TITLE

PHYTOPLANKTON AND PHYSICOCHEMICAL DYNAMICS OF LAKE BARINGO

by

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A thesis submitted in part fulfilment of the requirements for the degree of Master of Science

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Nairobi,
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1989

DECLARATION

This is my original work and has not been presented for a degree in any other University.

Date 2nd Feb. 1990. Signature, ...

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DEDICATION

To my parents, Mr. and Mrs Kotut Chemoiywo.

ACKNOWLEDGEMENTS

This work was made possible by a scholarship award from Kenyatta University. Additional funds were provided by East African Wildlife Club Society through Professor S.G. Njuguna of the National Museums of Kenya to whom I am most thankful.

I am most grateful to my supervisors, Dr. G. Patterson and Dr. F.M. Muthuri of the Botany Department Kenyatta University for their continuous guidance throughout the study.

Appreciation is extended to Operation Raleigh International for catering for my stay in the field, providing an equipped field laboratory and transport to the sampling sites. Without this assistance, this study would not have been possible. I am particularly indebted to Dr. C. Foxall of the Chemistry Department Kenyatta University, who introduced me to Operation Raleigh, and all the staff members and venturers of Operation Raleigh for their invaluable assistance in the field.

My sincere gratitude goes to Dr. G.D. Njagi, Chairman, Botany Department, Kenyatta University, for his administrative help and all the staff members of the Botany Department, Kenyatta University for their constant encouragement and constructive suggestions.

Many thanks are due to Mr. M. Kanyingi for his technical services and Mrs A. Waudo for undertaking the arduous task of typing this work.

Finally, special thanks are due to my parents, classmates and friends for their forbearance and unrelenting support during the study.

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ABSTRACT

Temporal and spatial variation, and the interaction of a number of physical, chemical and biological properties were examined in Lake Baringo (O° 46'N; 36° 15'E), a tropical freshwater Rift Valley lake, between July 1988 and March 1989. The study also included the four perennial rivers draining into the lake (Rivers; Mukutan-R_1, Ol-Arabel-R_2, Molo-R_3 and Perkerra-R_4) and the hot springs in the central island Kokwe.

The lake was very turbid (mean Secchi depth 0.05 m), a condition brought about by the excessively high silt in suspension. Vertical temperature measurement over a 24 hour period showed that the lake exhibits a diurnal mixing pattern in which stratification sets in under hot calm conditions and later on completely mixes. Mixing is wind induced and aided by nocturnal convective cooling. Owing to the above average rainfall received in the general area, during the study period, the lake level rose precipitously to peak value, 1.75 m above the original level.

The mean lake conductivity and total alkalinity showed some temporal variations that were negatively correlated to the lake level changes ($r=0.93$ and 0.83 respectively). The rivers' conductivity and alkalinity also showed some inverse relationship to their water volumes. The mean lake conductivity ranged from 690 to 1170 $\mu S\ cm^{-1}$ and alkalinity from 6.0 to 9.1 meq l^{-1} as $CaCO_3$. The other chemical properties of the lake showed no distinct temporal changes and had the following ranges: pH, 6.9 to 9.2; dissolved oxygen (DO),82 to 96% saturation ; ammonia nitrogen (NH_3-N), 11.4 to 61.6 $\mu g\ l^{-1}$; nitrite nitrogen (NO_2-N), 0.9 to 3.0 $\mu g\ l^{-1}$; total nitrogen (TN), 0.78 to 3.50 mg l^{-1}; soluble reactive phosphorus (SRP), 0.084 to 0.152 mg l^{-1}; total phosphorus (TP), 0.112 to 0.175 mg l^{-1}; and nitrogen phosphorus ratio (N:P), 4.3 to 15.3. Conductivity and alkalinity showed a positive temporal correlation ($r= 0.98$), a feature attributable to the predominance of carbonates and bicarbonates.

The lake showed no distinct spatial variation in its chemical composition except at the south end where increased river and stream inflows greatly decreased the water conductivity, alkalinity and pH. DO levels also decreased possibly due to the introduction of deoxygenating organic allochthonous materials by the flood water. The mean river conductivities ($\mu S\ cm^{-1}$) were: R_1, 450; R_2, 320; R_3, 240 and R_4, 130; the mean alkalinities (meq l^{-1} $CaCO_3$) were 4.8, 2.7, 2.1 and 1.4 respectively. The other chemical properties of rivers showed no appreciable variation and were all, except silica, lower than the mean lake levels. The saline hot springs in the N.E. shore and the W. Cliff had mean conductivities ($\mu S\ cm^{-1}$) of 3490 and 3470, and alkalinities (meq l^{-1} $CaCO_3$) of 30.4 and 37.5 respectively. The saline hot spring inflows, the supply of salts by the rivers and the fact that the lake is

topographically endorheic suggests that the lake has some mechanism of regulating its freshness. Seepage outflow is strongly suspected to be one such mechanism.

Phytoplankton chlorophyll a measured as an index of phytoplankton biomass lacked a distinct temporal variation pattern (coefficient of variation, 16.2%). The mean lake values ranged from 8.7 to 15.9 ug l^{-1}. A much wider fluctuation was, however, observed in the individual sampling sites. The phytoplankton community was dominated by the coccoid cyanophyte Microcystis aeruginosa which had a mean cell count of 1.17×10^3 cells ml^{-1}. The other common species Pseudanabaena catenata (1.4×10^2 trichomes ml^{-1}) and Nitzschia sp. (1.4×10^2 cells ml^{-1}) appear to be epiphytic on the mucilagenous coat of M. aeruginosa. The success of M. aeruginosa in the turbid waters of Lake Baringo possibly relies on its ability to regulate its buoyancy with gas vacuoles. On the lake surface, the dominant alga exhibits a patchy distribution which is wind induced. This behaviour explains the wide fluctuation in the biomass content of the individual sampling sites, and possibly masks the temporal patterns of change in chlorophyll a concentration and phytoplankton density. Over time, however, some qualitative changes were observed. These included the disappearance of Botryococcus braunii some time in December and the appearance around this time of some other algal genera, e.g. Anabaena sp., Scenedesmus sp. and Melosira sp.

Primary production measurement gave an areal rate of 3.8 g O_2 m^{-2} day^{-1}, a value much lower than that of other shallow freshwater East African Rift Valley lakes. As the lake had an N:P ratio of 11.8 and a high level of soluble reactive phosphorus, it is possible that neither nitrogen nor phosphorus limits phytoplankton growth and photosynthesis. As the lake is very turbid, the limiting role of light is strongly suspected.

CHAPTER 1. INTRODUCTION

1.1 GENERAL INTRODUCTION

The science of limnology appears to have evolved in Europe and North America at the beginning of the century. Limnological work, however, started much earlier (Goldman and Horne, 1983). In Africa, it can be said to have began in the 1890s with the two expeditions of J.E.S. Moore to Lake Tanganyika (Beadle, 1974). Since the Second World War, great advances in African Limnology have been achieved. This has been made possible by the dramatic innovations in equipment, techniques and ideas.

In the African continent the freshwater resources contribute a great deal to the nutrition and welfare of the population (Beadle, 1974). The waters form a great potential reservoir of animal protein for a population for which protein deficiency is a major and widespread dietary problem. Most of the information that has so far been obtained on African Limnology is general and based on the larger and/or more accessible lakes. African lakes differ widely from each other, owing to variation in the geology of their drainage basin, their geographical location, the climatic conditions of the area and their depth and width. It is therefore necessary, as far as possible, to obtain ecological data on each water system and to avoid extrapolating the results of one system to another. Such information will allow for the formulation of optimal

management strategies for the resources available in that particular water system and prevent errors common to the wholesale transfer of the management strategies workable in a different system.

1.2 LITERATURE REVIEW

1.2.1 Lakes of the East African Rift System

1.2.1.1 Formation and history

The lakes of the East African Rift System owe their existence to dramatic earth movements, mainly since the Miocene. These movements produced a complex of catchment basins and drainage channels in the Rift System and the surrounding areas. The detailed sequence of events culminating in the formation of the East African Rift System is unclear and has been a source of lively debate among geologists (e.g. Baker and Wohlenberg, 1971 and Frostick and Reid, 1987).

Evidence emerging from the study of raised beaches and sediments, some of which contain fossils of fish and other aquatic organisms, suggests that the amounts and distribution of standing waters in the Rift Valley floor have greatly fluctuated over time (Cole, 1954; Leakey, 1931 and Nilsson, 1940). The cause of these fluctuations is mainly changes in climatic conditions and it is from the

study of lake level fluctuations that evidence concerning the past climates of tropical Africa has been gained (Grove and Goudie, 1971; Leakey, 1931; Nilsson, 1940; and Richardson and Richardson, 1972). It is, however, only the climatic events of the past 20,000 years or so that can easily be related to the present conditions of the East African lakes and their biology. The introduction during the late 1940s of methods of extracting long cores from underwater sediments and the contemporary invention of radiocarbon (^{14}C) dating have expanded the scope of investigations and provided an absolute time scale. A significant finding arising from these investigations is the fact that all the lakes were at an exceptionally high level between 10,000 and 8,000 years ago (Beadle, 1974). During the last 8,000 years, there have been several small oscillations of water levels in most lakes but with a greater lowering towards the present levels. The present distribution of lakes in the East African Rift System is given in Fig. 1.1.

1.2.1.2 Physical conditions

A close relationship between the varying lake levels and the climatological patterns in their catchment area has been documented for some East African Lakes, e.g. Dyer (1979) for Lakes Chilwa and Sibaya and Vincent *et al.* (1979) for Lake Naivasha. According to Allanson *et al.* (1981), small lakes can often be considered to share the climate of their surrounding while the large lakes can themselves

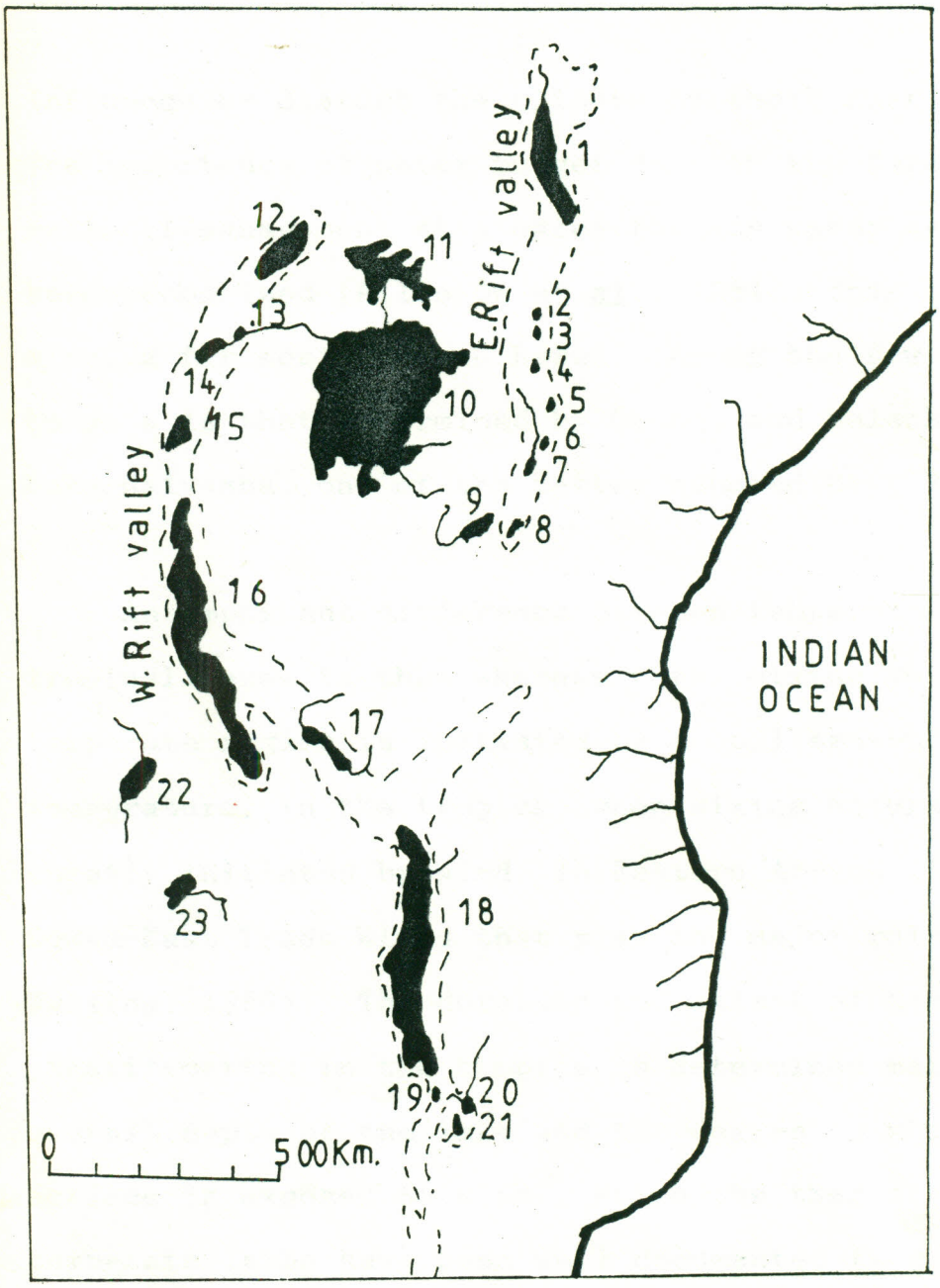
Fig. 1.1

The East African Rift System and the associated lakes. The map was redrawn from Beadle (1974).

KEY

1. Rudolf	9. Eyasi	17. Rukwa
2. Baringo	10. Victoria	18. Malawi
3. Bogoria	11. Kyoga	19. Malombe
4. Nakuru	12. Albert	20. Chiuta
5. Naivasha	13. George	21. Chilwa
6. Magadi	14. Edward	22. Mweru
7. Natron	15. Kivu	23. Bangwelu
8. Manyara	16. Tanganyika	

FIG.1.1


E.Rift valley
W.Rift valley
INDIAN OCEAN
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
0
500Km.

influence or distort the climate of their surrounding land. The importance of water budget data in the formulation of rational management strategies for any water system has been recognized (Allanson et al., 1981). This is, however, missing for most African Lakes. Among the few recent budgets is that determined by Gaudet and Melack (1981) for Lake Naivasha, one of the better studied Rift Valley lakes.

An important difference between temperate and tropical lakes is that whereas water mixing in the temperate region is initiated by a cool season drop in temperature, in the tropics, when mixing occurs, it is chiefly initiated by wind. In Eastern Africa it is the South-East Trade Winds that play the major role (Fryer and Talling, 1986). The duration and extent of temperature stratification in the tropics is determined mainly by the overall depth of the lake and the degree to which the lake surface is exposed to wind. While the thermal budgets of temperate lakes have been well documented (e.g. Lerman, 1978), those of tropical lakes are poorly understood and only few studies have been conducted, e.g. Lakes Nyumba ya Mungu (Denny, 1978), Albert (Talling, 1963) and Sibaya (Allanson, 1979). Any conclusions regarding the seasonal or diurnal heat budgets in the tropics must be qualified by a warning that the tropics are subject to irregular violent disturbances caused by wind and thunderstorms which in some lakes completely or to a great extent disrupt the stratification pattern.

1.2.1.3 Chemical conditions

The chemical composition of African lakes is extremely varied and includes features rarely found elsewhere (Talling and Talling, 1965). The subsaharan African lakes are usually characterised by an ionic composition arising from the incongruent dissolution of silicate rocks and rarely from the congruent dissolution of carbonates (Garels and Mackenzie, 1971 and Gaudet and Melack, 1981). These silicates are frequently feldspars of sodium rather than calcium. In the humid regions of the East African Rift Valley, high temperatures and rainfall promote the dissolution of feldspathoid volcanic rocks such as nepheline - $Na_3KAl_4Si_4O_{16}$ (Hecky and Kilham, 1973).

Certain lakes, though topographically endorheic, lose water via seepage (Allanson et al., 1981). Seepage helps to explain part of the anomaly that these lakes, endorheic in topography and having high evaporation rates, contain water low in dissolved salts. Seepage has been demonstrated for Lakes Naivasha (Gaudet and Melack, 1981), and Chad (Carmouze et al., 1977).

1.2.2 Phytoplankton physicochemical relationships in tropical African lakes

An important and familiar feature of most African lakes that have received prolonged studies is the seasonal variation in abundance, composition and photosynthetic

activity of the phytoplankton. Lind (1968), Melack (1976b), Prowse and Talling (1958) and Talling (1966, 1986) have described seasonal changes in species abundance and composition. Allanson and Hart (1975), Melack (1976b, 1979a) and Robarts (1979) have described seasonal changes in photosynthetic activity. Melack (1979b) has proposed that three patterns of temporal change in abundance and or photosynthetic rates of phytoplankton occur in tropical African lakes. Pattern A, which comprises most African lakes, has a very pronounced seasonality (e.g. Lakes, Victoria, Oloiden and Sonachi). In pattern B, little or no seasonality is obvious (e.g. Lake George and at times Lakes Naivasha and Nakuru). Pattern C exhibits a condition in which there is an abrupt switch from one persistent algal assemblage to another (e.g. Lakes Elmenteita and Bogoria). The distinction between pattern A and B is based on the calculation of the lake's phytoplankton biomass (as chlorophyll a) coefficient of variation (CV). In pattern A CV is greater than 25% and in B it is less than 20%. Fluctuations in phytoplankton abundance and/or photosynthesis usually correspond to pronounced seasonal weather changes which in turn influence the physicochemical status of the lakes. Njuguna (1988) recognises nutrient availability and the seasonal fluctuations in their supply as one of the principle factors controlling phytoplankton abundance in tropical Africa. In most of the alkaline soda lakes that have been studied, species succession has been shown to be a function of alkalinity change (Hecky and Kilham, 1973).

Comparative studies of the phytoplankton abundance in tropical African lakes have revealed the existence of an inverse correlation between phytoplankton abundance and the depth of the water basin. High algal concentrations are prevalent in shallow lakes such as Lake George (Ganf, 1974 and Ganf and Horne, 1975), Lakes Nakuru and Elmenteita (Melack 1979c) and Lake Kilotes (Talling et al., 1973). The inverse relationship might reflect pathways of nutrient circulation in the water mass, nutrient supply from sediments, or minimal light requirements in algal suspensions prone to self shading effects.

