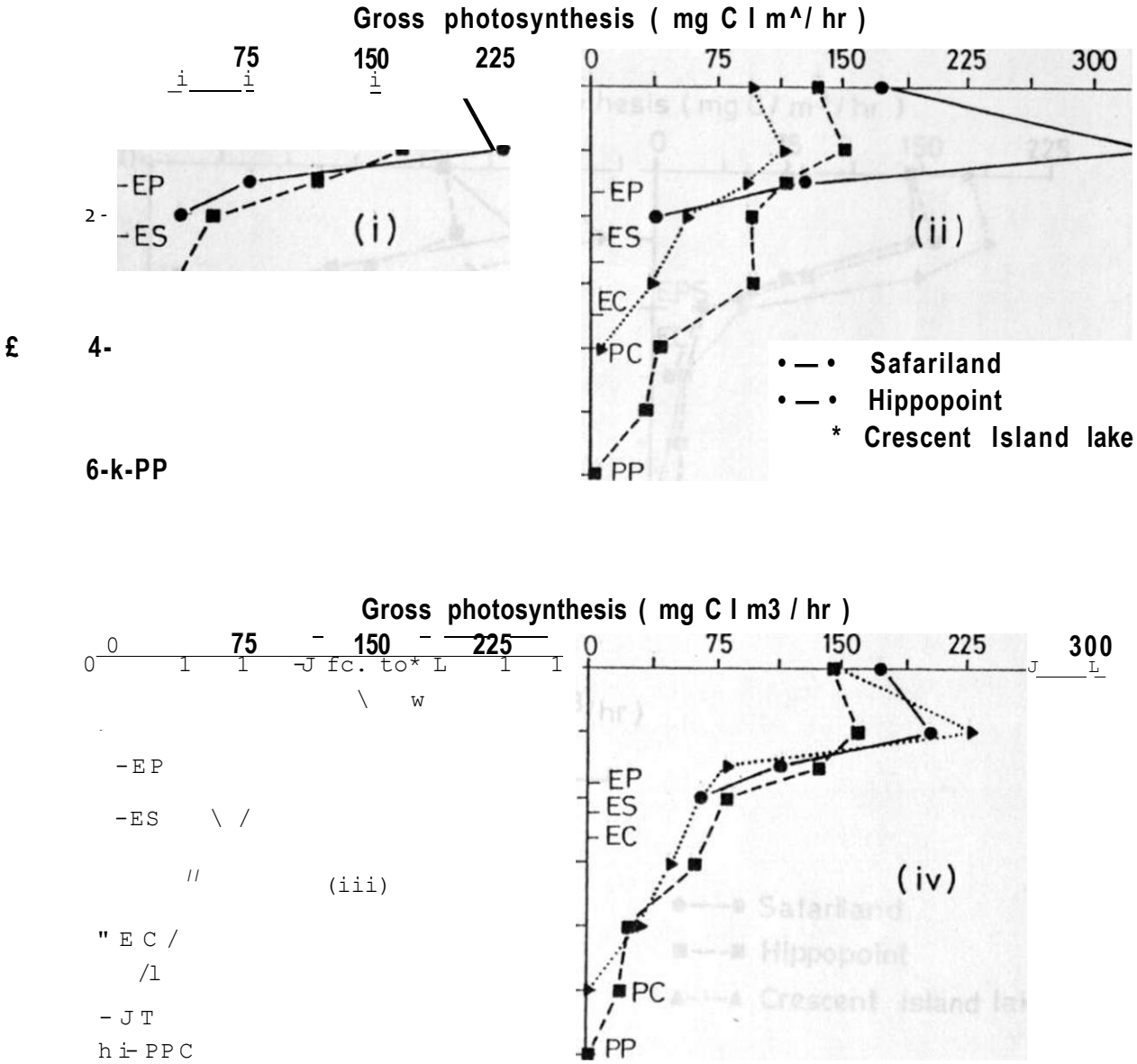


Fig. 15: Gross photosynthesis profiles of the three stations between January to April (i.iv) in 1990. Horizontal lines show Depth of Euphotic zone and Photosynthetic zone for Safariland (ES), Hippopoint (EP, PP) and Crescent Island Lake (EC, PC) respectively

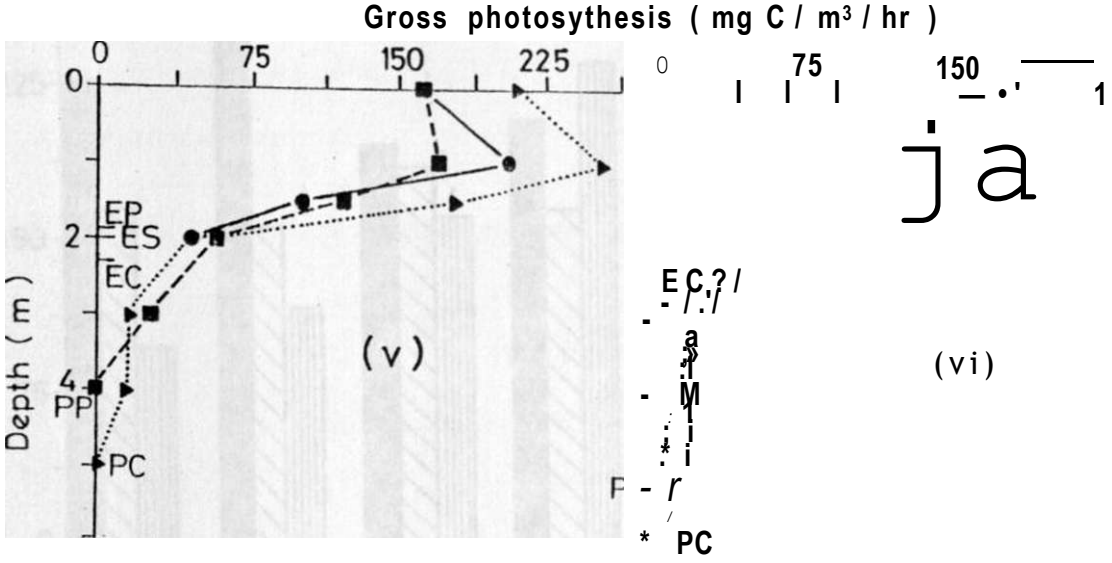


Fig. 15: Cont. Gross photosynthesis profiles of the three stations between May to July (v-vii) in 1990.