A good correlation between phytoplankton standing crop and total or biologically active phosphorus has been observed in temperate lakes (Vollenweider, 1968) suggesting that phosphorus deficiency often limits phytoplankton growth. Most of the tropical African lakes, notably the alkaline saline ones, often have a surplus of soluble reactive phosphate (Melack and Kilham, 1974; Peters and MacIntyre, 1976 and, Talling and Talling, 1965). Nutrient enrichment studies carried out in Lake Sonachi by Melack et al. (1982), however, showed that limitation of phytoplankton abundance by phosphorus can occur even in alkaline saline lakes. Other studies have shown nitrogen to be a growth limiting factor in some tropical African lakes (e.g. Moss, 1969; Nduku and Robarts, 1977 and Robarts and Southall, 1977). In summary, the main factors that influence the photosynthetic activity and abundance of the phytoplankton include nutrients, climate, lake morphometry

and circulation, optical properties of the water and the inter-specific phytoplankton interaction. Direct or indirect human activities also play a part.

In recent times, an approach to the evaluation of the potential fish production of a lake by comparative studies of the relationships between fish productivity and easily measured parameters has been devised. In African, Chinese and Indian lakes, commercial fish yields have been shown to increase logarithmically as productivity increases (Liang et al., 1981; McConnell et al., 1977 and Melack, 1976b). Consequently, continuous measurements of primary production and the monitoring of factors controlling it are important in the assessment of fish yields. Central to the sustained exploitation of an aquatic system's resources is a sound understanding of its physicochemical and biological dynamics. From this knowledge, the most profitable and ecologically sound management strategies can be formulated.

1.2.3 Previous studies on Lake Baringo

1.2.3.1 Formation and evolution

Lake Baringo lies in an asymmetric half graben in the central part of the Eastern Rift (Fig. 1.1). While carrying out a geological survey of the area surrounding Lake Baringo, Gregory (1921) found a series of well developed lake beds from which he postulated a much extended lake that existed during the upper Pleistocene. He called this

ancient lake, Lake Kamasia. From the name of the ancient lake, rocks of similar date throughout the Eastern Rift have come to be known as the Kamasian series. Since the Kamasian deposits are found as far north as the northern end of Lake Turkana and at least as far south as Lake Magadi, it is suggested (Gregory, 1921) that there may have existed a chain of great lakes, or one huge lake extending throughout this part of the Rift Valley. Arising from the study of old lake beaches in the Nakuru-Elmenteita and Naivasha basins is the fact that there was a long pluvial period (period of heavy rainfall) in the early or upper Pleistocene when the Kamasian beds were being laid down (Leakey, 1931). This was followed by a long dry period which led to the drying up of the original water systems. It was during the dry period that extensive faulting occurred throughout the Kamasian beds and the present lake beds were formed. Subsequent to this, there were four periods of high rainfall, when the lake levels rose, alternating with periods of relatively low rainfall, when the lake levels fell (Beadle, 1932). At the present moment a dry period following on the last wet phase is in progress. As described earlier (Section 1.2.1.1.), it is only the climatic events of the last 20,000 years or so that can easily be related to the present condition of most Rift Valley lakes. Studies of the lake deposits in the region between Lakes Baringo and Bogoria (Loboi Flats) have revealed that there was probably one lake common to the Baringo and Bogoria basin (Renaut, 1982). At some time prior to 20,000 BP (years before present), the two lakes

either separated by regression or delta progradiation. Between 20,000 to 10,000 BP, subsidence and minor faulting occurred in the Baringo depression. In recent years, significant fluctuations in the levels of Lake Baringo have been established. High water levels were recorded at the turn of the century (Renaut, 1982). The fluctuation in the lake levels has been mainly attributed to climatic changes (Section 1.2.1.1) though there may have been some continuous subsidence of the Rift Valley trough (Rowntree, 1985).

Lake level changes in Lake Baringo have been monitored by the Hydrology Department of the Ministry of Water Development since 1950. Similarly the Perkerra Irrigation Scheme in Marigat has been recording rainfall data since 1956. The rainfall and lake level data are presented together in Fig. 1.2. The water level readings have not, however, been continuous. In the years between 1952 - 1955 and 1959 - 1967, the readings were either absent or incomplete. It is possible that the water level during these periods may have gone down below the zero mark of the depth gauge. From the above information, the wide yearly fluctuation in lake level can be appreciated. A further illustration of the wide fluctuation in lake level can be deduced from the horizontal water marks on the south facing cliff of the Lesukut Island (Plate 1.1).

Fig. 1.2

Yearly changes in the mean water level in Lake Baringo since the 1950s and the total yearly rainfall recorded at the Perkerra Irrigation Scheme since 1950. The information was obtained from the Kenya Ministry of Water Development Hydrology Department.

FIG. 1.2

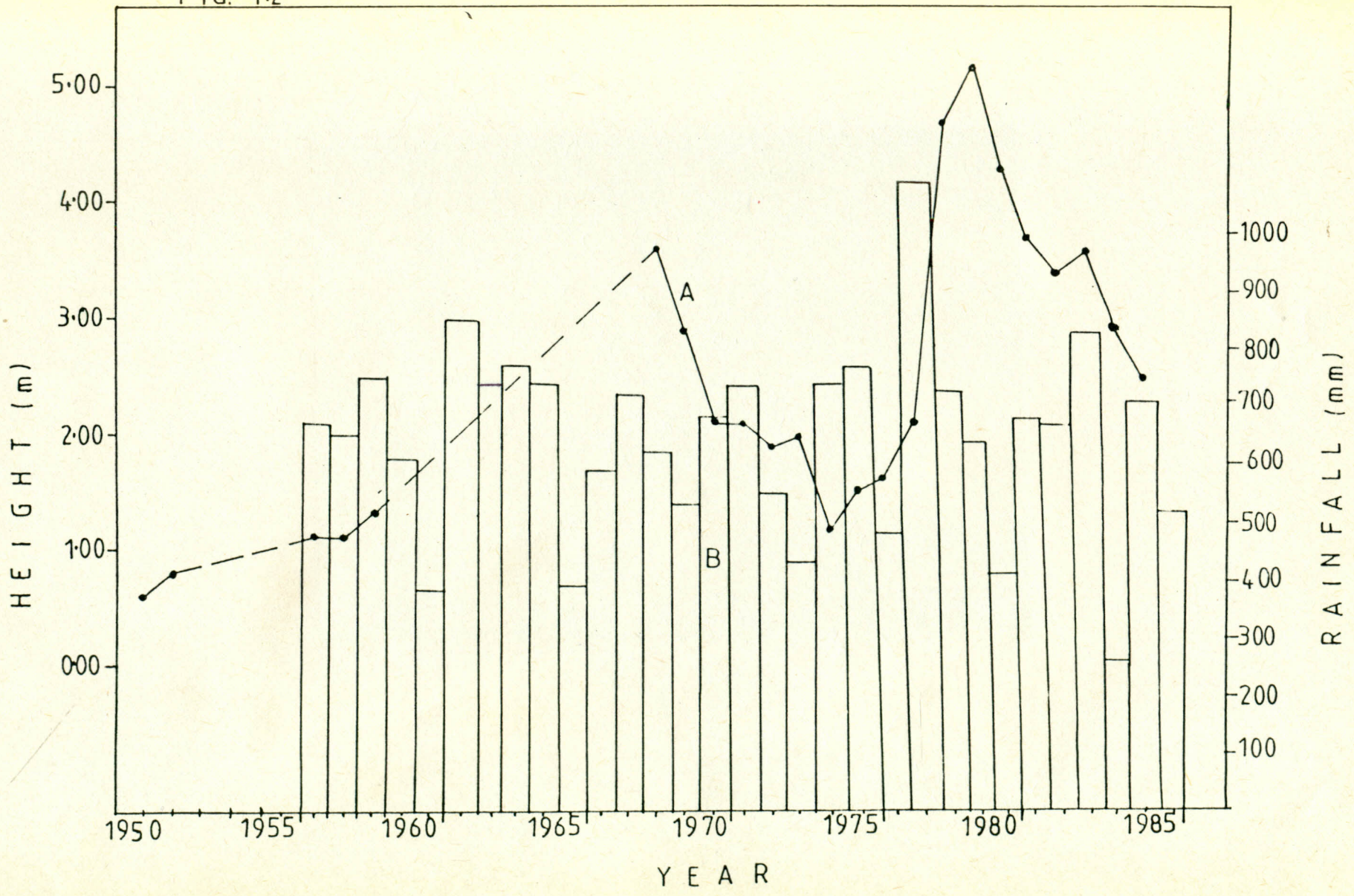

5·00
4·00
3·00
2·00
1·00
0·00
HEIGHT (m)
1000
900
800
700
600
500
400
300
200
100
RAINFALL (mm)
A
B
1950
1955
1960
1965
1970
1975
1980
1985
YEAR

Plate 1.1

The south facing cliff of one of the small islands in Lake Baringo (Lesukut). The horizontal markings on the rocks represent lake levels reached at some time in history. The vertical scale is approximately 1:20. The markings indicate that the lake level has fluctuated greatly over time.

1.2.3.2 Limnological studies on Lake Baringo

1.2.3.2.1 Introduction

Some of the earliest scientific reports on Lake Baringo came from geographers and geologists. For example Gregory (1921) in 1893 observed raised beaches suggestive of one time higher water levels (Section 1.2.3.1) and Powell-Cotton (1904) observed hot springs in the central island (Kokwe). It is, however, the visit of the Percy Sladen Expedition (Jenkin, 1932) that can be said to have marked the start of the limnological study of Lake Baringo.

The Percy Sladen Expedition, whose aim was to establish the biological status of a number of African Rift Valley lakes, visited Lake Baringo in 1929. It was followed by the Cambridge Expedition which visited the lake in 1930 and 1931 (Beadle, 1932) with the aim of establishing the interrelationships between the aquatic flora and fauna to the chemical and physical conditions of a number of East African lakes. A very comprehensive and comparative study of the chemical composition of a large number of East and Central African lakes (including Lake Baringo) was carried out between 1960 - 1962 by Talling and Talling (1965). After Talling and Talling (1965), very little limnological work was carried out in Lake Baringo up to 1976. Kallqvist (1980) carried out a series of measurements between 1976 - 1977 on the physicochemical and phytoplankton status of the lake. The study by Kallqvist was the most detailed of all

the studies. The following sections briefly review the findings of the above 4 groups of studies with respect to Lake Baringo.

1.2.3.2.2 Physicochemical status

Table 1.1 summarises the results of the physicochemical status of Lake Baringo as obtained during the studies outlined in Section 1.2.3.2.1. The results given were obtained from the analysis of open lake water samples.

Table 1.1 Summary of the available data on the physicochemical properties of Lake Baringo.

Reference	Jenkin	Beadle		Talling & Talling	Kallqvist	
Sampling date	1929 May	1930 Dec.	1931 Jan.	1962 May	1976 Dec.	1977 Feb.
Secchi depth m	-	0.2	-	-		
pH	-	-	8.7-8.8	9.0	-	9.1
Cond. $\mu S\ cm^{-1}$	-	-	-	416	980	1200
Total alk. meq l^{-1}	10	5.5	5.7	4.4	11.2	11.9
PO_4-P mgl^{-1}	-	1.37	1.28	-	-	0.35
Silica mg l^{-1}	-	18.2	5.8	23.5	-	-

From a series of sounding experiments, Beadle (1932) concluded that the maximum depth of the lake was no more than 7.5 metres. Diel temperature measurement during this period showed a large vertical temperature gradient of surface warming at midday and a small reverse gradient at dawn. A daily mixing pattern of the lake was observed and attributed to a stiff N.E. breeze that sets in in the late afternoon and completely mixes the lake. Vertical measurements of dissolved oxygen at midday gave a percentage oxygen saturation of 80 in the bottom water confirming the effectiveness of constant wind mixing. The hot springs on Kokwe Island were found to discharge saline water into the lake (alkalinity 32 meq l^{-1} $CaCO_3$). On the basis of the alkalinity results of the hot spring water and that of the Perkerra River (0.9 meq l^{-1} $CaCO_3$), Beadle (1932) concluded that , assuming the lake has an underground outlet, the bulk of the lake's soda is derived from underground spring sources. The difference in the alkalinity value reported by Jenkin (1932) and that by Beadle (1932) was attributed by Beadle (1932) to an intervening period of high rainfall.

The study conducted by Talling and Talling (1965) was aimed at providing a reference source for the chemical composition of water from most major and minor lakes in Africa, to outline the main trends and sources of variation in these lakes and to discuss correlations with some aspects of freshwater biology. From their conductivity findings, Talling and Talling (1965) divided the study lakes into 3 classes. Lake Baringo was placed in class 1 with

conductivity less than 600 μS cm^{-1}.

Kallqvist (1980) in the course of her study on primary production in Lake Baringo established a much smaller Secchi depth measurement than that recorded by Beadle (1932) suggesting an increase in turbidity. She attributed the high turbidity to the stirring action of strong winds which resuspends the silt from the muddy lake bottom. She also observed that oxygen saturation at a 2 m depth was 90% further confirming the effectiveness of wind mixing.

1.2.3.2.3 The phytoplankton status

The algal samples collected during the Percy Sladen and Cambridge Expeditions were identified by Rich (1932, 1933). The species list drawn from Rich's identification is given in Table 1.2.

Table 1.2 Phytoplankton of Lake Baringo observed during the Percy Sladen and Cambridge Expeditions.

Cyanophyta	Microcystis flos-aquae (Wittr) Kirch. Aphanocapsa grevillei (Hass.)Rabenh. Phormidium autumnale (Ag.) Gomont. Phormidium mucicola Nauman & Huber.
Chrysophyta	Melosira granulata Ehrenb. Ralff. Var. anguistissima O. Mull. Nitzschia microcephala Grun.
Chlorophyta	Oedogonium sp.

Rich referred to all Microcystis spp. in the lake as M. flos-aquae but admitted that there could be more than one species. Light penetration effective for photosynthesis was determined by the light and dark bottle technique on cloudless days (Beadle, 1932). From this study, it was observed that the light intensity sufficient for photosynthesis occurs only in the first one metre as compared to at least 4.5 metres in Lake Naivasha. In June 1929, the south end of Lake Baringo was devoid of large aquatic vegetation (Jenkin, 1932). In December 1930, however, a large swamp had developed owing to the intervening period of high rainfall (Beadle, 1932). During this period the lake shore with the exception of the S.E., S and S.W. ends was devoid of large aquatic vegetation.

The results of the phytoplankton density and biomass measurements, and the rates of primary production obtained by Kallqvist (1980) are summarised in Table 1.3.

Table 1.3 Phytoplankton density, biomass (as chlorophyll a) and areal primary production rates (as g O_2 m^{-2} day^{-1}) obtained by Kallqvist in Lake Baringo between July 1976 and February 1977.

Date		26/6/1976	20/7/1976	29/9/1976	16/12/1976	28/2/1977
Algal density Cells ml^{-1}	Microcystis sp.	$1.4x10^5$	$4.8x10^4$	$1.2x10^5$		
	Anabaena sp.	$1.4x10^3$	$1.7x10^4$	$1.3x10^4$		
1° production g O_2 m^{-2} d^{-1}			0.48	1.2	1.20	0.30
Chlorophyll a μg l^{-1} (at different depths)	0.0 m					47.0
	0.1 m					26.0
	0.3 m					34.0
	0.5 m				25.0	19.0

The very low rate of primary production in February was attributed to an exceptionally high water turbidity induced by wind mixing. The high rate in December was possibly due to the mass accumulation of algae on the water surface (Kallqvist, 1980). The phytoplankton species identified by Kallqvist between June 1976 and February 1977 are summarised in Table 1.4 below.

Table 1.4 Phytoplankton species identified by Kallqvist in Lake Baringo between July 1976 and February 1977.

Cyanophyta	Microcystis sp.
	Anabaena sp.
	Aphanothece sp.
	Pseudanabaena sp.
Chlorophyta	Ankistrodesmus sp.
	Oocystis sp.
	Selenastrum sp.
	Korshikoviella sp.
	Closterium sp.
	Tetraedron sp.
	Scenedesmus sp.
	Cosmarium sp.
	Pediastrum sp.
	Elakatothrix sp.
Chrysophyta	Melosira sp.
Euglenophyta	Euglena sp.

1.2.4 Economic importance and potential of Lake Baringo

1.2.4.1 Importance and potential

The freshwater body of Lake Baringo provides a suitable habitat for extensive swamps, commercial fishery and a diverse avifauna. The dominant fish species are; Labeo cylindricus, Clarias mossambicus, Barbus gregori, and Sarotherodon niloticus (District Fisheries Officer [DFO] pers. comm., 1989). The lake's fishery is of increasing importance and is being developed. There is a fish processing plant at Kampi ya Samaki. In 1982, about 488 tonnes of fish was landed. Welcomme (1972) gives an estimated maximum sustainable yield at 1500 tonnes per year. Lake Baringo is now one of the regular tourist circuits; there is one tourist hotel at Kampi ya Samaki and another one in the central island (Kokwe). Plans are under way to increase the amount of land under irrigation in the low potential zone using the waters of the inflowing rivers.

1.2.4.2 Problems facing the lake

The area surrounding the lake has a natural vulnerability to erosion (Otieno and Rowntree, 1986) which has been greatly increased by poor land management. This natural vulnerability is a consequence of the geological character of the area; of tectonic instability, recent extrusive rocks and extensive unconsolidated sediments. Another factor is the highly erosive nature of the rains

which often come in short heavy storms (Otieno and Rowntree, 1986). The high erosion rate has resulted in rapid siltation in the lake. Data on the denudation rates though scarce, clearly illustrate the severity of erosion. For example the Chemeron and Endao catchments have been estimated to have a yearly denudation rate of 2.2 mm (Sutherland and Bryan, 1989). PENCOL (1981) indicates the present day mean annual sedimentation rate from Lake Baringo's 4926 km^2 catchment area to be approximately 1015 tonnes km^{-2}. This excessively high sediment yields support the visual evidence of erosion as seen from severely gullied and water-washed hillslopes prevalent throughout the area. It is indeed feared that unless something is done, the lake will soon turn into a swamp.

Other upcoming problems are those resulting from the increased abstraction of the waters of the inflowing rivers. For example the recent damming of the Molo River for the Greater Nakuru Water Project has led to the Molo River drying before debouching into the lake during the dry season. Similarly irrigation work involving the Perkerra River is on the increase. Such activities carried out without a first-hand knowledge of the hydrological budget of the lake may upset the lake's physicochemical and biological balance. Sustained exploitation of the lake's resources requires a strict maintainance of its trophic balance. This can only be achieved through continuous monitoring of the lake's physicochemical and biological status so that undesirable changes can be sighted in good

time and corrective measures instituted.

1.3 OBJECTIVES OF THE STUDY

1.3.1 Rationale for the present study

Lake Baringo, when compared to other larger Kenyan Rift Valley Lakes, has received minimal limnological studies. A complete picture of tropical limnology relies on the formulation of generalisations based on as many tropical lakes as possible. The present study aims at providing some of the missing information for Lake Baringo.

Most of the studies carried out in Lake Baringo have been mainly spot samplings (Section 1.2.3.2) with a big delay between the sampling time and time for analysis or with the analysis using less refined field techniques. Where sampling over time has been used, the time interval has been too wide and without vital information on weather changes (e.g. Kallqvist, 1980). From the discussion given in Section 1.2.2 on the seasonal variation in the physicochemical and biological properties of tropical lakes as brought about by weather changes, an accurate description of the physicochemical and biological status of any lake requires a prolonged study. This should cover at least the dry and wet seasons. The present study hopes to achieve this for Lake Baringo.

Lake Baringo is of great economic importance and at the

same time is being faced with the danger of extinction (Section 1.2.4). For the continued and rational exploitation of its resources, and the tapping of those yet to be exploited, a close monitoring of the lakes trophic balance and the adoption of appropriate management strategies is necessary.

1.3.2 Specific study objectives

The study was conducted in Lake Baringo and had the following objectives:

i) establish the physicochemical parameters of the lake and determine their spatial and temporal variations.

ii) determine the spatial and temporal variation in phytoplankton biomass in the lake.

iii) identify the phytoplankton taxa of the lake and establish the temporal and spatial distribution patterns of the dominant species.

iv) evaluate the interrelationships between the phytoplankton and physicochemical properties of the lake.

v) establish the variations in the levels of some chemical properties of the inflowing rivers and assess their relationships to the lake's chemical levels.

vi) identify areas for further research in order to formulate rational management strategies for the lake's resources.

CHAPTER 2. STUDY AREA

2.1 LOCATION

Lake Baringo (0° 37'N; 36° 04' E) lies in an endorheic basin that occupies the central part of the Eastern (Gregory) Rift. The Lake is bounded by the Tugen Hills to the west, the Loyamarok area to the north, the Karau Escarpment to the east and the Loboi Plains to the south. It falls in the eastern lowlands of the Baringo District (975 m A.S.L) and covers an area of 130 km². Its catchment covers an area of 4926 km² (Otieno and Rowntree, 1986). A number of islands occur in the lake and according to Gregory (1921) those to the south of the lake centre are remnants of an early Pleistocene volcano. The Rift Floor around the lake has a broken topography which is the result of extensive grid faulting (Chapman et al., 1978).

2.2 GEOLOGY AND SOILS

The first description of the general features of the geology of the area around Lake Baringo was given by Gregory (1921). The rocks in the plain consist either of aqueous lavas or unconsolidated sediments resulting from the rapid erosion of the uplifted Tugen Hills (Rowntree, 1985). Tectonically, there has been much recent activity and the area is still probably unstable (Otieno and Rowntree, 1986). The Tugen Hills Range is the result of rapid uplift that took place about 2 million BP.

The soils in the basin vary with geology and topography. The main soil types include nitosols and ferralsols on summit ridges, regosols and lithosols on steep slopes and other severely eroded areas, and luvisols and solonchaks in more arid areas (Rowntree, 1983; Otieno and Rowntree, 1986). Soils developed from lavas tend to have a high clay content whilst those developed on sedimentary deposits are predominantly silty with local inclusions of clays and gravels. The soils in the Tugen Hills are friable and with low erodibility, but at lower altitudes most soils are prone to surface sealing, poor infiltration and rapid runoff. The lack of cohesion of the sedimentary silts increases their erodibility and gullying.

2.3 DRAINAGE

A number of rivers and several seasonal streams drain into Lake Baringo. Notable rivers that drain into the lake are the Perkerra, Molo, Ol-Arabel and the Mukutan Rivers. These four rivers are permanent except in very dry years.

The Perkerra River drains the Mau Escarpment west of Eldama Ravine and the Tugen Hills. This is the strongest flowing river in the area. Extensive irrigation utilising its waters occurs at the Perkerra Irrigation Scheme in Marigat. To the east of Marigat, the river's flow dwindles before debouching into the Oloi Matashu Swamp located to the north of Logumkum. Surface water from the swamp

reaches the lake through swamp channels.

The Molo River drains the Mau near Molo and Elburgon through its own headwaters and those of a major tributary, the Rongai River. This river tends to taper once it reaches the floor of the Rift Valley and does not carry such a great body of water. It is joined by the Ndolaita River, which has an additional water source from springs at the Ngarua Swamp.

The Ol-Arabel River drains the northern part of the Marmarnet Forest and the Ol-Arabel Forest. It is not permanent throughout the entire course and its tributaries are flood streams which drain the whole of the Ngelesha Reserve. These streams only flow briefly after heavy rainfall.

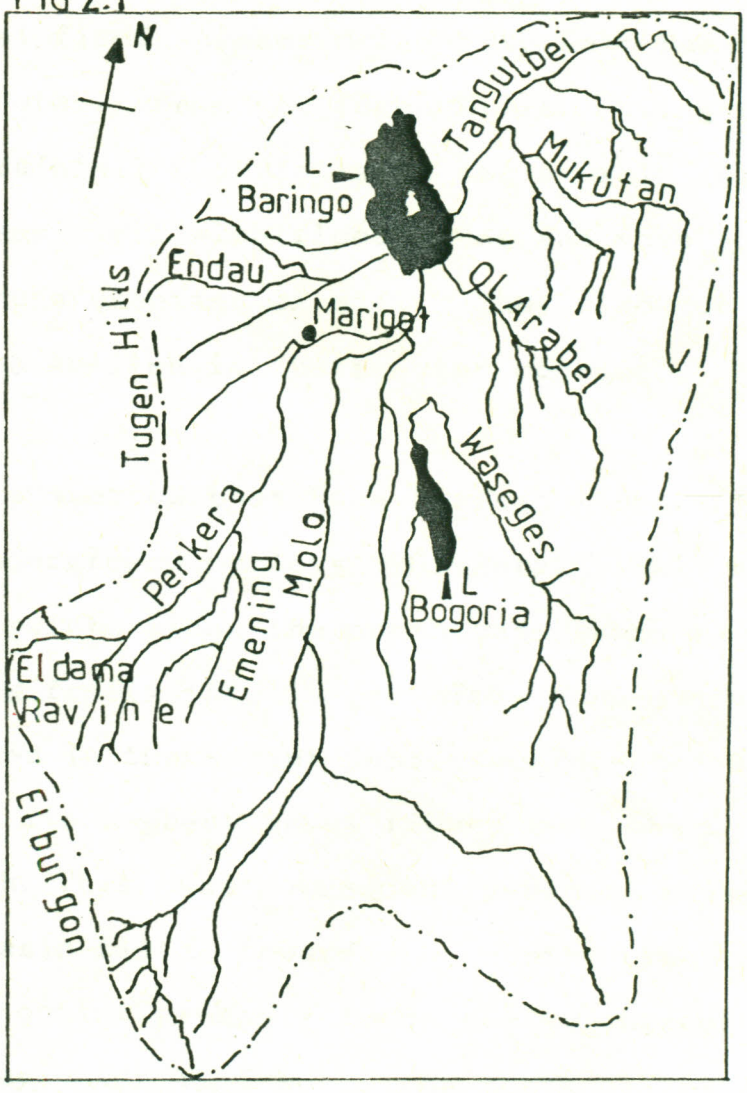
The Mukutan River drains the Aruru Escarpment. It enters the Mukutan Basin through the Mukutan Gorge. Along its course it is fed by several small streams before it joins up with its largest tributary, the Tangulbei River, at Chemoigut. The River finally debouches into Lake Baringo at the West shore, to the north of Loiminange.

Fig. 2.1

The Baringo Bogoria drainage basin showing the main rivers that drain into the two lakes.

Map redrawn from the Atlas of Kenya, 3rd edition 1970 Kenya Government.

FIG 2.1



—·—·— Approx. boundary of catchment area

Scale 1:1000000

Several flood streams drain into Lake Baringo directly, notably from the Tugen Hills. Owing to the high intensity rainfall that falls in the area in some seasons, these streams swell with flood water and move boulders, rocks and huge quanties of silt. They also cut deep channels and gullies in their water courses.

It is suspected that Lake Baringo in turn loses water via some underground outlets. Gregory, (1921) noted that, at several points along the north east shore the waters were pouring freely into lavas. This phenomenon has not been observed in the recent past. According to Gregory, the lake at its highest level flowed over the Lobat pass to the north. This pass subsequently became raised, and the whole basin tilted towards the north. The present underground outlet probably feeds the springs of the Kogore Valley which is 8 km to the north of the lake (Beadle, 1932).

2.4 CLIMATE

Temperature in the Baringo basin ranges from 10° C to 37° C with the coldest areas being the highlands and the hottest, north of Marigat.

Total rainfall in the basin varies greatly from the lowlands to the highlands. The area around the lake receives a mean annual rainfall of 600 mm, and the highlands, a mean annual rainfall that ranges from 1000 to

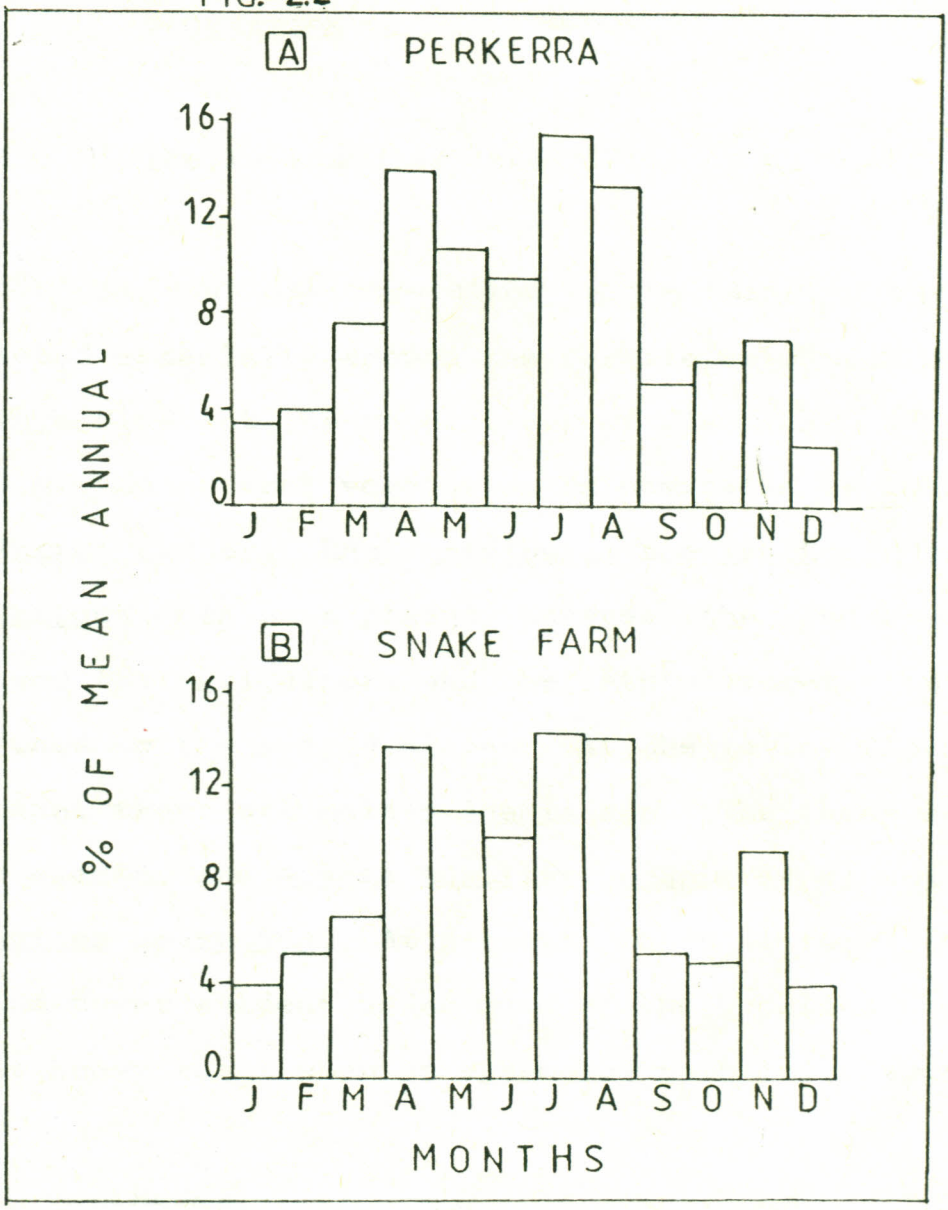
1500 mm depending on the locality. Rainfall data taken at the Perkerra Irrigation Scheme since 1956 (Section 1.2.3.1, Fig. 1.2) shows that the total yearly rainfall falling in the area around the lake fluctuates greatly over time. The yearly fluctuations in total rainfall is the cause of the frequent droughts that have plagued the area in the past years (Otieno and Rowntree, 1986). From the rainfall data taken over time at the Perkerra Irrigation Scheme and the Snake Park (located at Kampi ya Samaki), it can be said that the area has only one wet season (Fig. 2.2). Approximately 65% of the total mean annual precipitation falls in the five month period, April to August (Sutherland and Bryan, 1989) as shown in Fig. 2.2. Rainfall falling outside the wet season often comes as short heavy storms that cause severe erosion.

Humidity and evapotranspiration vary greatly from the highlands to the lowlands. Relative humidity increases with the rise in altitude and therefore evapotranspiration decreases with rise in altitude. In the lowlands surrounding the lake, evapotranspiration is estimated at 1200 mm per annum (District Fisheries Officer (DFO) pers. Comm., 1989). The lake lies in the climatic zone 5 of Pratt et al. (1966) with a moisture index between -42 and -51 - moisture index (MI) relates water loss through potential evapotranspiration (PE) to water gain through precipitation (P); $MI = \frac{100\ (P-PE)}{PE}$.

Fig. 2.2

Monthly rainfall data at the Perkerra Irrigation scheme and the Snake Park as a percentage of the mean yearly total. The data was obtained from Sutherland and Bryan (1989) and were computed from rainfull data collected over a 19 year period between 1966 - 1985.

FIG. 2.2


A
PERKERRA
16
12
8
4
0
J F M A M J J A S O N D
% OF MEAN ANNUAL
B
SNAKE FARM
16
12
8
4
0
J F M A M J J A S O N D
MONTHS

2.5 VEGETATION

2.5.1 The surrounding land

The present day vegetation in the basin is badly depleted especially around the fertile catchment of the Baringo District (Kenya Ministry of Planning, 1985). Above 2100 m, the natural vegetation is dominated by forests of Juniperus procera, Rhus natalensis and Trichocladus ellipticus. In most places, however, the land has been cleared for agriculture and the natural vegetation is confined to the rugged slopes. At the valley floor the dominant trees are mainly Acacia spp. The three dominant tree species are Acacia tortilis, Acacia seyal and Balanites aegyptica. At present, there is very little ground cover evident under much of the bushland except after heavy rains when an ephemeral herb layer appears.

2.5.2 Swamp

The southern shore of Lake Baringo, sections of the west and east shores stretching from Kampi ya Samaki to the Longicharo Island (Fig. 3.1) has a more or less continuous stretch of swamp. The largest swamp (Oloi Matashu Swamp) occurs in the south end of the lake. A greater stretch of the western shore, the northern tip and sections of the east shore have a continuous rocky shore occasionally interrupted by small swamps.

A zonation pattern is not easily discernable in the Lake Baringo swamps, possibly as a result of the continuously changing lake level. On the lake edge are mainly Polygonum senegalense, Cyperus papyrus, Vossia cuspidata, Aeschynomene cristata, some floating and some submerged macrophytes. The floating vegetation is composed of Pistia stratiotes, Azolla nilotica, Lemna sp. and Nymphaesp. (not very common). The main submerged plant species is Ceratophyllum demersum which in some places grows in close association with Najas pectinata.

CHAPTER 3. MATERIALS AND METHODS

3.1 THE SAMPLING SITES

A total of 12 sampling sites were carefully chosen at the start of the study programme; of these, 8 were established on the Lake (Fig. 3.1) and the other four on the four perennial rivers (Section 2.3) that drain into the lake (Fig. 3.2). As most of the water draining into Lake Baringo enters from the south end, the lake sampling sites were established along a transect running from the south to the north of the lake (L_1 - L_6). L_7 was established on the western section of the lake near Kampi ya Samaki. L_8 was established on the eastern shore near the mouth of the Mukutan River. L_7 was chosen to represent the western part of the lake and L_8 the eastern part. The precise locations of the river sampling sites were established on the basis of their accessibility by road transport from the Loiminange Camp site established on the foothills of the Loiminange Hill ruins (Fig. 3.1). Rivers to the west of Lake Baringo were excluded from the study as they were difficult to reach and flowed only seasonally. Two groups of hot springs, the West Cliff and the East Shore hot springs (Fig. 3.1), present on the central island (Kokwe) were also included in the study. Lastly a sampling site was chosen adjacent to Lesukut Island to monitor vertical changes of physicochemical and biological parameters during a 24 hour period. This site was chosen later in the course of the study on the basis that it had a number of

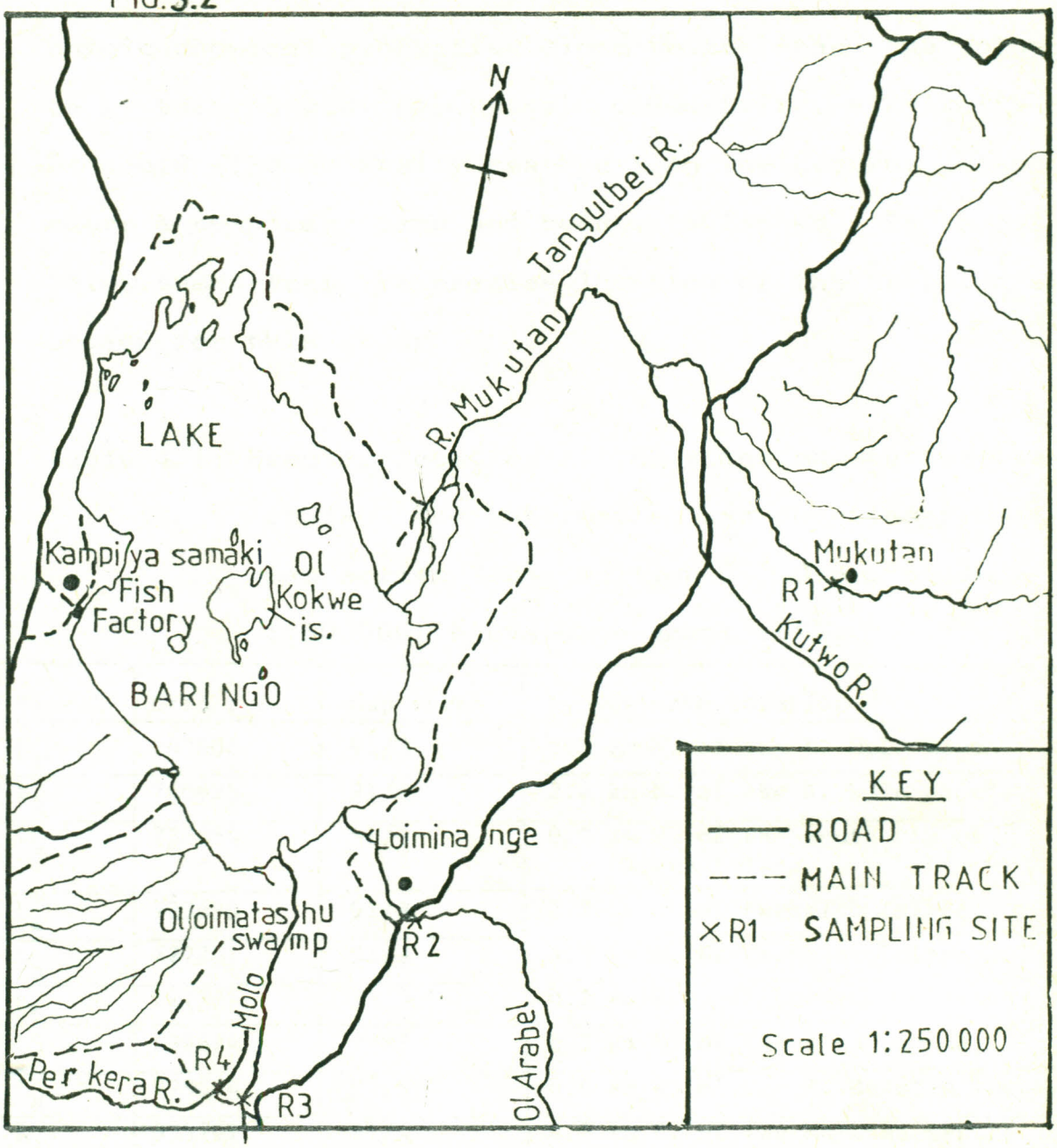
Fig. 3.1

Map of Lake Baringo showing the lake sampling sites.