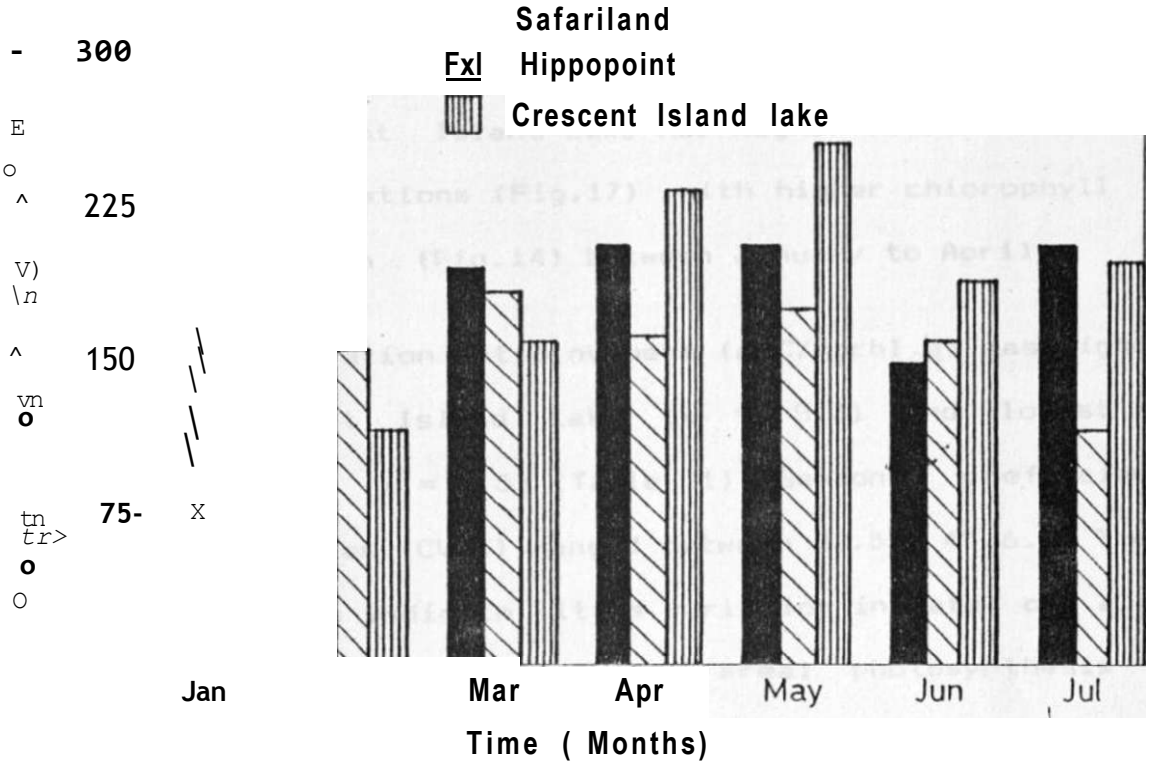


Fig. 16 Seasonal variation of the maximum gross photosynthesis (GP Max) in Lake Naivasha

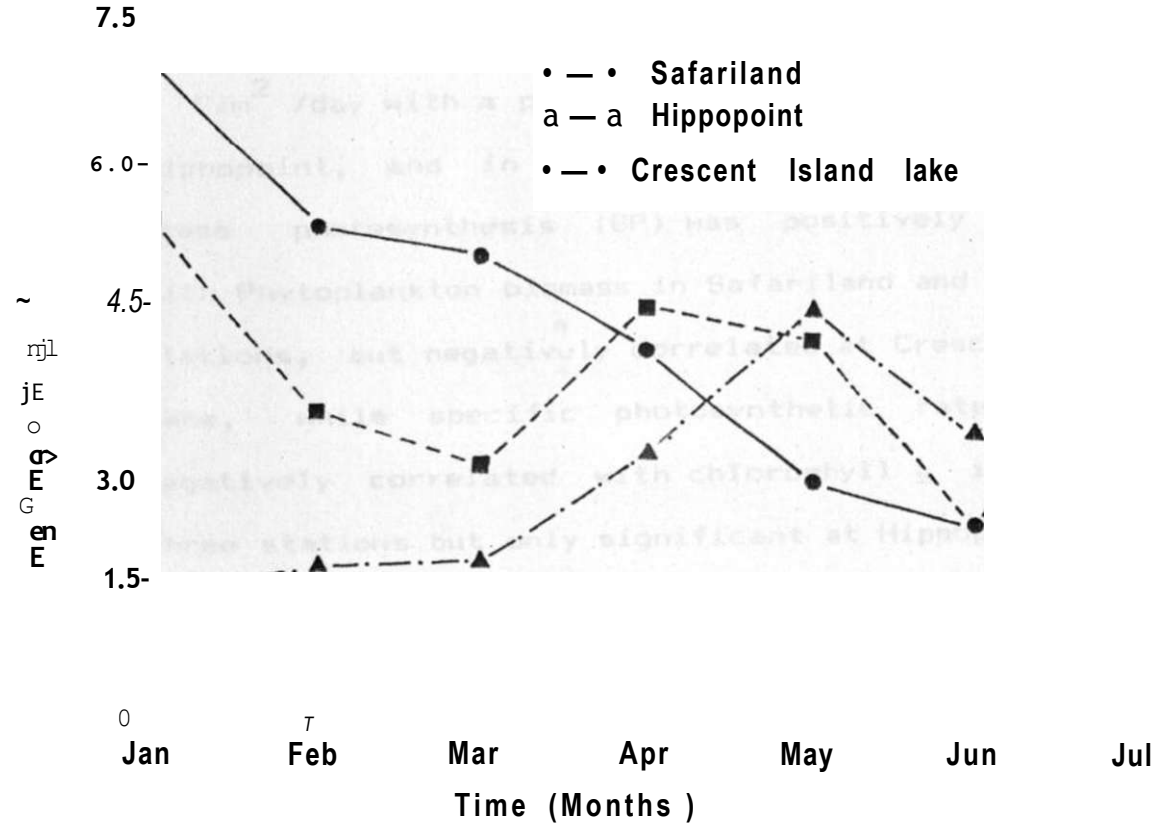


Fig. 17: Monthly changes of maximum specific photosynthetic rates (Pmax) in Safariland, Hippopoint and Crescent Island Lake.

Crescent Island Lake, respectively. Monthly changes in maximum specific photosynthetic rates (Pmax) showed that Crescent Island Lake had higher values than the other two stations (Fig.17) with higher chlorophyll a concentration (Fig.14) between January to April.

Assimilation ratio numbers (mgC/mgchl.a) was highest at Crescent Island Lake (x = 8.3) and lowest at Hippopoint (x = 4.5) (Table 11). Seasonal coefficients of variation (CV 7.) ranged between 28.5 - 45.6. These low values indicate little variation in rate of algal assimilation with time. The areal photosynthesis is shown in Table 12, with a range between 206.8-408.O, 276.4-471.8, 267.4-464.3 mg C/m^2 /hr at Safariland, Hippopoint and Crescent Island Lake stations, respectively. Daily productivity ranqpd between 2.2-5.2 g C/m^2 /day with a peak in February at Safariland and Hippopoint, and in September at Crescent Island Lake. Gross photosynthesis (GP) was positively correlated with Phytoplankton biomass in Safariland and Hippopoint stations, but negatively correlated at Crescent Island lake, while specific photosynthetic rate (P) was negatively correlated with chlorophyll a in all the three stations but only significant at Hippopoint (Table 7). The algal photosynthetic efficiency (Table 12) was highest at Crescent Island Lake (2.5 7.) which is deeper and more sheltered than the other two stations,

Table 11. Seasonal variation in assimilation ratio numbers (Pmax) (mgC/mgchl.a) and coefficients of variation (CV/.) For the three stations, from January to July, 1990.

Month	Safari1 and station	Hi ppopoint station	Crescent Island Lake station
January	11.4	3.1	ND
February	6.8	2.5	7.7
March	8	3.1	9.6
Apri1	6.9	5.1	11.1
May	6.7	7.1	6.4
June	3.8	5.4	4.9
Ju1y	3.6	5.5	9.9
Mean+S.E	6.1+2.8	4.5+1.7	8.3+2.4
CV(7.)	45.6	37.0	28.5

Mean + S.E (n = 7) for Safariland, Hippopoint, and 6 at Crescent Island lake)

ND = not determined

Table 12. Photosynthetic rates of Phytoplankton in Lake Naivasha, (*_A) areal rates per hour, and (£_AA) is areal rates per day.

Station and Date	4.A (MgC/m /hr) (calculated by pianimetry)	£AA (gC/day)	Irradiance (calories m /dx10)	Photosynthetic efficiency (%)
Safariland station				
13/1/90	318.8	3.5		
4/2/90	407.6	3.4		
2/3/90	278.9	3.0		
3/4/90	318.8	3.5	2.5	**2.6**
5/5/90	304.7	3.3	2.3	3.3
5/6/90	248.4	2.7	5.2	1.4
4/7/90	206.3	**2.2**	5.7	**1.0**
				x = 1.9
Hippopoint station				
16/1/90	399.5	4.3		
9/2/90	471.6	5.2		
7/3/90	440.6	4.8		
8/4/90	431.3	4.7	2.5	4.1
9/5/90	332.8	3.6	2.9	2.7
8/6/90	290.6	3.2	6.7	1.0
7/7/90	276.6	3.0	5.8	1.1
				x = 2.2
Crescent Island Lake				
19/1/90				
6/2/90	267.2	2.9		
3/3/90	377.4	4.1		
5/4/90	417.2	4.5	2.5	4.0
6/5/90	447.7	4.8	4.6	2.7
12/6/90	414.9	4.5	6.4	1.5
11/7/90	464.1	5.0	5.7	1.9
				x = 2.5

followed by the open water station (2.2 %) and the shallow littoral zone station (1.9 %). This indicates that efficiency is apparently reduced by the effect of wind because high efficiency tend to occur during calm sunny days (Table 12). This compares with Tailing (1965), and Melack (1979) results, where maximal efficiencies occurred on calm cloudy days.