Fig. 3.2

Map of Lake Baringo and a section of its drainage basin showing the river sampling sites.

FIG. 3.2


N
Tangulbei R.
R. Mukutan
LAKE
Kampi ya samaki
Fish
Factory
Ol
Kokwe
is.
BARINGO
Mukutan
R1
Kutwo R.
KEY
ROAD
MAIN TRACK
×R1 SAMPLING SITE
Scale 1:250000
Loiminange
Oloimatasihu
swamp
R2
Molo
R4
Perkera R.
R3
Ol Arabel

physicochemical properties close to the mean lake values (e.g. total depth, electrical conductivity, alkalinity and pH). It would also be easily reached from the Lesukut Island where a temporary camp had been established. Table 3.1 below summarizes the precise location of the sampling sites chosen for this study.

Table 3.1 Precise location of the sites chosen for the study. The information was compiled from the map series Y731, edition 3-D.O.S., scale 1:50,000, Kenya Government 1982.

Site	Grid ref.	Map sheet	Approximate location
L_1	743606	91/3	0.3 km N. of the R. Molo mouth.
L_2	740625	91/3	2.4 km N. of the R. Molo mouth.
L_3	737654	91/3	0.2 km W. of the south tip of Kokwe Island
L_4	723695	91/3	2.2 km N. of Parmalok Island.
L_5	727731	91/3	4.8 km N. of Parmalok Island.
L_6	727777	91/3	0.2 km S.E. of Lekoros Island.
L_7	699684	91/3	0.5 km E. of Kampi ya Samaki.
L_8	779674	91/3	0.6 km W. of the R. Mukutan mouth.
R_1	939701	91/4	0.4 km E. of the Mukutan centre
R_2	789595	105/1	River junction with the Marigat-Loiminange Road.
R_3	745504	105/1	River junction with the Marigat-Logumkum Road
R_4	721514	105/1	River junction with the Marigat-Logumkum Road.
24 hr.	749661	91/3	0.05 km E. of the north tip of Lesukut Island.

Mean lake values of most physicochemical and biological properties were calculated as an average of the measurements obtained in all the sampling sites in one sampling round (Table 3.2). The overall lake mean value was subsequently determined as the average of these means.

3.2 WATER SAMPLING TECHNIQUES

Water sampling was conducted in Lake Baringo, the larger inflowing rivers and the hot springs (Table 3.1). Access to the lake sites and the hot springs was by boat and the river sites by motor vehicle. All the chemical and biological analyses were based on integrated water samples unless otherwise stated. Integrated water samples were collected from down the water column with a 30 mm diameter weighted plastic tube described by Melack (1976a) only leaving out the last 20 cm to the lake bed. When water samples from specific depths were required, a hand operated vacuum pump was used to draw water from the required depth into a plastic 1 litre Buchner filter flask. By sucking off air from the Buchner flask, water from a predetermined depth was forced in via a calibrated and weighted plastic tube fitted tightly to the position normally occupied by the filtration equipment. Water samples for laboratory analysis were decanted into 500 ml plastic sample bottles. Since most laboratory analyses at the camp site began less than two hours after collection, no special preservation methods were applied (except where stated). For the samples that were to be analysed in Nairobi 0.8 ml of concentrated sulphuric acid was added to

500 ml of the sample after collection; upon arrival in Nairobi they were deep frozen until the time of analysis (APHA, 1975).

3.3 PHYSICAL ANALYSIS OF WATER

3.3.1 Water level and depth

Water level readings were obtained from the Rangeland Gauging Station (RGS) 2EHI at Kampi ya Samaki.

Water depths were measured with a weighted and calibrated nylon cable. The cable was lowered into the water from the calmer side of the boat until the weight touched the lake bed and the depth read to the nearest centimetre.

3.3.2 Temperature

Air and surface water temperatures were measured in the field with a glass mercury thermometer readable to tenths of a degree celsius. Subsurface water temperatures were determined with the temperature probe of an oxygen meter Model PT 1401, which was calibrated to measure depth in centimetres.

3.3.3 Water transparency

Water transparency was measured with a 20 cm

diameter Secchi disc divided into alternating black and white quadrants (Lind, 1979).

3.4 CHEMICAL ANALYSIS OF WATER

3.4.1 Field measurements

3.4.1.1 Electrical conductivity

Electrical conductivity was determined with a portable E-3 compact conductivity meter with automatic temperature compensation to 25° C.

3.4.1.2 pH

The water pH was measured with a Corning 105 pH meter fitted with an automatic temperature compensation probe.

3.4.1.3 Dissolved oxygen

In situ oxygen measurement was performed with an oxygen meter Model PT 1401. The probe was calibrated, at the beginning of the sampling trip, against the azide modification of the Winkler method (APHA, 1975).

3.4.2 Laboratory measurements

3.4.2.1 Dissolved oxygen

Regular measurement of dissolved oxygen content of surface water was carried out with the azide modification of the Winkler method (APHA, 1975). Dissolved oxygen fixation was, however, carried out in the field using BOD bottles or appropriate glass reagent bottles as outlined in APHA (1975).

3.4.2.2 Total alkalinity

Total alkalinity was determined titrimetrically with standard HCl solution using a pH meter to establish the titration end point of pH 4.5 (APHA, 1975 and Golterman et al., 1978). The alkalinity values were calculated as meq l^{-1} $CaCO_3$.

3.4.2.3 Orthophosphate or soluble reactive phosphorus (SRP)

SRP was determined by the method suggested by Murphy and Riley (1962) and outlined in APHA (1975). The procedures employed in the cleaning of glassware and sample bottles for phosphorus sampling and analysis were: washing with tap water and a special phosphate free glassware detergent (Decon 90), rinsing with tap water, 5% HCl, tap water and finally deionised water (Lind, 1979). SRP was measured colorimetrically as a blue complex after the addition of molybdate and reduction with ascorbic acid. All colorimetric readings were made using a Cecil 2393 Single Beam Spectrophotometer equipped with 1 cm cell cuvettes.

3.4.2.4 Total phosphorus (TP) and Dissolved or filtrable phosphorus (DP)

TP and DP determination were carried out on preserved (Section 3.2) unfiltered (for TP) and filtered (for DP) samples in Nairobi. All forms of phosphorus, organic phosphorus and polyphosphates, were converted to orthophosphate by autoclaving the water sample at 140° C under 15 psi for 40 minutes with potassium persulphate oxidizing agent (APHA, 1975). Orthophosphate concentration was measured by the method suggested by Murphy and Riley (1962) and given in Section 3.4.2.3.

3.4.2.5 Ammonia nitrogen (NH_3-N)

NH_3-N was determined colorimetrically as an intensely blue compound (indophenol) as outlined in Lind (1979).

3.4.2.6 Nitrite nitrogen (NO_2-N)

NO_2-N was measured colorimetrically as a strongly coloured azo-compound formed by the diazotization of NO_2-N with sulphanilamide and then coupling with N-(1-napthyl) ethylenediamine di-HCL (APHA, 1975).

3.4.2.7 Nitrate nitrogen (NO_3-N)

NO_3-N was measured by the diazotization method (described in Section 3.4.2.6) after the reduction of the

nitrates in solution to nitrites by the cadmium reduction method (Golterman et al., 1978).

3.4.2.8 Total nitrogen (TN) and dissolved or filtrable nitrogen (DN)

TN and DN were measured as nitrate nitrogen after the oxidation of all forms of nitrogen to nitrates by autoclaving the water samples and standards at 140° C, 15 psi for 40 minutes with potassium persulphate oxidizing agent. The nitrate concentration of the oxidized sample was analysed by the modified salicylate method (Scheiner, 1974).

3.4.2.9 Soluble reactive silica

Soluble reactive silica was determined as a yellow complex formed by the reaction with molybdate ions (Lind, 1979).

3.5 BIOLOGICAL ANALYSIS OF WATER

3.5.1 Phytoplankton chlorophyll a

Chlorophyll a concentration was determined as acetone extracts of filtrable seston. The seston was collected on 47 mm Whatman GF/C filters by gentle vacuum filtration of a known volume of the lake water sample on return to the laboratory. Chlorophyll a was extracted overnight in the

dark at 4° C in 90% neutralised acetone. Optical density was then measured with a Cecil 2393 Single Beam Spectrophotometer equipped with 1 cm cell cuvettes and actual concentration calculated using the equations given in APHA (1975) and summarised below where O.D.= optical density, λ = wavelength of spectrophotometer light beam in nanometres (nm) and Ca = chlorophyll a concentration in extract after correction for turbidity:

Ca = 11.6 OD at λ 663 - 1.31 OD at λ 645 - 0.14 OD at λ 630. Correction for turbidity; subtract from each OD reading the OD reading at λ 750.

Actual chlorophyll a conc. ($\mu g\ l^{-1}$) =

$$\frac{\text{Ca x extract volume (ml)}}{\text{litres of water filtered x cell path length (cm)}}$$

3.5.2 Plankton composition and phytoplankton density

Plankton compositon and phytoplankton density were determined from concentrated and preserved samples. 5 litres of an integrated water sample was concentrated using a 30 µm mesh size phytoplankton net to 75 ml and preserved in Lugols solution (Prescott, 1964). The choice of Lugols solution as a preservative was not only based on its ability to preserve, but also on the fact that it sediments blue green algae and to some extent fragments the colonies of the dominant alga Microcystis aeruginosa, hence easing enumeration. Plankton identification was done microscopically using the works of APHA (1975), Chapman (1973), Edmondson (1959) and Prescott (1964). Phytoplankton

enumeration was carried out using an improved Neubaeur Haemocytometer.

3.5.3 Phytoplankton photosynthetic rate

Photosynthetic rates were measured as the difference in dissolved oxygen concentration between transparent and opaque bottles (APHA, 1975). Dissolved oxygen was determined with an oxygen meter Model PT 1401. The transparent and opaque borosilicate bottles were lowered to predetermined depths and the stoppers removed so that they fill up with water at those depths. The samples were incubated for one hour, then dissolved oxygen concentration was measured and the exercise repeated for periods throughout the whole day (Section 3.6.2) to give the diurnal pattern of photosynthesis and to allow for the calculation of the total day's photosynthesis.

3.6 SAMPLING FREQUENCY

3.6.1 Lake and river sampling sites (L_1 to L_8, R_1 to R_4)

At the start of the study, it was planned that each sampling site was to be visited once every fortnight. To allow for making comparisons it was also planned that sites were to be visited within the shortest time interval possible. It was not, however, possible to strictly adhere to this schedule as there were interruptions caused by

transport inavailability and having to commute between Loiminange Camp site (Fig. 3.1) and Nairobi to complete the analyses. Except Rivers Mukutan (R_1) and Perkerra (R_4) all the other sampling sites were visited at least twice every month with the exception of January and March when all the sites were visited only once. R_1 and R_4 received less sampling attention owing to the distance of R_1 and the inaccessibility of R_4 due to flooding. Table 3.2 gives the dates when each site was visited.

3.6.2 The 24 hour study

During the 24 hour study, carried out on the 10th of March, 1989, a number of physicochemical and biological properties of the lake down the water column were studied at regular time intervals; this was every two hours during daylight and every four hours during the night. Conductivity, pH, dissolved oxygen and temperature were determined at the study site. Sample filtration for chlorophyll a measurement was also carried out in the field and the filters preserved in an iced cool box for transport to the camp site laboratory for final analysis. Water samples for SRP and alkalinity measurements were also preserved in the iced cool box. The laboratory analytical procedures were those described in Sections 3.4 and 3.5.

3.6.3 Hot Springs

During the study period, the hot springs were visited

Table 3.2 Sampling dates starting from 12th July 1988 and ending on 15th March 1989. All measurements carried out in any given week are taken to represent one sampling round

(1) Lakes and Rivers

		SAMPLING SITE											
	WEEK	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	R_1	R_2	R_3	R_4
1988	1	12/7	12/7	15/7	13/7	15/7	14/7	13/7	14/7	18/7	11/7	11/7	11/7
	3	27/7		27/7				24/7	24/7	24/7	19/7	20/7	20/7
	5	8/8	8/8	8/8		9/8	9.8	9.8	9/8		5/8	5/8	
	7	20/8	20/8	20/8		21/8	21/8	20/8	21/8	21/8	17/8	17/8	
	10	18/9	18/9	18/9	20/9	19/9	19/9	18/9	19/9	24/9	16/9	16/9	16/9
	12	30/9	30/9	30/9	1/10	1/10	1/10	30/9	1/10		28/9	28/9	28/9
	15	22/10	22/10	22/10	21/10	21/10	21/10	22/10	21/10	27/10	19/10	19/10	19/10
	17	3/11	3/11	3/11	5/11	5/11	5/11	3/11	5/11		1/11	1/11	1/11
	19	18/11	18/11	18/11	20/11	20/11	20/11	18/11	20/11	31/1	17/11	17/11	17/11
	22	9/12	9/12	9/12	8/12	8/12	8/12	9/12	8/12		2/12	2/12	2/12
	24	9/12	9/12	9/12	20/12	20/12	20/12	19/12	20/12		18/12	18/12	18/12
1989	27	13/1	13/1	13/1	14/1	14/1	14/1	13/1	14/1		12/1	12/1	12/1
	30	3/2	3/2	3/2	2/2	2/2	2/2	3/2	2/2		31/1	31/1	31/1
	32	15/2	15/2	15/2	14/2	14/2	14/2	15/2	14/2	13/2	13/2	13/2	13/2
	36	14/3	14/3	14/3	13/3	13/3	13/3	14/3	13/3	13/3	13/3	13/3	13/3

(2) Hot Springs

The hot springs were sampled on 12/2/89 and 15/3/89.

(3) 24 Hour Sampling Programme

Start	24.00 Hours (EAST)	10/3/89
End	24.00 Hours (EAST)	11/3/89

EAST East African Standard Times

twice; on the 12th of February 1989 and the 15th of March 1989.

3.7 METEOROLOGICAL INFORMATION

Some meteorological data were collected at the camp site over the study period. Maximum and minimum temperatures were read from a maximum and minimum mercury thermometer. Relative humidity values were calculated from the difference in the wet and dry bulb thermometer readings. Rainfall information was obtained from the Perkerra Irrigation Scheme, Rainfall Station 89.35.163 (Lat. 0° 28' N; Long. 35 ° 58' E).

CHAPTER 4. R E S U L T S

4.1 WEATHER CHANGES

During the study period (July 1988 to March 1989), the mean monthly maximum temperatures at the Loiminange Camp site (Fig. 3.1) ranged from 33.0° C in July and August to 36.5° C in September. Mean minimum monthly temperatures ranged from 17.0° C in December to 19.0° C in July, September, October, November and January. The monthly changes in mean minimum, mean daily and mean maximum temperatures are illustrated in Fig. 4.1 A. Fig. 4.1 B summarizes the changes in mean monthly relative humidity values at some specific hours of the day. The total rainfall received each month as recorded at the Perkerra Irrigation Scheme is given in Fig. 4.1 C. A total of 652 mm was received during the study period with the highest precipitation occurring in August (200 mm) and none being received in January. Given that the Perkerra Irrigation Scheme receives a mean annual rainfall of 630 mm (Sutherland and Bryan, 1989), and that the rainfall data given excludes three of the five months that form the wet season (Section 2.4), the rainfall received over the study period was above average.

4.2 LAKE LEVEL

The research commenced at the end of a dry spell that lasted through the last half of June and the first two weeks of July. Heavy rainfall around the

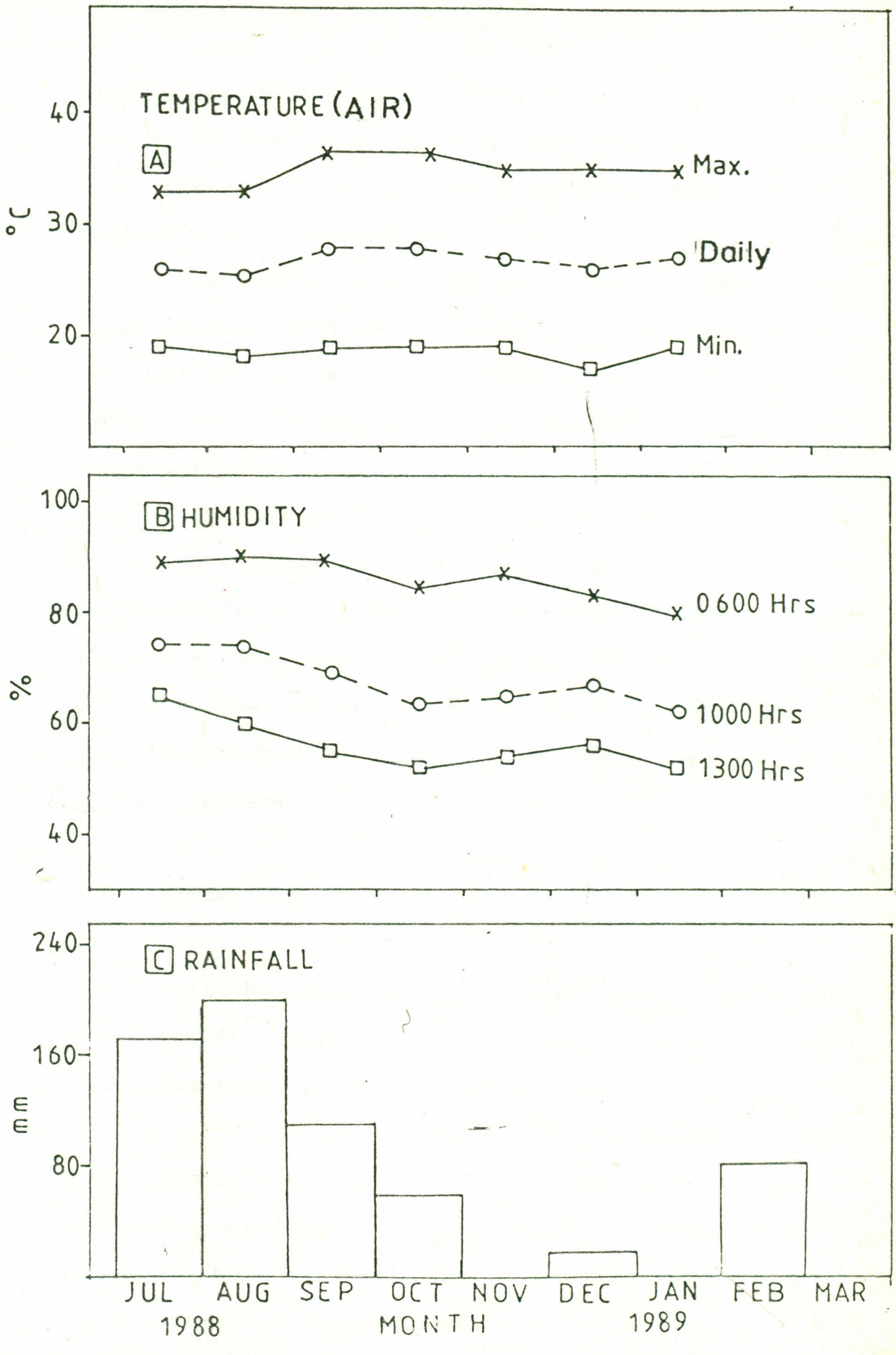
Fig. 4.1

A. Monthly changes in mean air temperatures (minimum; daily and maximum) at the loiminange Camp site.

B. Monthly mean humidity changes at the Loiminange Camp Site at different hours of the day.

C. Monthly total rainfall recorded at the Kenya Meteorological Department, Station 89.35.163 (Perkerra Irrigation Scheme.

FIG.4.1


TEMPERATURE (AIR)
A
40
30
20
°C
Max.
Daily
Min.
B HUMIDITY
100
80
60
40
%
0600 Hrs
1000 Hrs
1300 Hrs
C RAINFALL
240
160
80
mm
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
1988
MONTH
1989

lake and evidently within the catchment area started at the end of the second week of the study. In response to the increased discharge, the lake level rose sharply maintaining a steep gradient throughout July and August and by the second week of September it had risen from a gauge reading of 1.36 m (above the datum level) at the start of the study to 2.89 m (Section 3.3.1). A short dry period after the second week of September brought down the water level to 2.82 m. It then rose to a maximum level of 3.11 m after which it remained more or less steady, declining towards the end of the study period. At the end of the study period the lake level was 2.79 m. Changes in the lakes level over the study period are summarised in Fig. 4.2. The end of the study period (March 1989) coincided with the start of a rainy period, hence the lake level would be expected to start rising again.

4.3 TEMPERATURE

At all the sampling sites, air temperature ranged from 21° C to 34° C depending on the time of the day and the month. Surface water temperatures varied from 23° C to 31° C in the lake and from 21° C to 31° C in the rivers depending on the time of the day and the prevailing weather conditions. Vertical temperature measurements in the lake showed that thermal stratification sets in on hot calm periods of the day and is disrupted by strong winds in the evening and/or nocturnal convective cooling. Fig. 4.3 summarises the vertical temperature changes in the lake

Fig. 4.2

Variation in the mean weekly water levels in Lake Baringo between 7th July 1988 to 15th March 1989. The information was obtained from the Rangeland Gauging Station 2 EHI of the Kenya Ministry of Water Development Hydrology Department.

FIG.4.2 LAKE LEVEL .

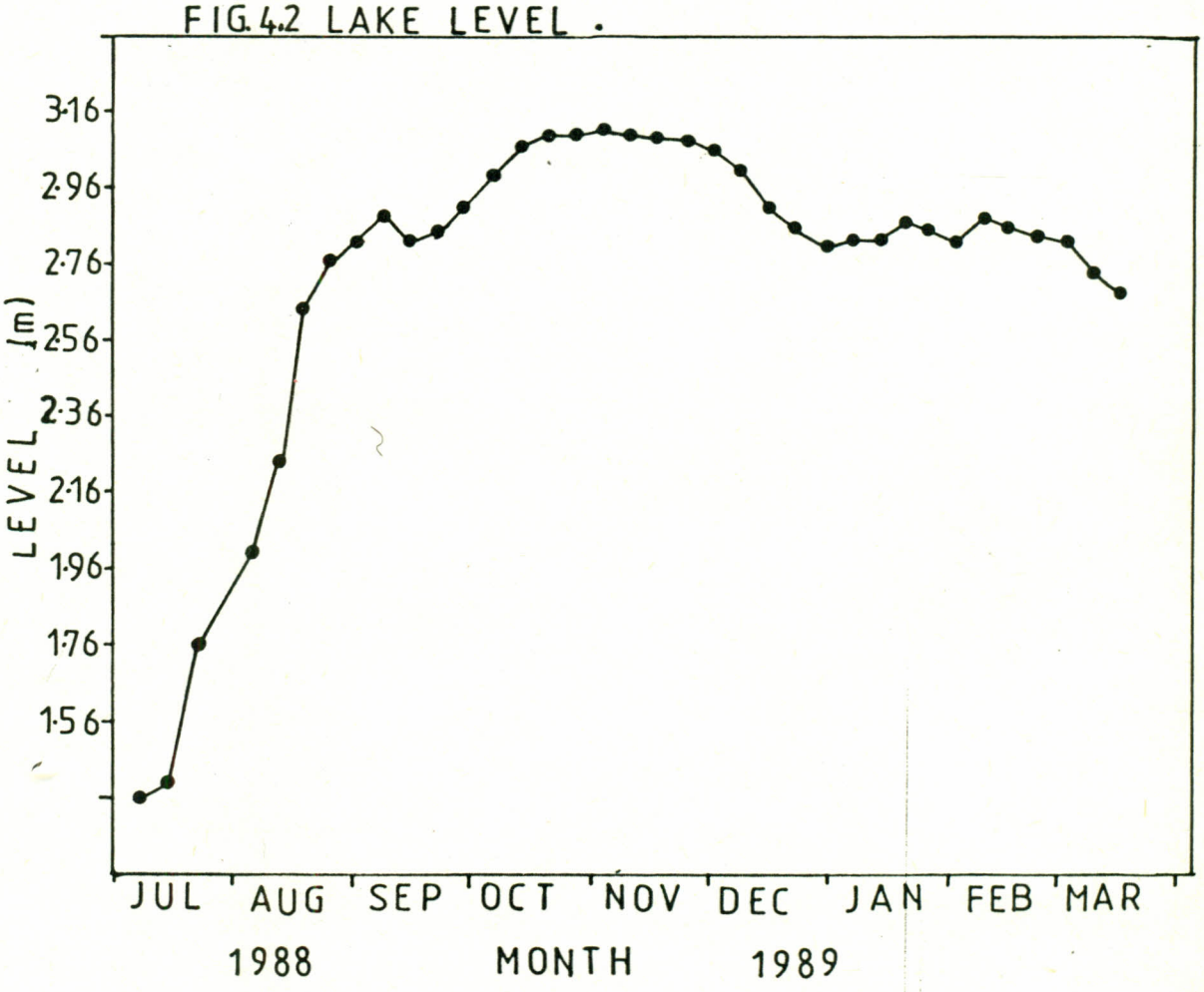
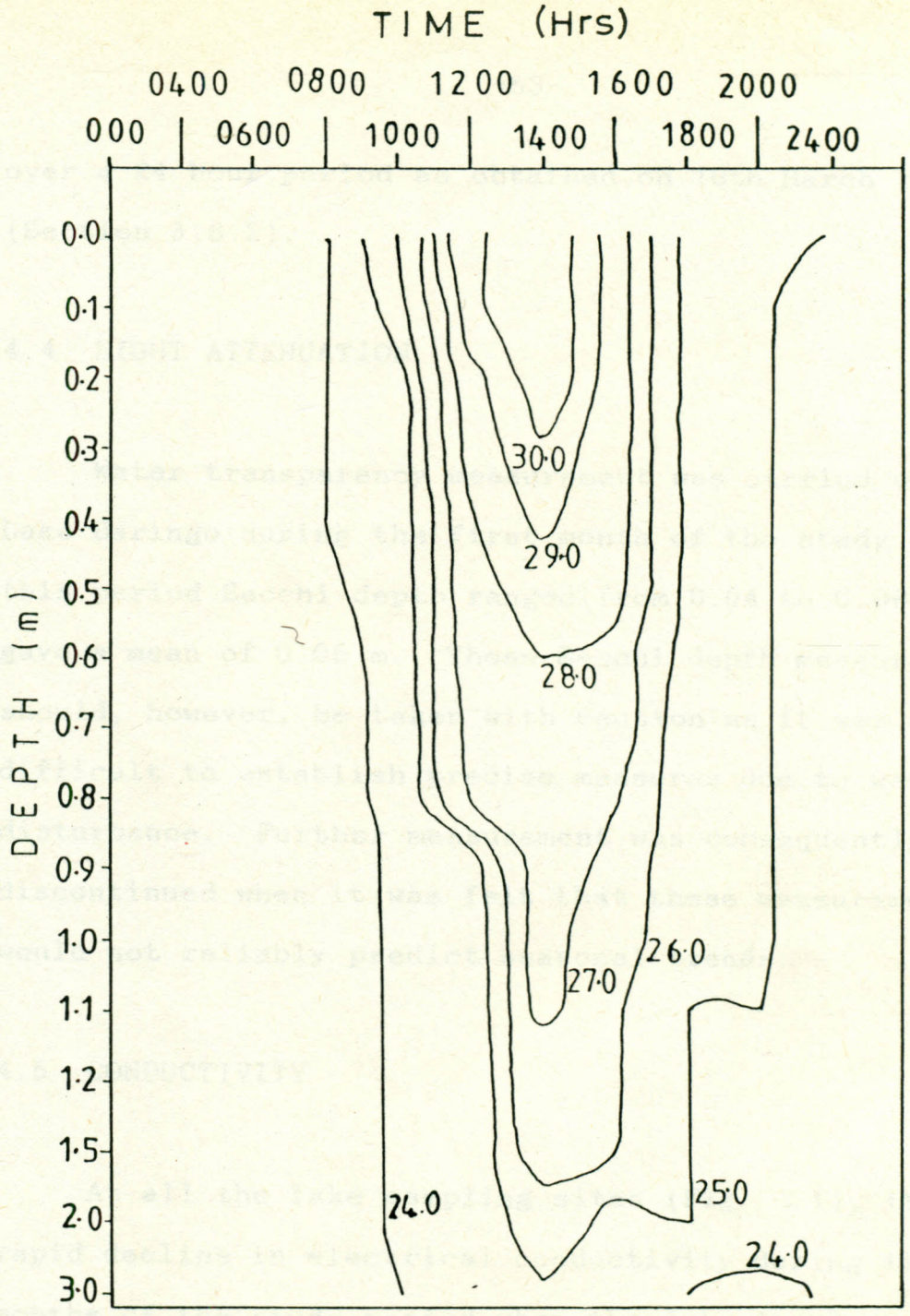


Fig. 4.3

Depth-time diagram of temperature change in Lake Baringo as obtained on the 10th March 1989. The isotherms are in ° C (See Appendix C for the actual values)

FIG. 4.3


TIME (Hrs)
0400
0800
1200
1600
2000
000
0600
1000
1400
1800
2400
DEPTH (m)
0·0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
1·1
1·2
1·5
2·0
3·0
30·0
29·0
28·0
27·0
26·0
25·0
24·0
24·0

over a 24 hour period as obtained on 10th March 1989 (Section 3.6.2).

4.4 LIGHT ATTENUATION

Water transparency measurement was carried out in Lake Baringo during the first month of the study. Over this period Secchi depth ranged from 0.04 to 0.06 m, and gave a mean of 0.05 m. These Secchi depth measurements should, however, be taken with caution as it was very difficult to establish precise measures due to wave disturbance. Further measurement was consequently discontinued when it was felt that these measurements would not reliably predict seasonal trends.

4.5 CONDUCTIVITY

At all the lake sampling sites (Fig. 3.1), there was a rapid decline in electrical conductivity during the first 3 months of the study period when the lake level was rapidly rising. The different sampling sites showed different rates of decline (Fig. 4.4 A). In general the decline rate increased on moving from the north end (L_6) to the south end (L_1) (compare Figs 3.1 and 4.4 A). At the start of the study (July, 1988), conductivity ranged from 1135 $\mu S\ cm^{-1}$ (L_1) to 1220 $\mu S\ cm^{-1}$ (L_6). Increased discharge of water from the south end, however, greatly diluted the lake water at this end and by the second week of August the range was from 120 $\mu S\ cm^{-1}$ in the south (L_1) to 1150 $\mu S\ cm^{-1}$ in

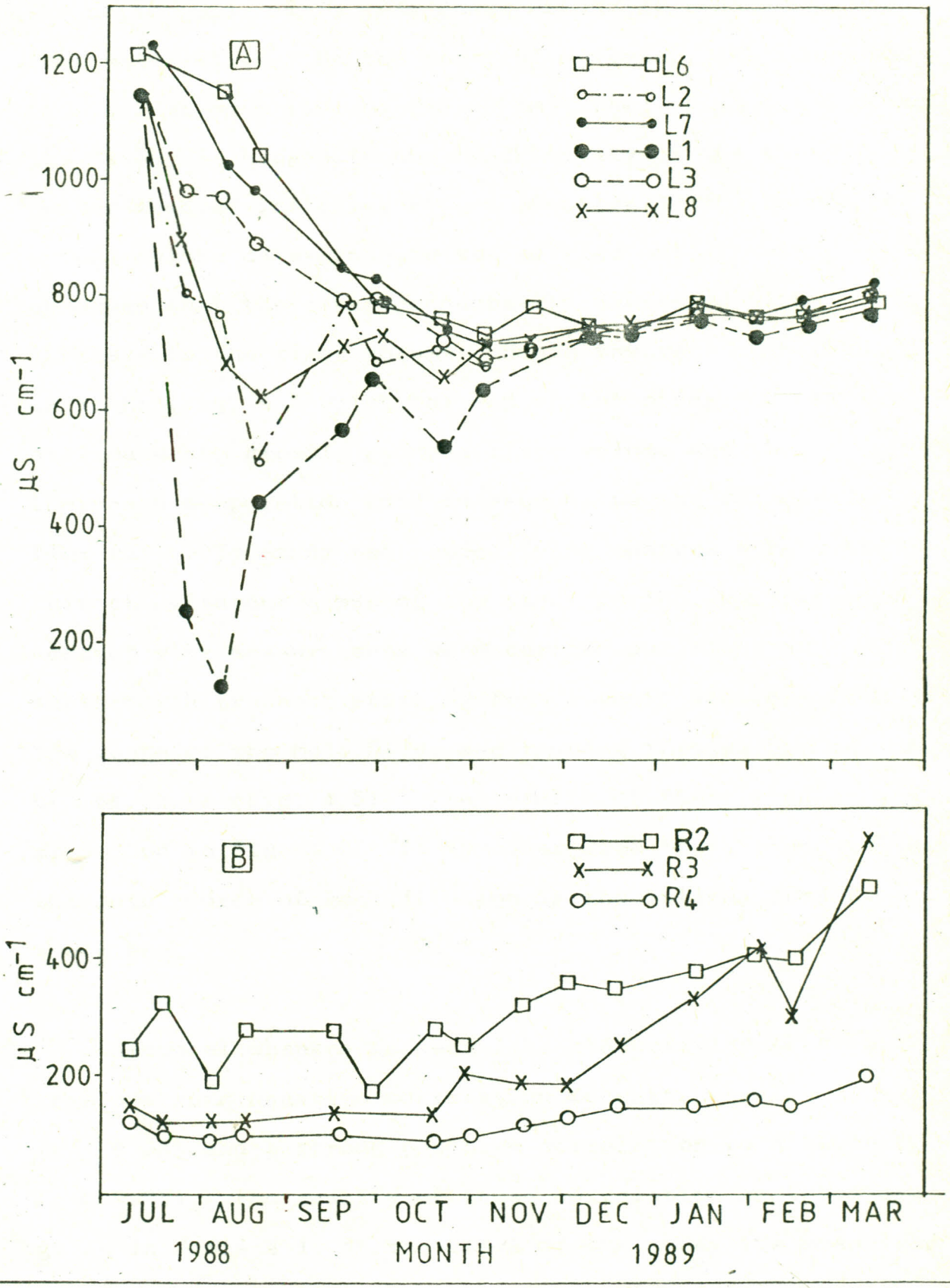
Fig. 4.4

Temporal changes in conductivity;

A. at some selected lake sampling sites, and

B. at some selected river sampling sites.

FIG. 4.4 CONDUCTIVITY



the north (L_6). This wide range gradually reduced as the lake water mixed. By the start of November, the range was from 640 $\mu S\ cm^{-1}$ (L_1) to 730 $\mu S\ cm^{-1}$ (L_6). Fig. 4.4 B gives the temporal changes in the conductivity of the three better studied inflowing rivers (Section 3.1). Though no actual volume determination was carried out, it was observed that the river conductivity decreased with increase in the river volume. Hence the very high reading as in R_3 (Fig. 4.4 B) at the end of the study can be attributed to greatly reduced river volume and the increased evaporation rate consequent to the decreased flow rate. To study the conductivity changes across the lake at different times of the study period, continous conductivity measurements were carried out along a south-north transect starting from a short distance from the mouth of the Molo River and running through L_1, L_2, L_3, L_4, L_5 to L_6 (Fig. 4.5). The results of these studies are presented in Fig. 4.6. It is clear from these findings that the main source of lake dilution is the inflows from the south end.