5.4 Discussion

5.4.1 Species composition and seasonality

The phytoplankton species composition observed was much like that reported by Njuguna (1982), Mavuti (1983), KaIff & Watson (1986), Harper (1987). Previous studies indicated that the phytoplankton assemblage in Naivasha was dominated by diatoms in 1931 (Beadle 1932), desmids in 1964 (Lind 1967, 1968), and blue green algae (Melack 1976, Anon 1978, Kallquist 1979). Between January and March 1990 the lake supported a poor planktonic community dominated by Closterium sp. in the Main Lake and Melosira spp. in Crescent Island Lake. Species richness peaked in May to July in both the Main Lake and Crescent Island Lake, during the high water level and the phytopiankton assemblage was dominated by Melosira. Closterium. Microcystis. Scenedesmus. Pediastrum and Ceratium spp. The inference to be made here is that inputs of nutrients by rainfall, seepage

and stirred sediments may have resulted in increased algal richness. Although Lake Naivasha is shallow there is a predictable seasonal succession of phytopiankton. During high water levels the phytop1ankton consisted mainly of r-strategist species such as Ankistrodesmus. Scenedesmus. Tetrastrum. Navicula. Synedra. and Fraqi1aria spp., which are highly productive and fast-growing but there is no clear-cut distinction by season between r and k-strategists because some K-Strategist species (Microcystis. and Ceratium spp.) were prevalent throughout the study. This relates to Reynolds (1984) suggestion that Microcystis and Ceratium species are able to flourish under extreme conditions due to their physiological and behavioural flexibility.

Tailing (1966) in Lake Victoria, Hecky & Kling (1981, 1987) in Lakes Tanganyika, Malawi and Edward, and Anadu ei al- (1990) working in the coastal waters of Ghana pointed out that the end of rains (March to April) coincided with phytoplankton dominance by Chlorophyta and Cyanophyta, which is comparable with results of this study. Hecky & Kling (1987) further indicated that periods of stable stratification with maximum light availability and low nutrient supply favour Chlorophyta and Cyanophyta assemblages, especially certain colonial species of Chlorococcales.

Moss (1969) pointed out that when a lake is subjected to severe changes of level and chemical composition, the algal communities undergo very severe and rapid changes, especially in endorheic lakes e.g. Lakes Chilwa and Malawi in Africa. There was a rather slow change in algal communities in Lake Naivasha during this study, which may be due to high frequency of lake level fluctuation resulting in constant presence of some species adapted to water turbulence and level fluctuation disturbances (White 1979).

Different workers have emphasised different factors controlling algal seasonality and sociology. Reynolds (1973) for example stressed that dominance in species may be modified by effects of attacks of fungal parasites. Stirn (1981), Njuguna (1982) and Reynolds (1984) all empasized that seasonal variation in water temperatures, mixed depths, Secchi transparencies and nutrient concentrations frequently regulate the abundance, and community composition of phytop1ankton assemblage. Tailing (1966), Lewis (1978), Schindler (1978), Hpcky & Kling (1981, 1987) and Kalff & Watson (1986) stressed the importance of availability rather than concentration of nutrients and light in determining the species composition and succession of phytop1ankton in tropical lakes. Pearsall (1930, 1932), Sakamoto (1966), Dillon el aj_. (1978), and Molot A Dillon (1991)

noted the importance of N/P ratios for algal blooms in 1akes.

The diatom genus Melosira which has previously been documented to have dominated Lake Naivasha's phytop1ankton, has been reported as characteristic of eutrophic lakes in Japan (Sakamoto 1966), Lake Victoria (Tailing 1966) and Lake Chad (Carmouze et al. 1983). Melosira spp. are usually confined to lakes with < 600 uS/cm conductivity (Tailing & Tailing 1965) and < 8 meq/1 alkalinity, including shallow, turbulent, well-mixed and moderately eutrophic lakes (Kilham & Kilham 1975). In this content of Melosira spp. the Lake Naivasha phytop1ankton community is similar to that reported from other tropical African waters by Fritsch (1907), Prowse & Tailing (1958), Fox (1957), Rzoska & Tailing (1966), Biswas (1966), Kilham & Kilham (1975), Carmouze et aj_. (1983), and ' Idiem Opute (1990).

5.4.2 Algal biomass and productivity rates.

Distinct differences in algal biomass between Main Lake stations and Crescent Island Lake are similar to results obtained by Melack (1976, 1979). Within the Main Lake, the littoral zone station contained a lower algal standing crop except between April to July. This is in agreement with Harper in 1982 (Harper 1987), who reported higher algal biomass in the open water compared

to the shallow Menell's lagoon on the western side of the lake. The open water verses littoral difference could be due to the influence of shading by Salvinia molesta mats and competition for nutrients between phytopiankton or/and submerged and free - floating macrophytes. An indication of competition is portrayed by the fact that there was no significant correlation between any nutrient and the algal biomass in Safariland which, could mean that the nutrients were not all available to phytopiankton for growth.

Lake Naivasha is highly productive with reported values of 12.2-59.7 mg Chi. a/m^2 (present study) 21.3 mg Chi. a/m^3 (Njuguna 1982) and 20-52 mg Chi. a/m^3 (Harper 1987). Values for other fresh water lakes in Africa, are often lower, e.g. 1.25 mg Chi. a/m' and 3.0 mg Chi. a/m^3 have been reported for Lakes Tanganyika and Victoria, respectively (Hecky & Kling 1981, Tailing 1966). Although Anon (1978), Njuguna (1982), and Harper (1987) categorised Lake Naivasha as moderately eutrophic because of its algal biomass, but Tailing et al. (1973) pointed out that the chlorophyll a recorded was below the maximum found in very nutrient rich lakes. There was a clear indication that increase in species richness is correlated with increases in chlorophyll a concentrations in Crescent Island Lake, but these results are not clearly portrayed at Main Lake stations

i.e Safariland and Hippopoint.

An indication of advanced eutrophic statues in Lake Naivasha is revealed by high photosynthetic rates during these study, which ranges within documented values of eutrophic tropical African lakes.

The consistent sub-surface maxima of photosynthesis observed, even during periods of near isothermy, suggest that reduced gross photosynthesis near the surface was due to photo-inhibition because phytopi1ankton biomass or species composition remained relatively constant with depth. This agrees with Steemann-Nielsen (1952, 1962), Ryther (1956), Goldman et al_. (1973), Harris & Lot (1973), Viner (1973) and Reynolds (1984) suggestion that surface Photo-inhibition could be due to the effects of L/V radiation on algae which can have inhibitory effects on photochemical redox systems, damage of organic structures, and increased photorespiration.

Photosynthetic rates can depend on quantity and species composition of phytop1ankton, but the rates obtained in this study were relatively constant across time and space despite large differences in biomass and algal species composition across stations and months. Although, there was no distinct differences in maximal photosynthetic rates in the main lake stations and Crescent Island Lake, in contrast to results of Melack

(1976, 1979) and Harper (1987). Photosynthetic rates observed at Crescent Island Lake were higher than the rates documented by Richardson (1964, 1969), Millbrink (1977), Melack (1979), Njuguna (1982) and Harper (1987). This could have been due to high phytopiankton species richness and biomass observed during this study unlike in the previous studies.

Areal productivity rates observed lie within the high theoretical rates of Vollenweider (1968) and eutrophic ranges of Steemann-Nielsen (1952) and Rodhe (1958), agreeing with Melack's (1976, 1979) and Njuguna's (1982) conclusions that Lake Naivasha is eutrophic. The range of 2.2-5.2 g C/m^2/day obtained is generally higher than that found in other lakes including 2.8 g C/m^2/day at Lake Victoria (Tailing 1966), 1.86 g C/m^2/day at Lake Tanganyika (Hecky & Kling 1981) and 1.6 g C/m^2/day in Lake Chad (Lemoalle 1981). Values for Lake George of 7.8 g C/m^2/day (Ganf 1974) are closer to those recorded here for Lake Naivasha.

Tailing (1966) pointed out that nutrient availability is a major factor controlling the levels of phytopiankton biomass and productivity in tropical lakes and indeed nutrient concentrations are low in Lake Naivasha, with moderate algal biomass and high productivity rates. Njuguna (1982) suggested that there

is a dependence on both internal and external inputs of nutrients in Lake Naivasha resulting in high productivity rates. Viner (1973) noted that algal productivity rates and biomass tend to keep pace with combined mineralization and influx rates, even though Willen (1972) pointed that chlorophyll content varies in different algal groups.

Non-significant relationships between algal biomass and total phosphorus collaborate Njuguna's (1982) results. This could be explained by Brylinsky & Mann (1973) idea that biologically available phosphorus may not all be available to phytopiankton because bacteria, fungi, submerged and free floating macrophytes could compete effectively for phosphorus with phytopiankton These results are in contradictory to results of Vollenweider (1968), Dillon «< Rigler (1974), Schindler & Fee (1974), Oglesby (1977), and Oglesby & Schaffner (1978), who found good correlations between phytopiankton standing crop and total or biologically available phosphorus across temperate lakes. The inference to be made here is to support Njuguna (1982) idea that predictive models of total phosphorus to algal biomass used in relationships based on inter-lake comparisons may be misguiding when used in intra-lake comparisons.

CHAPTER 6

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General discussion

The complete mixing of the whole water column in Lake Naivasha is suggested by the vertical distribution of temperature, oxygen and even distribution of algal biomass. The water column mixing is brought about by nocturnal cooling (Melack 1979) and prevailing south-easterly winds which tends to promote afternoon mixing Mixing processes influence nutrient supply rates, algal distribution, primary productivity, (Melack 1976, 1979, Njuguna 1982), zooplankton abundance (Mavuti 1983, 1990), and fish yields (Malvestuto 1973). Although seasonality in nutrients levels at Lake Naivasha can be attributed to changes in external loading through seepage rather than through internal circulation or recycling (Njuguna 1982).

The phytopiankton productivity in the lake tends to increase during and immediately after the wet season due to inputs of nutrients from inflowing rivers such as the Malewa, Gilgil and Karati, seepage and stirring of the sediments. Low concentrations of nitrate (NO_3-N) and soluble reactive phosphorus (PO_4-P) suggest that they could be potential limiting nutrients in Lake Naivasha agreeing with reports by Fish (1956), Tailing &

Talling (1965), Tailing (1966), MOBS (1969), Viner (1973), Roberts «< SouthHall (1975, 1977), Peters & MacIntyre (1976), Melack et. aj_. (1982), and Kalff (19Q3). However, low external concentrations of dissolved nutrients do not necessarily mean that nutrients are limiting because most of algae can store a reasonable quantity of nutrients in their cells (Reynolds 1984).

Biney (1990) reported that uptake of nutrients by phytop1ankton reduces the levels of nutrients in a water body leading ultimately to biomass reduction. This seems to be the case in Lake Naivasha as decrease in biomass, nitrate (NO_3-N) and soluble reactive phosphorus (PO_4-P) concentrations coincide with increases in phytopiankton species richness. This may indicate that there is a general increase in biological demand for these nutrients by the existing phytop1ankton population hence resulting in reduction in biomass. The general relationships of nutrients with algal biomass in Lake Naivasha is summarised by the following regression equations

Chi. a (mg/m^3) = 0.98Tp + 31.73, r^2 = 0.00006, P > 0.

Chi. a (mg/m) = - 12.15PO_4-P +32.35, r^2= 0.001, P > 0.05

Chi. a (mg/m) = - 0.8 DIN + 40.39, r^2 = 0.35, P <0.001*

Chi. a (mg/m) = - 0.92NH_4-N +40.13, r^2 = 0.35, P < 0.001*

Chi. a (mg/m^3) = - 9.24NO3-N +36.71, r^2 = 0.05, P > 0.05

* Significant

Variations in phytop1ankton abundance, species composition, and richness corresponds to changes in physico-chemical factors of the lake, especially lake level during this study. This results agrees with Harper (1987), Harper et a], (1990) idea that Lake Naivasha level fluctuation has resulted in continous change in the lakes ecology. Records of Lake Naivasha level date back to 1880 and have been discussed by Sikes (1936), Gaudet (1977), Njuguna (1982) and Syren (1986). In general these levels are characterised by long-term and short-term seasonal oscillations, which are known to be influenced by rainfall, seepage and river discharge. However there was no significant correlation between lake level and rainfall during the time of this study.

Changes in phytopiankton composition and biomass in the euphotic zone is well reflected by changes in intergral areal photosynthetic rates per unit time than gross rates. This is because the higher the phytopiankton biomass (chlorophyll a) the higher the light which is attenuated possibly by the algae resulting to reduction in depth of the euphotic zone. This negative correlation between biomass and euphotic zone is similar to what Njuguna (1982) and Harper (1987) found in previous studies in Lake Naivasha. Several people have shown chlorophyll a-secchi depth

relationship in many water bodies (Bactiman & Jones 1974, Oglesby & Schaffner 1978), indicating that algal biomass causes a significant light attenuation hence affects water transparency.

The phytopiankton biomass and productivity levels measured in this study lie within the documented range for tropical African lakes (with low biomass but high production rates) (Hecky & Kling 1981, 1987, Melack 1976, 1979, and Njuguna 1982), characterising Lake Naivasha as moderately eutrophic.

These results act as a preliminary study for further research to be able to understand seasonal effects of nutrient (nitrogen and phosphorus) concentrations on algal biomass, species composition and primary production, requiring longer periods of study and more experiments in. situ following the work of Anon (1979), Melack e^ aJL- (1982), Njuguna (1982) and Harper (1987) before any new fish species could be introduced in Lake Naivasha.

6.2 Conclusions

Several conclusions can be made from this study.

1- Both submerged and free-floating macrophytes play an important role in uptake and removal of dissolved nutrients, in Lake Naivasha.

2- External input of nutrients from the catchment area

is a major source of nutrients into the Main Lake while at Crescent Island Lake internal recycling from the sediment plays a major role in nutrient availabi1ity.

3 The lake level fluctuations influences nutrient supply through alternative submergence and emergence of the drawdown region. This has a direct effect on the phytop1ankton composition, biomass and productivity rates.

4 Lake Naivasha is moderately eutrophic.

6.3 Recommendations

The following are some important recommendations which can be made from this study :

1 The loss of papyrus and other aquatic plants could result to increase in nutrients levels, through surface run-off, leaching and seepage-in from the highly populated and farmed areas around the lake. Therefore strict management of catchment area and lake edge vegetation should be implemented.

2 There is a need for long-term and continous ecological and hydrological monitoring especially on nutrients seasonal dynamics. This anables one to understand seasonal effects of nutrients to algal biomass and diversity, which could be used as an indicator of eutrophication level in the lake.

3. There should be controlled water abstraction from

A,

the lake, in order to establish a stable ecosystem conducive to further introduction of any fish species. There is still (cf. Njuguna 1982 recommendation) a serious imbalance between water use (for irrigation, cooling of geothermal power turbines and public water supply) and water inputs coupled with storage capacity.