Temporal changes in mean lake conductivity (Fig. 4.7 A) gave a strong negative correlation to water level ($r = 0.93$) and a strong positive correlation to alkalinity ($r = 0.98$). The results of these correlation analyses are given in Table 4.1. At the start of the study the mean lake conductivity was 1170 $\mu S\ cm^{-1}$. The rapid rise in the lake level (Section 4.2) brought about a rapid decline in the lake's mean conductivity. By the third week of October, it

Fig. 4.5.

Map of Lake Baringo showing the approximate conductivity transect route.

FIG. 4.5

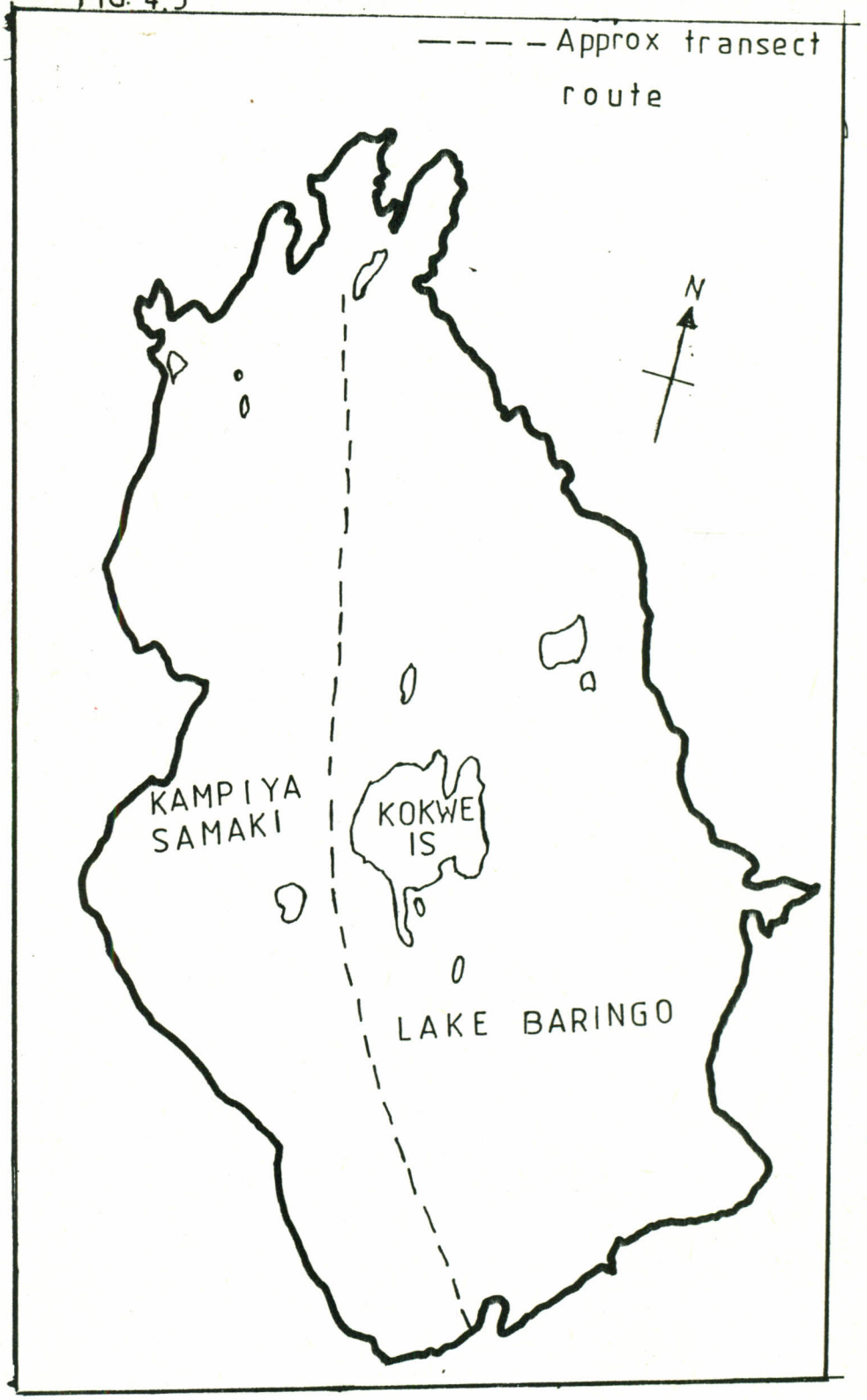

Approx transect route
N
KAMPIYA SAMAKI
KOKWE IS
LAKE BARINGO

Fig. 4.6

Conductivity changes across Lake Baringo starting from near the mouth of the Molo River to Lekoros Island during three different periods:

9-8-1988 period of very rapid rise in lake level,

18-9-1988 period of high and fairly stable lake level,

9-2-1989 period when the lake level began declining.

FIG. 4·6

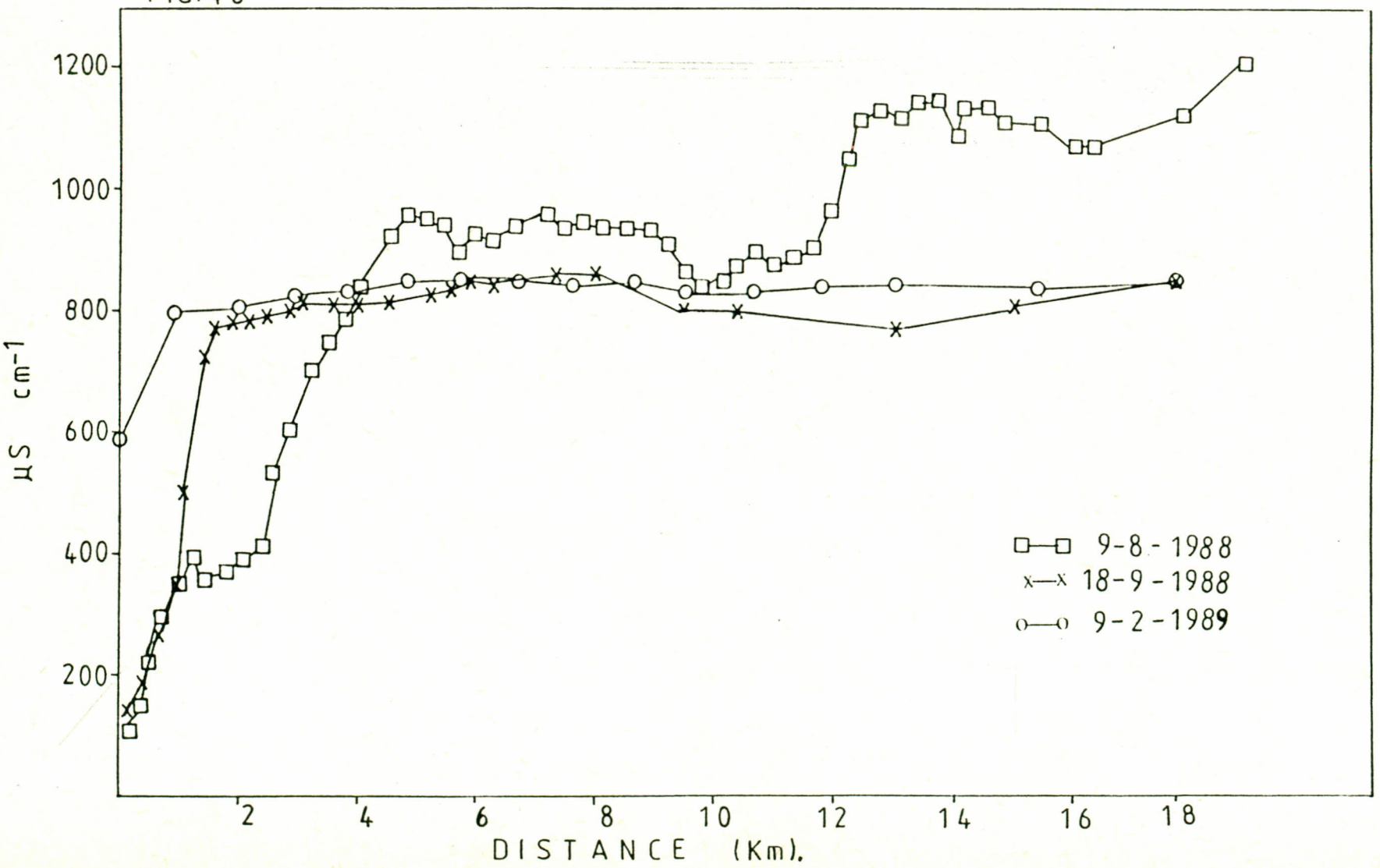

1200
1000
800
600
400
200
µS cm⁻¹
2
4
6
8
10
12
14
16
18
DISTANCE (Km).
9-8-1988
18-9-1988
9-2-1989

Fig. 4.7

A. Temporal variation in the mean lake conductivity.

B. Spatial changes in the mean lake and river conductivities. Vertical bars indicate ± 1 S E

was down to 690 uS cm^{-1}. It then rose and continued fluctuating up and down and by the end of the study period (mid March 1989), it was 800 uS cm^{-1}. The temporal changes in the mean levels of the physical, chemical and biological parameters studied are given in Table 4.2 and Appendix B.

Table 4.1 Summary of correlation between the temporal changes of some chemical and physical properties of Lake Baringo.

Correlation	r	t	p
Conductivity: Water level	0.93**	9.3	<0.001
Total alkalinity: Water level	0.83**	6.3	<0.001
Conductivity: Total alkalinity	0.98**	15.8	<0.001
Total nitrogen: Total phosphorus	0.43	1.59	>0.05

** Highly significant

The mean conductivity of the lake and river sampling sites is given in Fig. 4.7 B. Table 4.3 summarises the spatial variations in the mean levels of the physical, chemical and biological parameters studied. Some sampling sites are near points of river discharge into the lake (Fig. 2.1). These sites have slightly lower conductivity values than the other lake sites. The rivers differ widely from one another in their mean conductivity. There is an overall reduction in conductivity on moving from River Mukutan (R_1) with a mean of 450 uS cm^{-1}, through River Ol Arabell (R_2) (320 uS cm^{-1}) and River Molo R_3 (240 uS cm^{-1}) to River Perkerra (R_4) (130 uS cm^{-1}). The hot springs in central

Table 4.2 Temporal changes in the mean values of some chemical and biological properties of Lake Baringo
The values given are the averages of all measurements in the lake's sampling sites.

WEEK	Conductivity $\mu S\ cm^{-1}$	Diss. O_2 mgl^{-1}	Diss. O_2 % sat.	Alkalinity $meq\ l^{-1}$	NH_3-N $\mu g\ l^{-1}$	NO_2-N $\mu g\ l^{-1}$	Total Nitrogen $mg\ l^{-1}$	Dissolved Nitrogen $mg\ l^{-1}$	PO_4-P $mg\ l^{-1}$	Dissolved Phosphorus $mg\ l^{-1}$	Total Phophorus $mg\ l^{-1}$	TN: TP ratio	Chlorophyll a $\mu g\ l^{-1}$	M. aeruginosa cells ml^{-1}	P. Catenata trichomes ml^{-1}	Nitzschia sp. cells ml^{-1}
1	1170	6.7	91	9.1									13.6	10660	700	150
3	880	6.2	84		61.6				.118	.113	.146					
5	820	7.1	96	6.2	59.8	2.9	2.62	1.57	.113	.135	.161	16.3	13.6			
7	760			6.0		2.5	2.69	1.67	.152	.159	.175	15.4	9.4	9280	570	60
10	760	6.7	91	6.3	22.3	2.7	3.50	2.68	.134	.147	.165	21.2	13.3	7680	300	210
12	750	6.5	88	6.8	59.4	1.6	1.09	0.83	.121	.131	.141	7.7	12.7			
15	690	6.1	82	6.1	31.0	3.5	2.23	1.74	.108	.120	.129	17.2	9.7	21160	850	210
17	700	6.4	98	6.3	52.6	2.8	1.39	1.00	.105	.119	.130	10.7	11.7			
19		7.0	95	6.3	83.1	0.9	0.81	0.63	.098	.111	.125	6.5	8.7	14440	720	200
22	740	6.3	85	6.0	34.3	1.3	0.82	0.63	.116	.127	.142	5.8	13.8			
24	740	6.2	84	6.1		3.0	0.78	0.63	.103	.116	.132	5.9	15.9	9360	230	40
27	775	6.4	98	6.3	29.6	1.9	0.76	0.56	.150	.163	.175	4.3	13.0	7530	160	20
30	760	6.4	98	6.4	39.7	1.8	1.38		.102		.122	11.3	12.7	14300	120	100
32	770	6.3	85	6.6	11.45	3.2	1.38		.086		.112	12.3	14.2			
36	800	6.8	92	6.3		2.1	1.27		.084		.105	12.1	11.5	10700	280	70
MEAN	790	6.5	88	6.5	44.1	2.3	1.59	1.19	.114	.133	.140	11.3	12.4	11660	440	120

Table 4.3 Spatial variation in the mean values of some chemical and biological characters of Lake Baringo and some of the inflowing rivers. The values given are the averages of all the determinations carried out over the study period.

	Conductivity $\mu S\ cm^{-1}$	Diss O_2 mgl^{-1}	Diss. O_2 % sat.	Total Alkalinity $meq\ l^{-1}$	NH_3-N $\mu g\ l^{-1}$	NO_3-N $\mu g\ l^{-1}$	NO_2-N $\mu g\ l^{-1}$	Total Nitrogen $mg\ l^{-1}$	Dissolved Nitrogen $\mu g\ l^{-1}$	PO_4-P(SRP) $\mu g\ l^{-1}$	Dissolved Phosphorus $mg\ l^{-1}$	Total Phosphorus $\mu g\ l^{-1}$	TN:TP Ratio	Silica $mg\ l^{-1}$	Chlorophyll a $\mu g\ l^{-1}$	Mean depth m
R_1	450			4.8		28	2.3	2.51	1.97	.076	.087	.128		27.4		
R_2	320			2.7		20.7	1.5	1.33	0.98	.035	.048	.078		30.2		
R_3	240			2.1		45	4.2	2.02	1.05	.069	.081	.104		32.9		
R_4	130			1.4		34.5	1.8	1.44	0.96	.047	.064	.081		31.3		
L_1	620	5.5	74	5.4	33.9	33.0	2.2	1.56	0.83	.094	.112	.129	12.1	25.9	13.2	2.5
L_2	760	6.6	89	6.1	49.1	36.2	2.4	1.70	1.51	.115	.130	.141		27.9	10.7	3.0
L_3	230	6.9	93	6.7	34.9	37.2	3.0	1.65	1.13	.116	.135	.143	11.5	29.4	12.2	4.8
L_4	590	6.7	91	6.6	71.2	37.1	2.3	1.53	1.30	.113	.136	.139	11.0	29.8	8.9	4.8
L_5	810	6.7	91	6.7	22.9	36.5	1.8	1.68	1.40	.108	.126	.131	12.8	28.7	9.9	5.3
L_6	850	6.7	91	7.1	26.3	29.3	2.6	1.60	1.35	.118	.142	.145	11.0	26.6	12.0	5.0
L_7	870	6.8	92	7.0	63.1	29.1	2.4	1.45	1.06	.119	.138	.142	10.2	23.1	13.9	3.0
L_8	770	6.4	86	6.4	46.6	38.3	1.8	1.50	0.95	.121	.145	.150	10.0	24.5	18.9	2.5

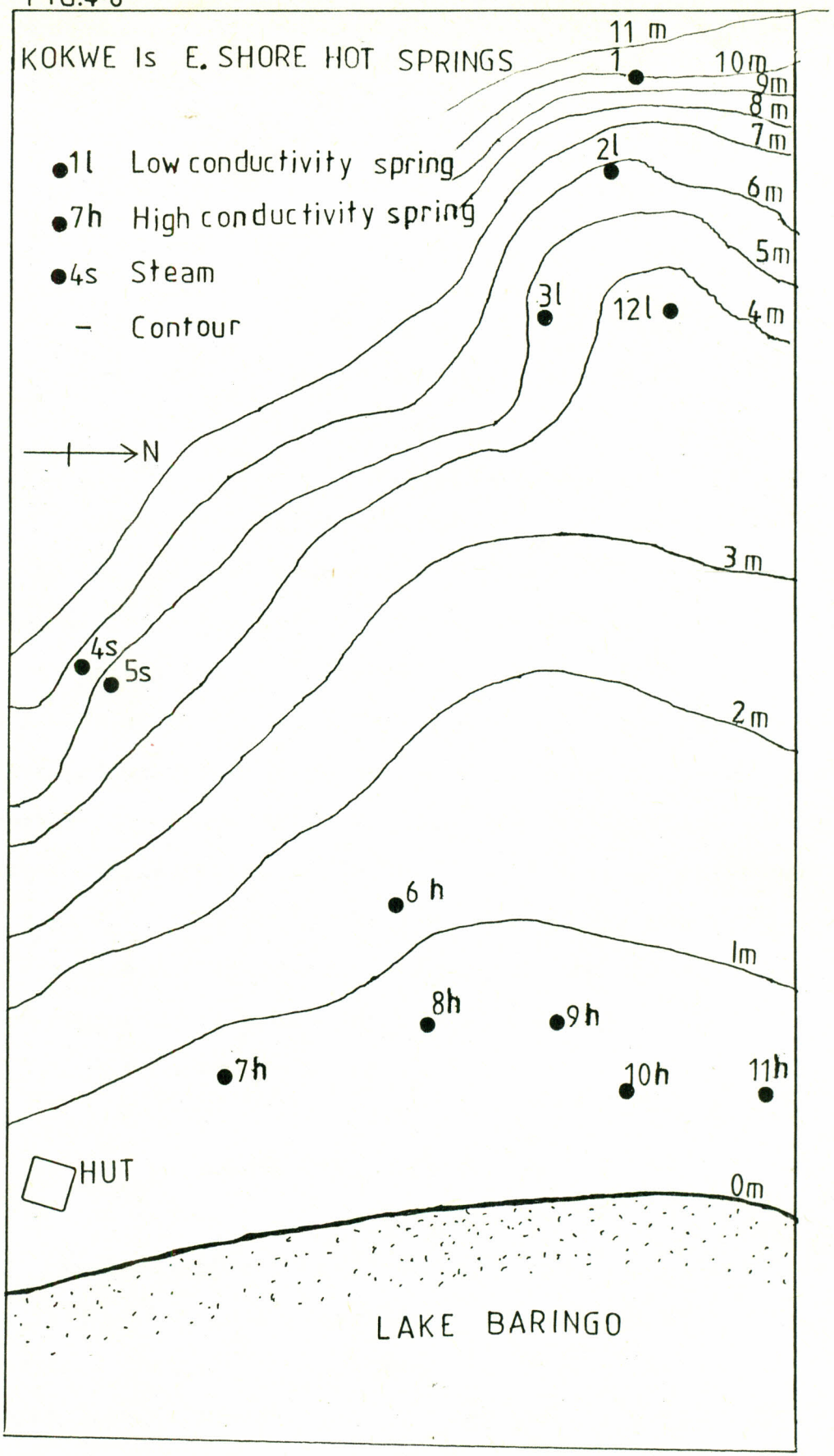
island Kokwe (Section 3.1) had varying conductivity values. Two distinct groups were identified. These were the low conductivity and the high conductivity hot springs. The high conductivity hot springs occur in both the W. cliffs and the N.E. shore while the low conductivity hot springs only occur in the N.E. shore (Fig. 3.1). The distribution of hot springs in the N.E. shore is shown in Fig. 4.8. The mean conductivity of the low conductivity hot springs was 390 $\mu S\ cm^{-1}$ and that of the high conductivity hot springs at the N.E. shore 3490 $\mu S\ cm^{-1}$. The W. cliff hot springs had a mean conductivity of 3470 $\mu S\ cm^{-1}$. The above mean values are the averages of the mean values of the individual hot springs in each area. In each sampling trip to the hot springs it was not possible to obtain water from all the individual springs as they were many, at times connected by their surface run-off and some would be dry. The latter case was more prominent in the low conductivity hot springs which apart from being placed at a higher elevation from the lake were common only after a rainy period. Some of the high conductivity hot springs were evidently under the lake and others would be occasionally submerged at higher lake levels.

Vertical conductivity measurements over a 24 hour period showed no vertical or diel variation. Measurements done on the 10th March 1989 gave a constant vertical and diurnal measure of 800 $\mu S\ cm^{-1}$.

Fig. 4.8

Map showing the distribution of hot springs in the N.E. shore of Kokwe Island. The map was redrawn from the original works of Operation Raleigh Surveyors, 1988.

FIG.4·8


KOKWE Is E. SHORE HOT SPRINGS
1l Low conductivity spring
7h High conductivity spring
4s Steam
– Contour
N
11 m
10m
9m
8 m
7m
6m
5m
4m
3m
2m
1m
0m
1
2l
3l
12l
4s
5s
6 h
7h
8h
9h
10h
11h
HUT
LAKE BARINGO

4.6 pH

Lake pH ranged from 8.0 to 9.2 during the study period in all the sampling sites except L_1 (Fig. 2.1) whose pH fell to as low as 6.9 at the end of July and the start of August (Fig. 4.9 A) owing to increased river discharge from the south end. There was no distinct temporal or spatial changes in pH as in the case of conductivity. River pH values were lower than those of the lake but showed a wider fluctuation depending on the river volume. The pH range in the four rivers were; R_1, 6.2 to 8.4; R_2 7.0 to 8.9; R_3, 6.9 to 8.7 and R_4, 7.2 to 8.8. Vertical profiles of pH over a 24 hour cycle showed no definite pattern of change (Fig. 4.9 B). The small variation may be attributable to the meter drift. Hot springs pH ranged from 7.2 to 9.7. The pH of the low conductivity hot springs (Section 4.5) ranged from 7.2 to 7.5. In the high conductivity hot springs, the range was from 8.0 to 9.7 in the N.E. shore and 8.3 to 9.4 in the W. Cliff.

4.7 DISSOLVED OXYGEN (DO)

Surface water DO saturation in the lake ranged from 80% to 101% except in L_1 where as low as 49% was at one time measured (Fig. 4.10 A). Mean lake surface water DO saturation, although showing some temporal fluctuation, exhibited no temporal trend (Fig. 4.10 B). Mean DO saturation of the different lake sampling sites did not vary much from each other except for L_1 with

Fig. 4.9

A. Temporal changes in the pH of some selected lake sampling sites.

B. Vertical profiles of pH change over a 24 hour period as obtained on 10th March 1989.

FIG. 49 pH

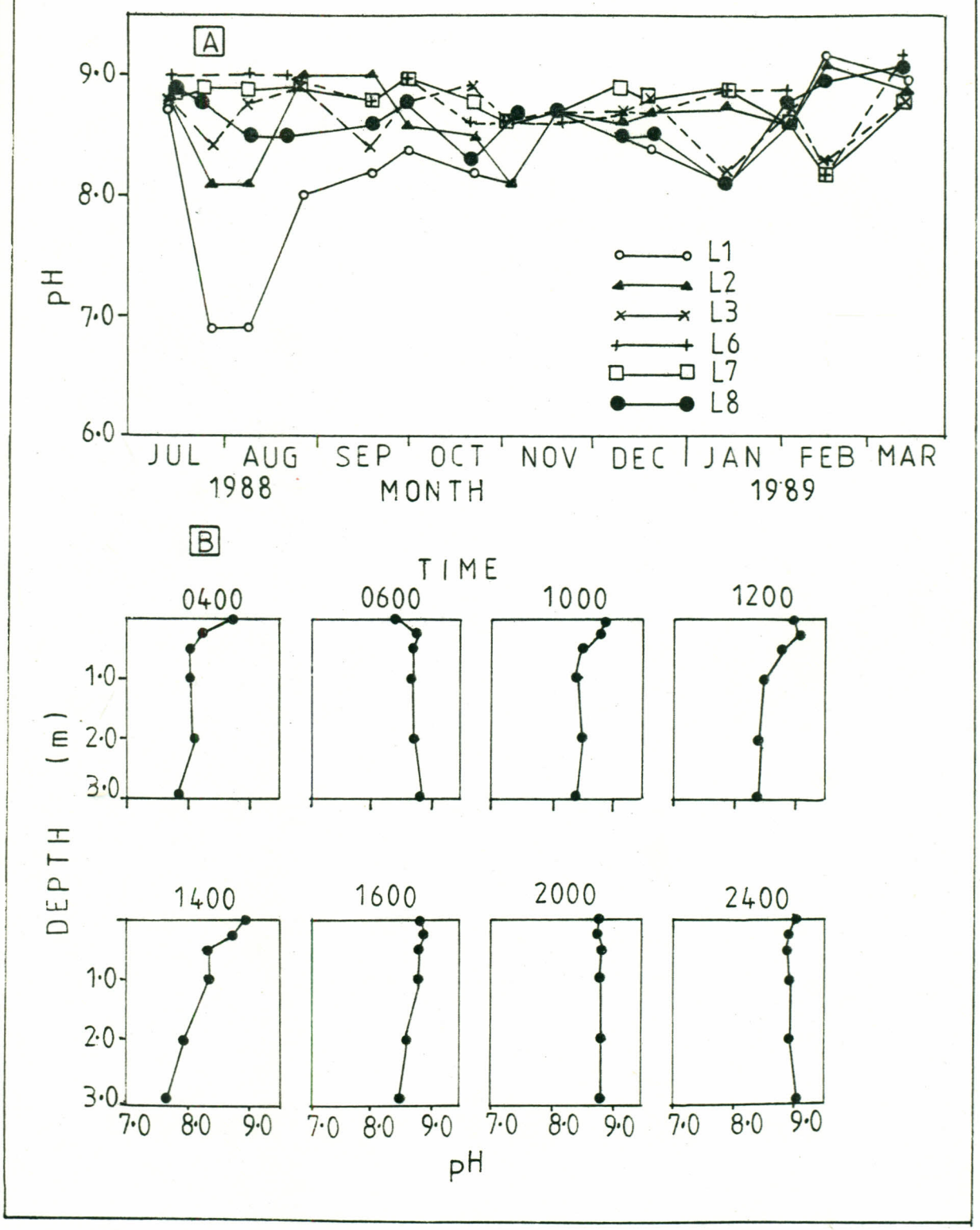

A
9·0
8·0
7·0
6·0
pH
L1
L2
L3
L6
L7
L8
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
1988
MONTH
1989
B
TIME
0400
0600
1000
1200
1400
1600
2000
2400
1·0
2·0
3·0
DEPTH (m)
7·0
8·0
9·0
pH

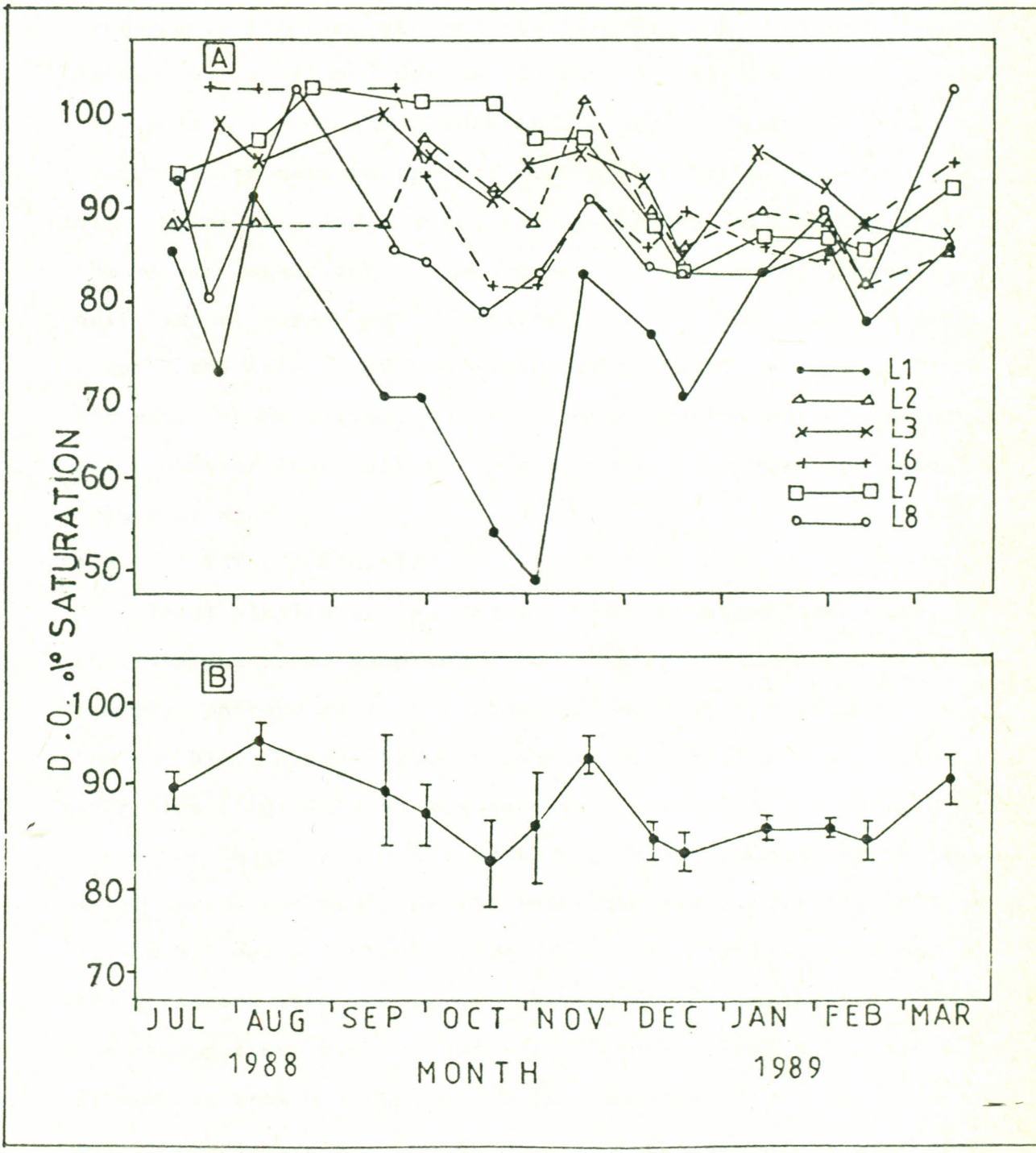
Fig. 4.10

Temporal changes in;

A. dissolved oxygen (DO) % saturation of some selected lake sampling sites, and

B. mean lake dissolved oxygen % saturation . Vertical bars, indicate ± I S E.

FIG. 4.10 DISSOLVED OXYGEN.



a slightly lower value (Fig. 4.11 A). The results of *in situ* oxygen determination at some specific points down the water column over a 24 hour period (Section 3.6.2) are summarized in Fig. 4.11 B. From these results, it appears that DO concentration measures at all depths steadily declined over time. Since the oxygen meter was calibrated only at the start of the 24 hour study there appears to have been a continuous drift in the oxygen meter reading towards giving lower values. Despite the effects of the meter drift, there was evidently an increase in the surface water DO concentration during the day and a more-or-less uniform distribution of DO down the water column at night.

4.8 TOTAL ALKALINITY

Total alkalinity (as meq l^{-1} $CaCO_3$) changes over time, at the lake and river sampling sites (Figs 4.12 A and B), had a temporal pattern similar to that of conductivity (Figs 4.4 A and 4.4 B). Changes in mean lake total alkalinity measurements over time (Fig. 4.13 A) was inversely correlated to changes in the water level ($r = 0.83$) as in the case of conductivity (Table 4.1). During the study period mean lake alkalinity ranged from 6.0 to 9.1 meq l^{-1} (Table 4.2). The mean alkalinity values of the different lake and river sampling sites similarly followed the same pattern with conductivity (Compare Figs 4.7 B and 4.13 B) varying from 5.4 (L_1) - 7.0 (L_7) and 1.4 (R_4) - 4.8 (R_1) meq l^{-} respectively. The W. Cliff hot springs had a mean total alkalinity of 37.5 meq l^{-1}. At the N.E. shore the high conductivity hot springs had a mean of 30.4 meq l^{-1}. At the N.E. shore, the high conductivity hot springs had a mean of 30.4 meq l^{-1} and the low conductivity ones, a mean of 1.5 meq l^{-1}.

Fig. 4.11

A. Mean saturation of dissolved oxygen at the different lake sampling sites.

B. Vertical profiles of dissolved oxygen (in mg l^{-1}) concentration over a 24 hour period as obtained on the 10th March 1989.

Vertical bars indicate $\pm$ 1 S E

FIG. 4.11 DISSOLVED OXYGEN % SATURATION

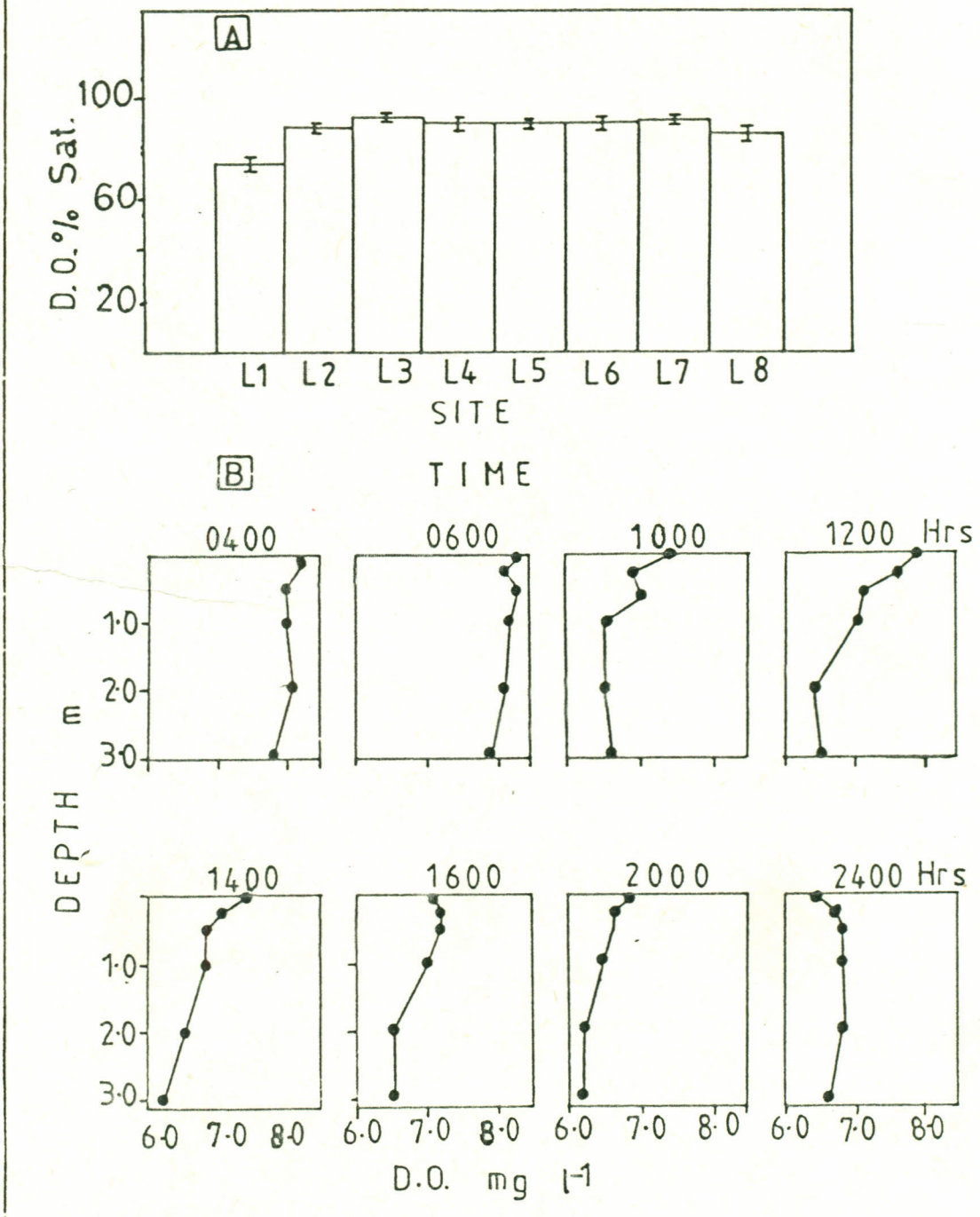


Fig. 4.12

Temporal changes in alkalinity;