REFERENCES

Adeniji, H.A., 1973. Preliminary investigations into the composition and seasonal variation of the plankton of Kainji Lake, Nigeria. Geophys. Monogr. Ser.17: 617-619

Anadu, D.I., Obioha. A. & Ejike. C., 1990. Water quality and phytopiankton periodicity in two contrasting mine lakes in Jos, Nigeria. Hydrobiol. 208: 17-25.

Anon, 1978. Limnological investigation of Lakes in Kenya, 1976-1977. Technical Report No. 6. Water Quality and Pollution Control Section, Ministry of Water Development, Kenya, 71 pp.

American Public Health Association (APHA) 1971. Standard methods for the examination of water sewage and industrial wastes (13 Ed.) New York, 769 pp.

Arad, A. & Morton, W.H., 1969. Mineral springs and saline lakes of Western Rift Valley, Uganda. Geochim. cosmochim. acta 33: 1169- 1181.

Bactiman, R.W. «< Jones, J.R., 1974. Phosphorus inputs and algal blooms in Lakes of Iowa State. J. Res. 49: 155-160.

Baker, B.H., 1958. The geology of the Magadi area. Mem. Geol. Surv. Kenya, Rep. 42, 81 pp.

Beadle, L.C., 1932. Scientific results of the Cambridge expedition to the East African Lakes, 1930-1,4. The water of some East African Lakes in relation to their fauna & flora. J. Linn. Soc. Zoo., 38: 157-211.

Biney, C.A., 1990. A review of characteristics of freshwater and coastal ecosystems in Ghana. Hydrobiol. 20S: 45-53.

Biswas, S., 1966. Oxygen and phytopiankton changes in newly formed Volta Lake in Ghana. Nature 209: 218-219.

Br"ylinsky, M. & Mann, K.H., 1973. An analysis of factors governing productivity in Lakes and reservoirs. Limnol. Oceanogr. 18: 1-14.

Carmouze, J.P., Durand J.R. and L'eveque, C., 1983. Lake Chad. Ecology and productivity of a shallow tropical ecosystem. Junk publishers Hague, 145-175 pp.

Currie.D. «< Ka1ff,J.,1984. A comparison of the abilities of "freshwater algae and bacteria to acquire and retain phosphorus. Limnol. Oceanogr. 29: 311-321

Cochran, W.G., 1950. The comparison of percentages in matched samples Iji Green R.H., 1979. Sampling Design and Statistical methods for Environmental biologist, Wiley - Intersci. publ., 191-192 pp.

Cole, G.A., 1979. Textbook of Limnology. Mosby, St. Louis, 426 pp.

Cur1, H. & Small, L.F., 1965. Variation in photosynthetic assimilation rating in natural marine phytop1ankton communities. Limnol. Oceanogr. 10: 67-73.

Dillon, P.J., 1975. The phosphorus budget of Cameron Lake, Ontario. The importance of flushing rates to the degree of eutrophy of lakes. Limnol. Oceanogr. 20: 28-39.

Dillon, P.J., & Rigler, F.H., 1974. The phosphorus-chlorophyll relationship in Lakes. Limnol. Oceanogr.19: 767-773.

Dillon, P.J., Nichol1as, K.H. & Robinson, G.W., 1978. Phosphorus removal at Gravenhurst Bay, Ontario: An 8 year study of water quality changes. Verh. Internat. Verein. Limnol. 20: 263-272.

Edmondson, W.T., 1956. The relation of photosynthesis by phytoplankton to light in lakes. Ecology 37: 161-174.

Elliot & Porter 1971.In. Mackereth,F.J.H, Heron,J. & Tailing J.F. 1978. Water analysis: some revised methods for Limnologists. Sci. Publ. Freshwat. Biol. Ass. 36, 72 pp.

J.H., 1961. Growth of Lake Victoria phytop1ankton in enriched cultures. Nature, Lond. 189: 417.

isH, G.R., 1956. Chemical factors limiting growth of Phytoplankton in Lake Victoria. E. Afr. Agric. J. 21: 152-158.

°x - 1957. A first list of marine algae from Nigeria. J- Linn. Soc. Bot. 55: 615-631.

Critsch, F.E., 1907. The sub-aerial and freshwater algal flora of the tropics. Ann- Bot. 21: 235-275.

f, G.G., 1972. The regulation of net primary production in Lakes George Uganda, East Africa. Iji Kaja,Z.,& Hi 1 lbrisht (eds.). Productivity problems of freshwaters, Polish Scient. Publ. Ilkowska, 693-708 pp.

Ganf, G.G., 1974. Phytoplankton biomass and distribution in a shallow eutrophic lake (Lake George, Uganda). Oecologia 16: 9-29.

Ganf, G.G.,& Viner, A.B., 1973. Ecological stability in a shallow equatorial Lake (Lake George, Uganda). Proc. Royal Soc. Lond. 184: 321-346.

Gaudet, J.J., 1977. Natural drawdown of Lake Naivasha, Kenya and the origin of papyrus swamps. Aquat. Bot. 3: 1-17.

Gaudet, J.J., 1978. Effects of tropical swamps on water quality. Verh. Internat. Verein. Limnol. 20 : 2202-2206

Gaudet, J.J. 1979. Seasonal changes in nutrients in a tropical swamp, North Swamp, Lake Naivasha, Kenya. J. Ecol. 67: 953-981.

Gaudet, J.J. & Melack, J.M., 1981. Major ion chemistry in a tropical African basin. Freshwat. Biol. 11: 309-331.

Gaudet, J.J. & Muthuri, F.M., 1981. Nutrient relationships in shallow water in an African Lake, Lake Naivasha. Oecologia 49: 109-118.

olterman, H.L., 1969. Methods for chemical analysis of freshwaters. IBP Handbook No.B, Blackwell Scientific **Publication** Oxford, 166 **pp.**

Qolterman, H.L., 1975.In. Gaudet J.J.,& Muthuri F.M., 19B1. **Nutrient relationships in shallow** water **in an** African lake, Lake Naivasha. Oecologia 49: 109-118.

Goldman, C.R., Mason, D.T. & Wood, B.B., 1973. Light injury and inhibition in Antarctic fresh water phytopiankton. Limnol. Oceangr. 8: 313-322.

Gregory, J.W., 1921. The rift valleys and geology of East Africa. Seeley, Service & Co., London, 479 pp.

Handerson, H.F., 1978. The productivity of water bodies. Sixth FAO (SIDA Workshop on aquatic pollution in relation to protection in living resources Nairobi, Kenya. Fir: TPLR/78/2: 276-287.

Harper, D., 19B7. Studies on the Lake Naivasha Ecosystem (1982—1984). University of Leicester final report to the Kenya Government, May 1987, 37-69 pp.

Harper, D., 1989. Interim report of investigations carried out by University of Leicester in col 1aboration with the University of Nairobi and Fisheries Dept. of Govt. of Kenya.

Harper, D., Mavuti, K.M. & Muchiri, S.M.,1990. Ecological and management of Lake Naivasha, Kenya, in relation to climatic change. Alien species,introductions,and Agricultural Development. Env. conserv. 17: 328-336.

Harris, G.P., 1973. Diel and annual cycles of net plankton photosynthesis in Lake Ontario. J. Fish. Res. Bd. Can. 30: 1779-1789.

Harris, G.P. & Lott, J.N., 1973. Light intensity, photosynthetic rates in phytopiankton. J. Fish. Res. **Bd.** Can. 30: 1771-1778.

Havilan» E.J., Wallis, D.M., Morris, R, & Woolnough, J.A., . A rnicro-calorimetric method for determination of ammonia in Kjeldahl digest with manual spectrophotometer. Lab- pract. 26: 545-547.

Hecky, R.E., & Kilham, P., 1973. Diatoms in alkaline, saline lakes: geochemical implications. Limnol. Oceanogr. 18: 53-71.

Hecky, R.E., & Kling, H.J., 1981. The phytopiankton and protozooplankton of the euphotic zone of Lake Tanganyika species composition, biomass, chlorophyll content, and spatio-temporal distribution. Limnol. Oceanogr. 26: 548-564.

Hecky, R.E.,8< Kling, H.J., 1987. Phytopiankton ecology of Great Lakes in the Rift Valley of Central Africa. Arch. Hydrobiol. Beih. Ergebn. Limnol. 25: 197-228.

Hutchinson, G.E., 1975. A treatise of limnology. Vol. I. Part 2. Chemistry of Lakes. John Wiley and Sons, Inc. New York, 727-877 pp.

Idiem' Opute, F.J., 1990. Phytopiankton flora in the Warri/Forcados Estuary of Southern Nigeria. Hydrobiol. 208: 101-109.

?nkin, P.M., 1932. Reports on the Percy Sladen Expedition to some Rift Valley Lakes in Kenya in 1929. Introductory account of the biological survey of five freshwater and alkaline lakes. Annal. and Magazine Nat. Hist., Ser. 10, 9: 533-553.

Jewsen, D.H. & Taylor, J.A., 197B. The influence of turbidity on the net phytoplankton photosynthesis in some Irish lakes. Freshwat. Biol. 8: 573-584.

Kalff, **J.** 1983. Phosphorus limitation in some tropical African Lakes. Hydrobiol. 100: 101-112.

Kalff, J. «, Watson, S., 1986. Phytop1ankton and its dynamics in two tropical lakes, a tropical and temperate zone comparison. Hydrobiol. 138: 161-176.

^llquist, T., 1979. Phytopiankton and primary production in Lakes Baringo and Naivasha, Kenya. Sil/UNEP Workshop on African Limnology, Nairobi. 16-23 December, 1979.

Kilham, P., 1971. Biogeochemistry of African Lakes and Rivers. Ph.D Thesis, Duke University, Durham, North Carolina, 199 pp.

^i1ham, S.S. & Kilham, P.J., 1975. Melosira granulata (Ehr) Ralfs: Morphology and Ecology of a cosmopolitan freshwater diatom. Verb. Internat. Verein. Limnol.19: 2716-2721.

Leakey, L.S.B., 1931. East African lakes. Geogr. J. 77: 497-514.

Lemoelle, J., 19B1. Photosynthetic production in the euphotic zone of some African and temperate lakes. Rev. Hydrobiol. trop. 14(i): 31-37.

Lewis, W.M., Jr., 1978. Dynamics and succession of phytop1ankton in a tropical lake: Lake Lanao, Phi11ipines. J. Ecol. 66: 849-880.

Likens, G.E., 1975. Primary productivity of inland aquatic ecosystems. In. Leith, H., & Whittaker, R. H. (eds) Primary Productivity of the Biosphere. **Spr**inger-Ver1ag, New York.

Likens, G.E., & Loucks, O.L., 1978. Analysis of five North America Lake ecosystem. III. Sources loading and fate of nitrogen and phosphorus. Verh. Internat. Verein. Limnol. 20: 568-573.

Lind, E.M., 1965. The phytopiankton of some Kenya waters. ***J.*** E. Afr. Nat. Hist. Soc. 25: 76-91.

Lind, E.M., 1967. Some East African desmids. Nova Hedwigia 22: 535-584.

Lind, E.M., 1968. Notes on the distribution of phytopiankton in some Kenya waters. Br. phyc. Bull. 3(3):481-493.

O.T., 1979. Handbook of common methods in limnology. C.V. Mosby Company, 137 pp.

L-indemann, R.L., 1942. The trophic dynamic aspect of ecology. Ecology 23: 399-41B.

itterick, M.R., Gaudet, J.J., Kalff, J. & Melack, J.M., 1979. The Limnology of Lake Naivasha. Document presented SIL-UNEP Workshop on African Limnology, Nairobi 16-23 December, 1979, 73 pp.

Livingstone, D.A., 1977. Response of **a** tropical rain forest **to global** climatic change In. Njuguna, S.G., 1982. Nu**tr**ient-**produc**tivity relationship in tropical Naivasha **basin lakes** Kenya. Ph.D. Thesis University of Nairobi, 4 PP-

Mackereth, F.J.H., Heron, J. & Tailing, J.F. 1978. Water analysis: some revised methods for Limnologists. Sci. Publ . Freshwat. Biol.Ass. 36, 120 pp.

flakin, J., 1967. The soils and ground waters of the Animal Husbandry Research Station. Soil Survey Unit Special Report, Kenya Soil Survey, Nairobi.

Malvestuto, S., 1974. The fishes of Lake Naivasha their biology, exploitation and management. Mimeographed report to the Director of Fisheries, Government of Kenya, Nairobi, Kenya ,34 pp.

Malvestuto, S. P., 1975. Contracaecumosis of Tilapia leucosticta in Lake Naivasha, Kenya. M.sc. thesis, University of Nairobi, 65 pp.

Mavuti, K.M., 1983. Studies on the community structure, population dynamics and productivity of the limnetic zooplankton of the tropical lake, Lake Naivasha, Kenya. Ph.D Thesis, University of Nairobi, 209 pp.

Mavuti, K.M., 1990. Ecology and role of zooplankton in the fishery of Lake Naivasha. Hydrobiol. 208: 131-140.

Mavuti, K.M., & Litterick, M.R., 1981. Species composition and distribution of zooplankton in a tropical lake, Lake Naivasha, Kenya. Arch. Hydrobiol. 93: 52-58.

McCauley, E., Downing, J. A.,& Watson, S.,1989. Sigmoid relationships between nutrients and chlorophyll among lakes. Can. J. Fish. Aquat. Sci. 46: 1171-1175.

Melack, J.M., 1976. Limnology and dynamics of phytoplankton in equatorial African Lakes. Ph.D thesis, Duke University Durham, 453 pp.

Mel ack, J.M., 1978. Morphometric, physical and chemical feature of volcanic crater lakes of western Uganda. Arch. Hydrobiol. 84: 430-453.

Melack, J.M., 1979. Photosynthetic rates in four tropical African fresh waters. Freshwat. Biol. 9: 555-571.

Melack, J.M., & Kilham, P., 1974. Photosynthetic rates of phytopiankton in East African alkaline, saline lakes. Limnol. Oceanogr.19: 743-755.

Melack, J.M., Kilham, P., & Fisher, T.R., 1982. Responses of phytoplankton to experimental ferti1ization with ammmonium and phosphate in African Soda Lake. Oecologia 52: 321-326.

Millbrink, G., 1977. On the limnology of two alkaline lakes (Nakuru & Naivasha) in the East Rift Valley system in Kenya. Intern. Rev. ges. Hydrobiol. 62: 1-17.

Molot, L.A.,& Dillon, P.J.,1991. Nitrogen/phosphorus ratios and the prediction of chlorophyll in phosphorus limited lakes in central Ontario. Can. J. Fish. Aquat. Sci. 48: 140-145.

Moss, B. 1969. Limitation of algal growth in some central African waters. Liimiol. Oceanoqr . 14: 591-601 .

Mortimer, C.H., 1956. An explorer of lakes in E.A Birge, a memoired G.C. Sellery. Univ. of Wisconsin , 165-206 pp.

^Isson, E., 1931. Quaternary glaciations and pluvial lakes in British East Africa. Geogr. Ann. 13: 249-349.

Nilsson, E., 1940. Ancient changes of climate in British East Africa and Abyssinia. Geogr. Ann. 22: 1-79.

Njuguna, S.G., 1982. Nutrient-productivity relationship in tropical Naivasha Basin Lakes, Kenya. Ph.D thesis University of Nairobi, 300 pp.

Oglesby, R.T., 1977. Phytoplankton summer standing crops and annual productivity as functions of phosphorus loading and various physical factors. J. Fish. Res. Bd. Can. 34: 2255-2270.

Oglesby, R.T. & Schaffner, W.R., 1978. Phosphorus loading to Lakes and some of their responses. Part I. A new calculation of phosphorus loading and its application to 13 New York lakes. Limnol. Oceanogr. 23: 120-134.

Ongweny, G., 1973. The significance of the geographic and geologic factors in the variation of groundwater chemistry in Kenya. M.Sc. thesis University of Nairobi, Kenya.

•wens, M., Knowles, G. & Clank, A., 1969. The prediction of the distribution of dissolved oxygen in rivers. Advances in water pollution, Research proc. of the 4th. Inter. Conf. in Praque, Pergamon Press, Oxford ,125-147 pp.

Patrick, R., 1950. A proposed biological measure of stream conditions.Proc. 5th Indust. Waste Conf. Purdue University. Eng. bull. 34: 379-399.

Pear5a11, W.H., 1930. Phytopiankton in the English lake District.I. J. Ecol. 18: 306-330.

Pearsall, W.H., 1932. Phytop1ankton in the English Lakes. II. J. Ecol. 20: 241-262.

Peters, R. H., & Maclntyres, S., 1976. Orthophosphate turnover in East African lakes. Oecologia (Berl) 25: 313-319.

eter"5en» B.J., Barlow, J.P., «, Savage, A.E., 1974. The physiological state with respect to phosphorus of Cayuga lake phytop1ankton. Limnol. Oceanogr. 19: 396-408.

Pr~att» D.J., Greenway, P.J. «< Gwyne, M.D., 1966. A classification of East African rangeland, with an appendix on terminology. J. Appl. Ecol. 3: 369-382.

Prosser, M.V., Wood, R.B. & Baxter, R.M., 1968. The Bishoftu crater lakes: A bathymetric and chemical study. Arch. Hydrobiol. 65: 309-324.

Rrowse, G.A. & Tailing, J.F., 1958. The seasonal growth and succession of plankton algae in the White Nile. Limnol. Oceanogr. 3: 223-238.

Rachillo, J.R., 1977. Soil conditions of the Kinangop plateau. Site Evaluation Report. No. P35. Kenya soil Survey, Nairobi.

Reynolds, C.S., 1973. The seasonal periodicity of diatoms in a shallow eutrophic lake. Freshwat. Biol. 3: 89-110.

Reynolds, C.S., 1984. The ecology of freshwater phytopiankton. Cambridge Univ. Press, Cambridge, 384 pp.

Rhee, G.Y., 1972. Competition between an algae and aquatic bacterium for phosphate. Limnol. Oceanogr. 17: 505-514.

Richardson, J.L., 1964. The history of an African Rift Lake: An interpretation based on current regional limnology. Ph.D. thesis Duke University, Durham N.C, 473 pp.

Richardson, J.L.,1966.Changes in level of Lake Naivasha, Kenya, during post-glacial times. Nature. 209: 290-291

Richardson, J. L., 1969. Characteristic planktonic diatoms of the lakes in tropical Africa. Intern. Rev. ges. Hydrobiol. 54: 175-176.

Richardson, J.L. & Richardson, A.E., 1972. History of an African Rift Lake and its climatic implications. Ecol. Monogr. 42: 499-534.

Rigler, F.H., 1966. Radiobiological analysis of inorganic phosphorus in Lake water. Verli. Internat. Verein. Limnol. 16: 465-470.

Roberts, R.B.,& Southall, G.C., 1975. Algal bioassay of two tropical Rhodesian reservoirs. Acta Hydrochin. Hydrobiol. 3: 369-377.

Roberts, R.B. & Southall, G.C., 1977. Nutrient limitation of phytoplankton growth in seven tropical man-made lakes, with special reference to Lake Mcllwaine, Rhodesia. Arch. Hydrobiol. 79: 1-35.

Rodhe, W., 1958. The primary production in lakes: Some results and restrictions of the C-14 method. Rapp. Proc. Cons. Intern. Explor. Mer 144: 122-128.

Ryther, J.H., 1956. Photosynethesis in the Ocean as a function of light intensity. Limnol. Oceanogr. Is 61-70.

Rzoska, J. & Tailing, J.F., 1966. The development of plank--ton in relation to hydrological regime in the Blue Nile. J. Ecol. 55: 637-662.

Sakamoto, M., 1966. Primary production by phytopiankton community in some Japanese Lakes and its dependance to the lake depth. Arch. Hydrobiol. 62: 1-28.

Schindler, D.W., 1978. Factors regulating phytopiankton production and standing crop in the worlds freshwaters. Limnol. Oceanogr. 23: 478-486.

Schindler, D.W. & Fee, E.J. 1974. Primary production in freshwater. Proc. of the first International Congress of Ecology. Centre for Agriculture publication and Documentation, Wageningen, 155-158 pp.

Schindler, D.W. & Fee, E.J.,1975. in Livingstone, D.A., & Melack, J.M., 19B4. Some lakes of subsaharan Africa. Elsevier Science Publishers B.V. Amsterdam, 467-497 pp.

Siddiqui, A.Q., 1977. Lake Naivasha (Kenya, East Africa) fishery and its management together with a note on the food habits of the fishes. Biol. Conserv. 12: 217-227.

Sikes, H.L., 1936. Notes on the hydrology of Lake Naivasha. **J**. E_ Afr. Uganda Nat. Hist. Soc. 13(1-2): 73-84.

Steemann-Nielsen, E., 1952. On the detrimental effects of high light intensities on the photosynthetic mechanism. Physiologia plantarum 5: 334-344.

Steemann—Nie1sen, E., 1962. Inactivation of photochemical mechanisms in photosynthesis as a means to protect the cells against too high light intensities. Physiologia plantarum 15: 161-171.

Stirn, J., 1981. Manual **Df** methods in aquatic environment research, 8. Ecological assessment of pollution effects. FAO Fish. Tech. Pap. No. 209, Rome, 70 pp.

Strickland, J.D.H. & Persons, T. R., 1972. A practical handbook of seawater analysis. Fish Res. Board Can Bull. 167 (2 eds), 310 pp.

Syren, P., 1986. Studies on Lake Naivasha Kenya and its drainage area. Engelsic Text. Universitet Stockholm , 75 pp.

Tailing, J.F., 1965. The photosynthetic activity of phytopiankton in East African Lakes. Intern. Rev. ges. Hydrobiol. 50: 1-32.

Tailing, J.F., 1966. The annual cycle of stratification and phytopiankton growth in Lake Victoria, East Africa. Intern. Rev. ges. Hydrobiol. 51: 545-564.

Tailing, J.F. & Driver, D., 1963. Some problems in the estimation of Chlorophyll a in phytop1ankton. Proc. Conf. of Primary productivity measurement, Marine & Freshwater, Hawii Honolulu US. Atomic Energy Comm (1963)

7633: 142-146.

Tailing, J.F., 8, Tailing, I.B., 1965. The chemical composition of African lake waters. Intern. Rev. ges. Hydrobiol. 50: 421-463.

Tailing, J.F., Wood, R.B., Prosser M.V.,& Baxter, R.M., 1973. The upper limit of photosynthetic productivity by phytopiankton: evidence from Ethiopian soda lakes. Freshwat. Biol. 3: 53-76.

Thompson, A.O. & Dodson, R.G., 1963. Geology of the Naivasha Area. Geological Survey of Kenya Report No. 55. Government Printer, Nairobi, BO pp.

Vareschi, E., 1981. Tn Njuguna, S.G., 1982. Nutrient-productivity relationship in tropical Naivasha basin lakes, Kenya Ph.D thesis, University of Nairobi, 204 pp.

Vincent, C.E., Davies, T.D. & Baresford, U.C., 1979. Recent changes in the level of Lake Naivasha, Kenya, as an indicator of Equatorial Westerlies over East Africa. Climatic Change 2: 175-191.

Viner, A.B., 1973. Responses of a mixed phytop1ankton population to nutrient enrichments with ammonia and phosphate, and some associated ecological implications. Proc. R. Soc. Lond. B: 183: 351-370.

Viner, A.B., 1977. Relationships of nitrogen and phosphorus to a tropical phytopiankton population. Hydrobiol. 52: 185-196.

Vol 1enweider, R.A., 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. OECD.Tech. Rep. DAS/CS1/69 27: 1-82.

Vol 1enweider, R.A., 1969. A manual of methods of measuring primary production in aquatic Environment. IBP Handbook No. 12 Blackwel1, Oxford, 358 pp.

Water Research Centre (1973). A method for the

determination of chlorophyll a in algae using boiling methanol. WRC Medmenham. England, 2 pp.

Wetzel, R.G., 1983. Limnology. Saunders company, Philadelphia (2 eds), 223-297 pp.

Wetzel, R.G. & Likens, G.E., 1979. Limnological analysis. Saunders Company, Philadelphia, 357 pp.

Wetzel, R.G. & Likens, G.E., 1991. Limnological analysis. Springer - verlag, Newyork (2 eds), 391 pp.

White, P.S., 1979. Pattern process and natural disturbance. Veg. Bot. Rev. 45(No.3): 229-299.

Willen, T., 1972. The gradual destruction of Sweden's Lakes. Ambio. 1: 6-14.

Winkler 1888.In Mackereth,F.J.H.,Heron,J.,& Tailing J.F.,1978. Water analysis: some revised methods for 1imno1ogists. Sci.Publ. Freshwat. Biol. Ass. 36, 124 pp.

Youngman, R.E., Johnson, D. & Farley, M.R., 1976. Factors influencing phytopiankton growth and succession in Farmoor Reservoir. Freshwat. Biol. 6: 253-263.

APPENDIX

e I: Regression analysis of Naivasha Lake level in relation to rainfall.

Regression Analysis - Linear modal : Y = a + bX

Dependent variable: NAIVASHA.LEVEL, Independent variable: NAIVASHA RAINFALL

Parameter	Estimate	Standard Error	T Value	Prob. Level	
Intercept	1884.39	0.104118	18098.6	0	
Slope	-7.081E-4	1.02092E-3	-0.693591	0.496793	(49%)

Analysis of Variance of the Regression equation

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Leve]
Model	.0230049	1	.0230049	.481069	.49679
Error	.860770	18	.047821		
Total (Corr.)	.883775	19			

Correlation Coefficient = -0.161339 R-squared = 2.60 percent
Stnd. Error of Est. = 0.218679

APPENDIX

Table 2: Cochrans Q-Test

(a) Main Lake Species Composition

NUMBER OF SPECIES

Time	1	2	3	A	5	6	7	8	9	10	11	12	13	1A	15	16	17	18	19	20	21	22	23	2A	25	26	27	28	29	30	Gi	Gi2
1										1		1	1						1												A	16
2										1		1	1						1												A	16
3					1					1		1	1	1					1									1		1	8	6A
4					1					1		1	1	1					1									1		1	8	6A
5	1	1	1		1	1	1			1		1	1	1		1			1	1		1	1		1	1	1	1		1	21	AA1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1		1		1	1	1	1	1			1	1	1	25	625
7	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1		1	1	1	1	1	1		1		1	25	625
8	1							1		1	1		1			1	1	1	1		1	1	1		1			1		1	15	225
9	1							1	1	1			1		1	1	1	1	1		1	1	1		1					1	15	225

Gi = 125 Gi^2 - 2301

L	5	3	3	2	5	3	3	5	2	9	3	7	9	5	2	5	A	2	9	1	A	5	5	2	5	2	1 6	1 7	Lj-125			
L^2	25	9	9	A	25	9	9	25	A	81	9	A9	81	25	A	25	16	A	81	1	16	25	25	A	25	A	1	36	1	49	L_2-6*81*		

Cone. Table 2

(b) Crescent Island Lake Species Composition

NUMBER OF SPECIES

Time	I	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	Gi	Gi^2
I										1	1		1									1												4	16
2										1	1		1									1												4	16
3										1	1											1												3	9
A		_								1	1	1		1								1												5	25
5	1	1	1	1	I		1	1		1	1	1		1				1				1	1	1	1	1					1	1	1	20	400
6	1	1			1		1	1		1		1	1	1				1	1	1		1		1	1	1		1	1	1		1		1	21	441
7	1			1				1		1	1		1							1		1		1	1	1		1			1			1	41	196
8	1	1	1	1	1	1		1			1	1	1	1	1			1	I		1	1	1	1	1	1		1	1	1	1	1	1	1	27	729
9	I			1	1	L		1			1	I	I	1	1		1	1		1	1		1	1	1	1	1	1	1	1		1		1	24	576
L	5	3	2	4	4	2	2	5		7	3	5	6	5	2		I	4	2	3	2	8	3	5	5	5	1	4	3	3	5	2	5	L-L22	
L^2	25	9	4	16	16	4	4	25		49	81	25	36	25	4		1	16	4	36	4	64	9	25	25	25	I	16	9	9	25	4	25	L^2-573	

Gi-122 , Gi^2-240

HO: No variation is species composition with time

Therefore:-

$$Q = \frac{(K-1)\ (KGi^2-(Gi^2)}{^{KL}1\ -\ ^{L}2}$$

$$= \frac{(9-1)\ ((9)\ (2301)\ -\ (125)^2)}{9(125)\ -\ 681}$$

$$= \frac{8\ ((9)\ (2301)\ -\ (125)^2)}{9(125)\ -\ 681-}$$

$$= \frac{8\ ((9)(2301)\ -\ 15625.0)}{9(125)\ -\ 681}$$

$$= \frac{40672.00}{444.0}$$

$$= 91.603604$$

Q(8df) 91.6 at Mainlake

104.4 at Crescent Island lake

Therefore:-

$$^{X}0.05\ ^{(8df)} = ^{15,507}$$

We reject HO

Therefore, concluding that spp diversity as measured by number **of** species docs vary with season.

APPENDIX i

Table 3: Analysis of Variance of Chlorophyll a by stations and months.

Source of variation	Sum of squares	DF	Mean Square	F	Signif. of F
Main effects	26166.188	10	2616.619	56.459	.000
STATION	18914.093	2	9457.046	204.056	.000
MONTH	7252.095	8	906.512	19.560	.000
2-way Interactions	65667.122	16	4104.195	88.557	.000
STATION MONTH	65667.122	16	4104.195	88.557	.000
Explained	91833.310	26	3235.050	76.211	.000
Residual	22523.876	486	46.345		
Total	114357.186	512	223.354		

APPENDIX

Table 4: Analysis of Variance of Chlorophyll a with depth,

(a) Safariland Station:

Source of variation	Sum of Squares	DF	Mean Square	F	Signif. of F
Main effects	189.204	3	63.068	.416	.742
DEPTH	189.204	3	63.068	.416	.742
Explained	189.204	3	63.068	.416	.742
Residual	15757.099	104	151.511		
Total	15946.303	107	149.031		

(b) Hippopoint Station:

Source of variation	Sum of squares	DF	Mean Square	F	Signif. of F
Main effects	130.650	5	26.130	.110	.990
DEPTH	130.650	5	26.130	.110	.990
Explained	130.650	5	26.130	.110	.990
Residual	36904.971	156	236.570		
Total	37035.621	161	230.035		

(c) Crescent Island Lake:

Source of variation	Sum of Squares	DF	Mean Square	F	Signifi. of F
Main effects	1966.650	8	245.831	1,421	.189
DEPTH	1966.650	8	245.831	1,421	.189
Explained	1966.650	8	245.831	1,421	.189
Residual	40494.519	234	173.054		
Total	42461.169	242	175.459		