A. at some selected lake sampling sites and

B. at some selected river sampling sites.

FIG. 4.12 TOTAL ALKALINITY

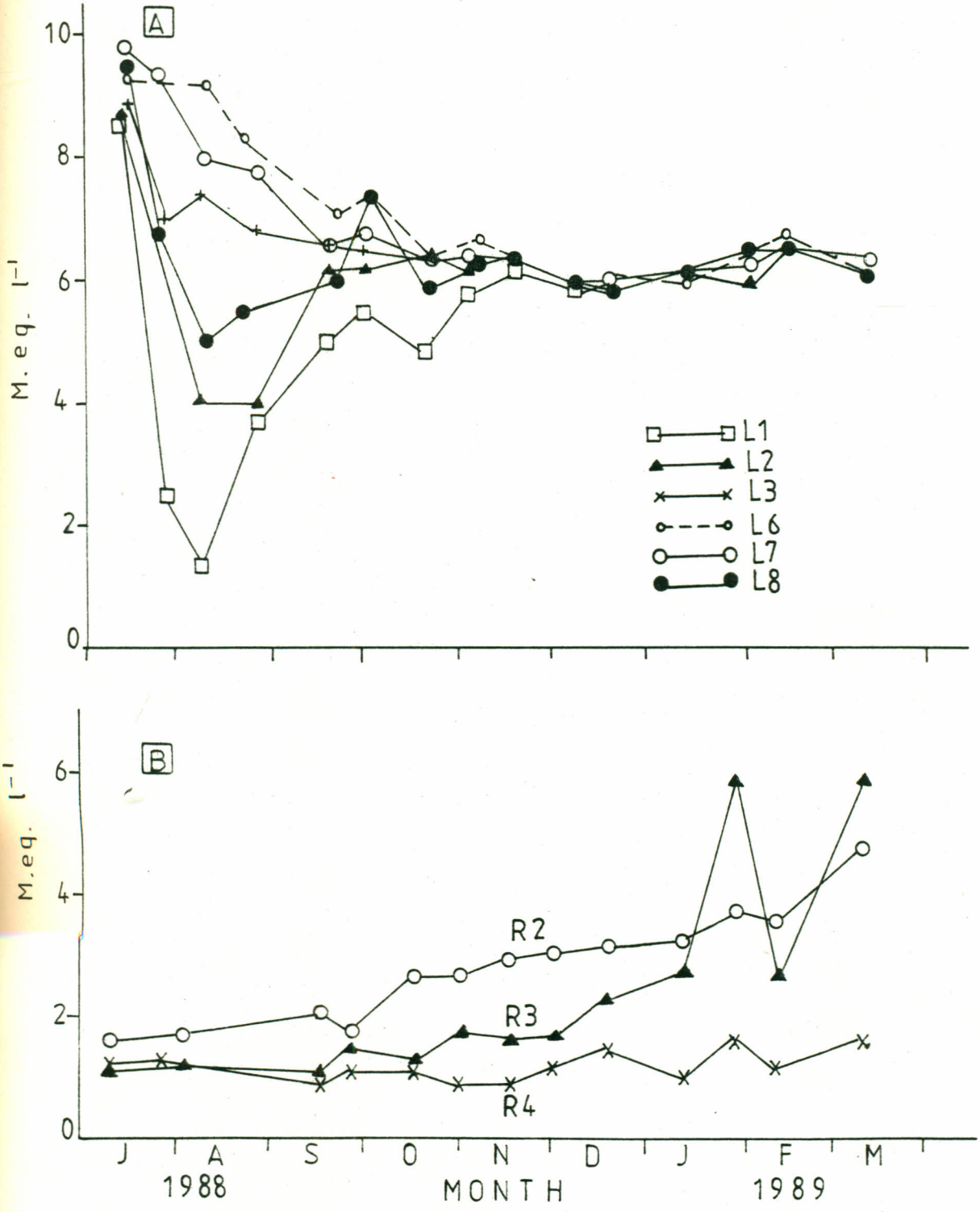


Fig. 4.13

A. Temporal changes in mean lake alkalinity.

B. Spatial changes in mean alkalinity of the lake and river sampling sites. Vertical bars indicate ± 1 S E.

4.9 PHOSPHORUS

4.9.1 Orthophosphate (PO_4-P) or soluble reactive phosphorus (SRP)

Lake SRP concentration at the different sampling sites during the study period ranged from 0.070 mg l^{-1} measured at L_7 (Fig. 3.1) to 0.160 mg l^{-1} measured at L_3. An exceptionally low value (0.014 mg l^{-1}) was obtained in the second week of August at L_1 during a period of increased discharge from the south end (Fig. 4.14 A). Temporal changes in the SRP concentration of the different lake sampling sites and the overall mean lake concentrations showed no distinct trends (Figs 4.14 A and B). The river sampling sites had relatively lower SRP concentration when compared to the lake (Fig. 4.15 A). The SRP concentration range in the four rivers were: R_1, 0.046 to 0.100 mg l^{-1}; R_2, 0.017 to 0.068 mg l^{-1}; R_3, 0.042 to 0.086 mg l^{-1} and R_4 from 0.032 to 0.070 mg l^{-1}. The W. Cliff hot springs had a mean SRP concentration of 0.041 mg l^{-1}. In the N.E. shore, the high conductivity hot springs (Section 4.5) had a mean of 0.031 mg l^{-1} and the low conductivity ones, 1.741 mg l^{-1}. Vertical SRP measurements over a 24 hour period gave some irregular variation both vertically and diurnally (Fig. 4.15 B).

Fig. 4.14

A. Temporal changes in the concentration of soluble reactive phosphorus (SRP) in some selected lake sampling sites.

B. Temporal changes in the mean lake concentration of soluble reactive phosphorus, dissolved or filtrable phosphorus (DP) and total phosphorus (TP).

FIG.4.14 PHOSPHORUS

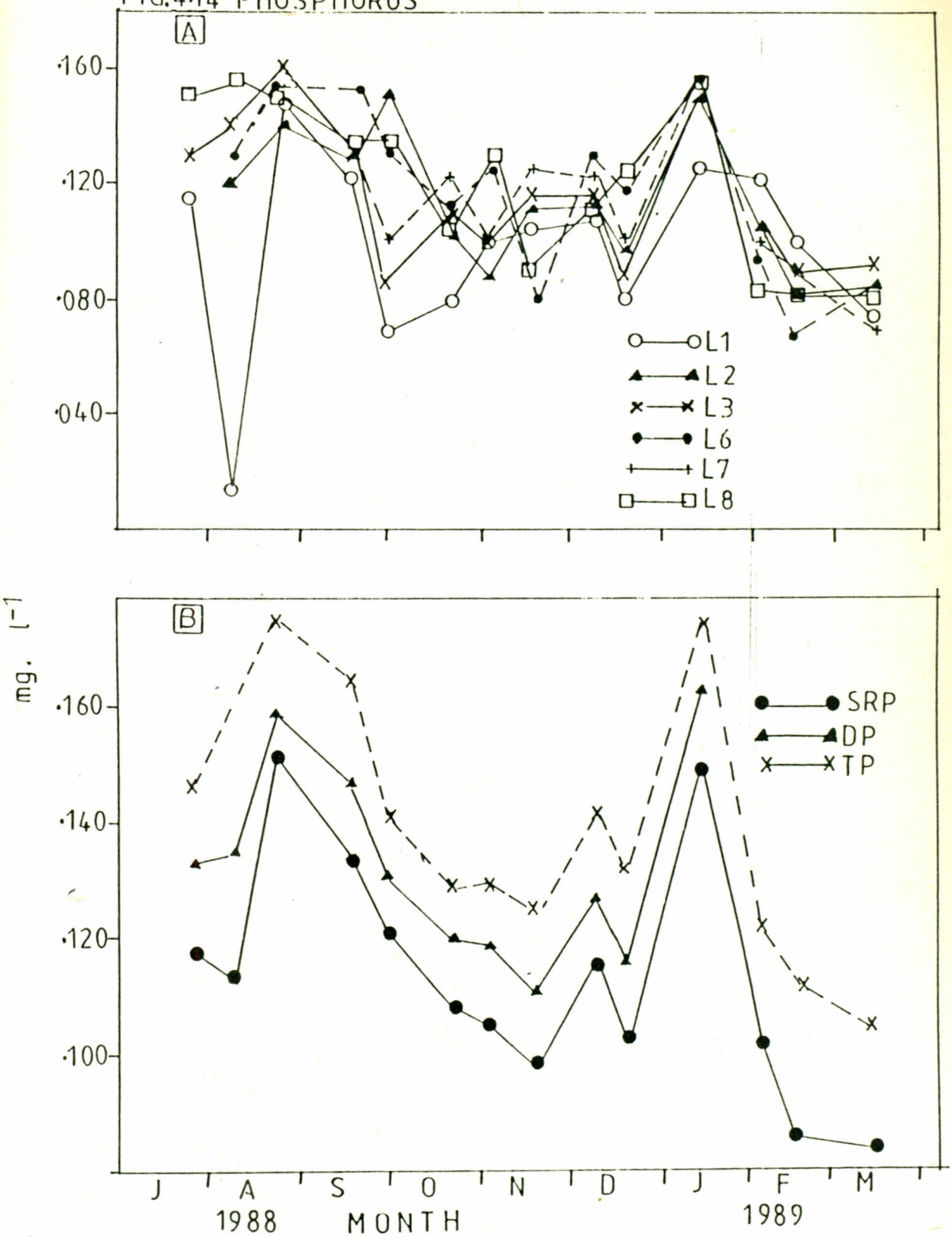
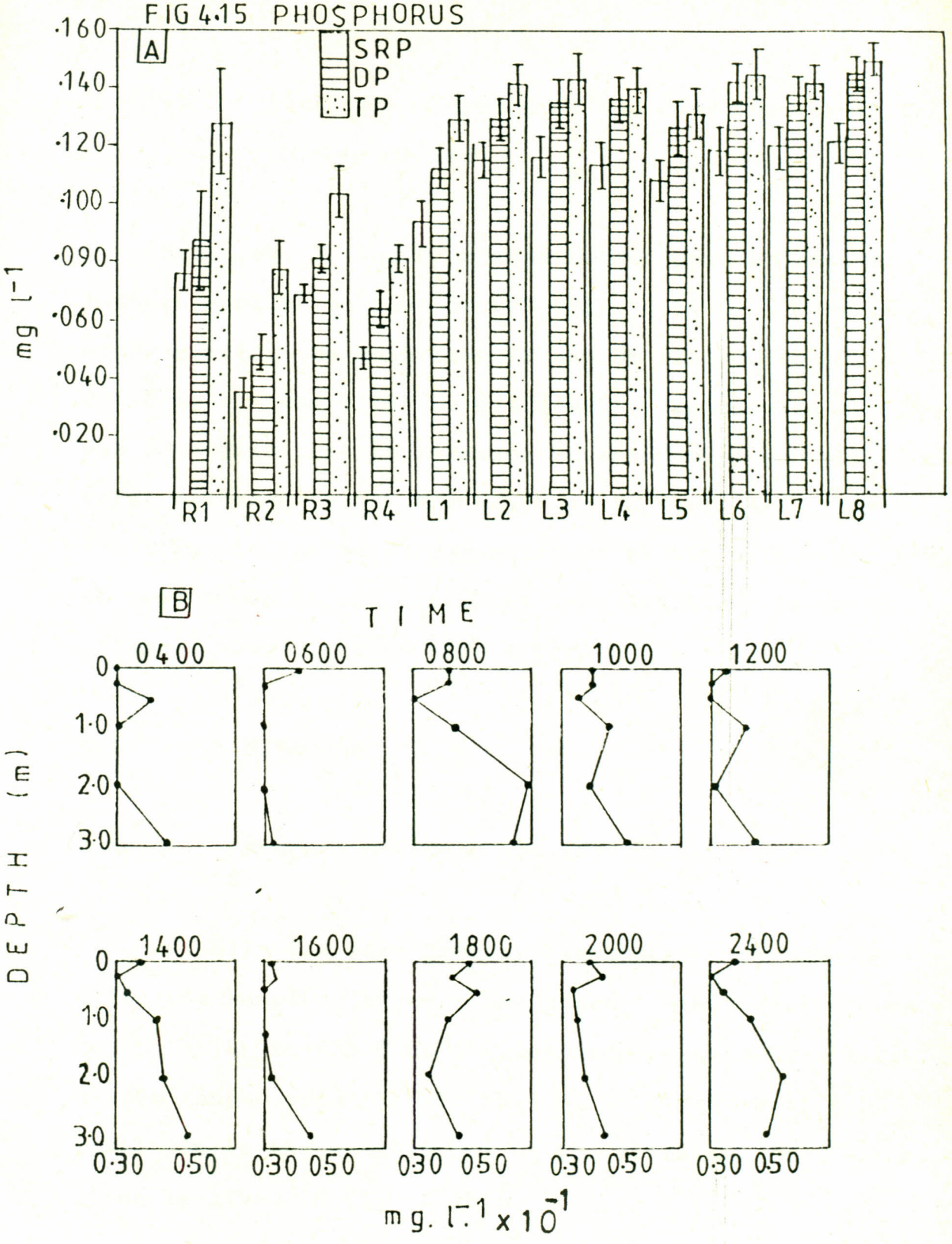


Fig. 4.15

A. Mean concentration of soluble reactive phosphorus (SRP), dissolved or filtrable phosphorus (DP) and total phosphorus (TP) at the lake and river sampling sites.

B. Vertical profiles of soluble reactive phosphorus (SRP) concentration obtained on the 10th March 1989 in Lake Baringo over a 24 hour cycle.
Vertical bars indicate $\pm$ 1 S E

FIG 4.15 PHOSPHORUS



4.9.2 Total phosphorus (TP) and dissolved or filtrable phosphorus (DP)

Mean lake TP and DP concentration gave a temporal pattern similar to that of SRP (Fig. 4.14 B). Over the study period, the mean lake TP and DP ranged from 0.105 to 0.175 mg l^{-1} and 0.101 to 0.168 mg l^{-1} respectively. There was no significant correlation between total phosphorus and total nitrogen ($r = 0.43$) as shown in Table 4.1. The variation in the mean concentration of the different forms of phosphorus at the different lake and river sampling sites is summarised in Fig. 4.15 A.

4.10 NITROGEN

4.10.1 Ammonia nitrogen (NH_3-N)

NH_3-N in the lake greatly fluctuated over time at the different sampling sites. The concentration ranged from 0.8 µg l^{-1} at L_1 to 435.0 µg l^{-1} measured at L_4. Mean lake values ranged from 11.5 to 59.4 µg l^{-1} (Fig. 4.16 A). Variation in the mean values of the different lake sampling sites is given in Fig. 4.16 B.

4.10.2 Nitrite nitrogen (NO_2-N)

NO_2-N concentration in all the sampling sites ranged from undetectable levels (<0.7 µg l^{-1}) to 9.5 µg l^{-1}. Figs 4.17 A and B summarises the temporal variation in the mean

Fig. 4.16

A. Temporal changes in the mean lake ammonia-nitrogen (NH_3-N) concentration.

B. Spatial variation in the mean ammonia-nitrogen concentration of the lake sampling sites. Vertical bars indicate $\pm$ 1 S E.

FIG. 4.16 NH_3 – N

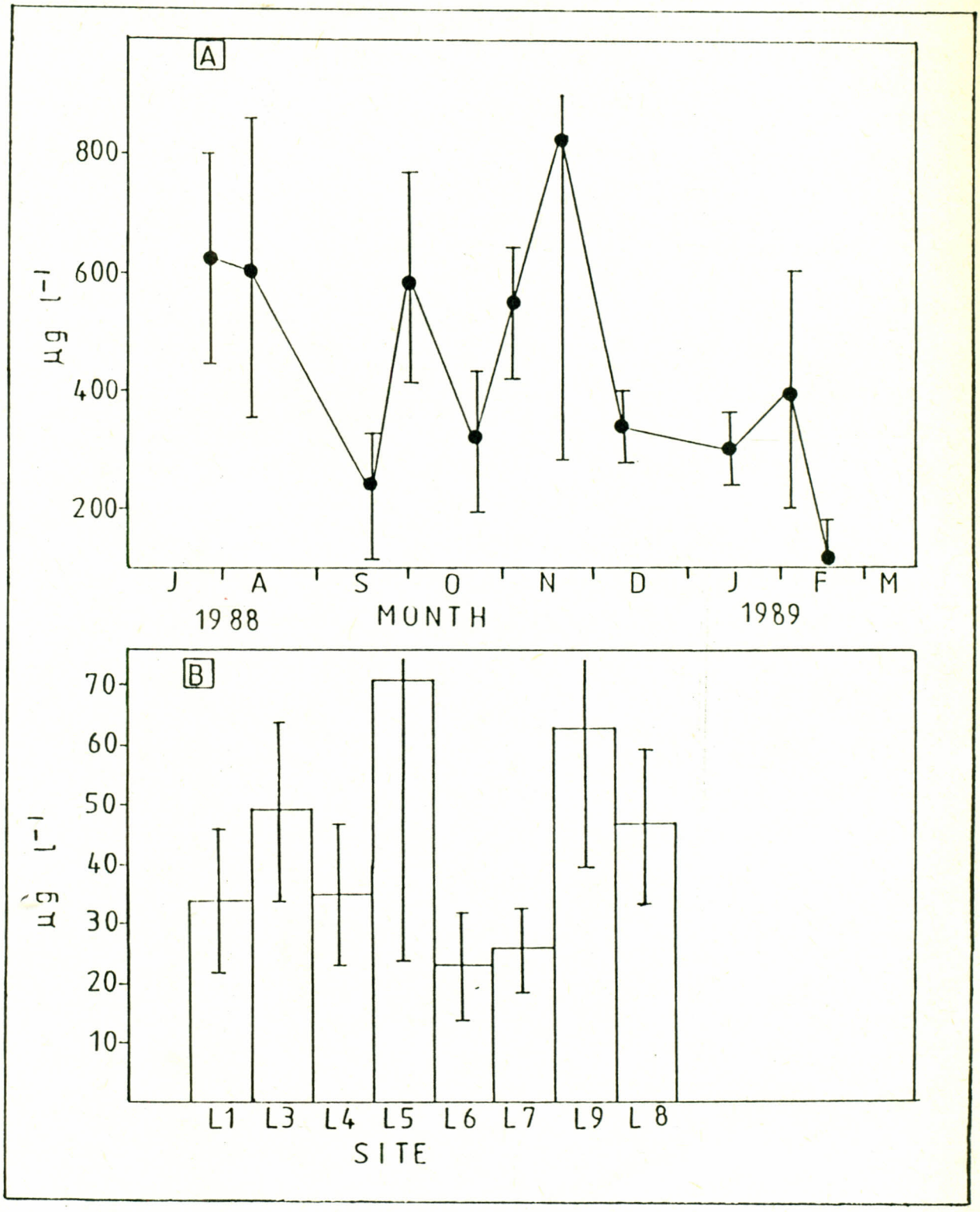

A
800
600
400
200
µg l⁻¹
J
A
S
O
N
D
J
F
M
1988
MONTH
1989
B
70
60
50
40
30
20
10
µg l⁻¹
L1
L3
L4
L5
L6
L7
L9
L8
SITE

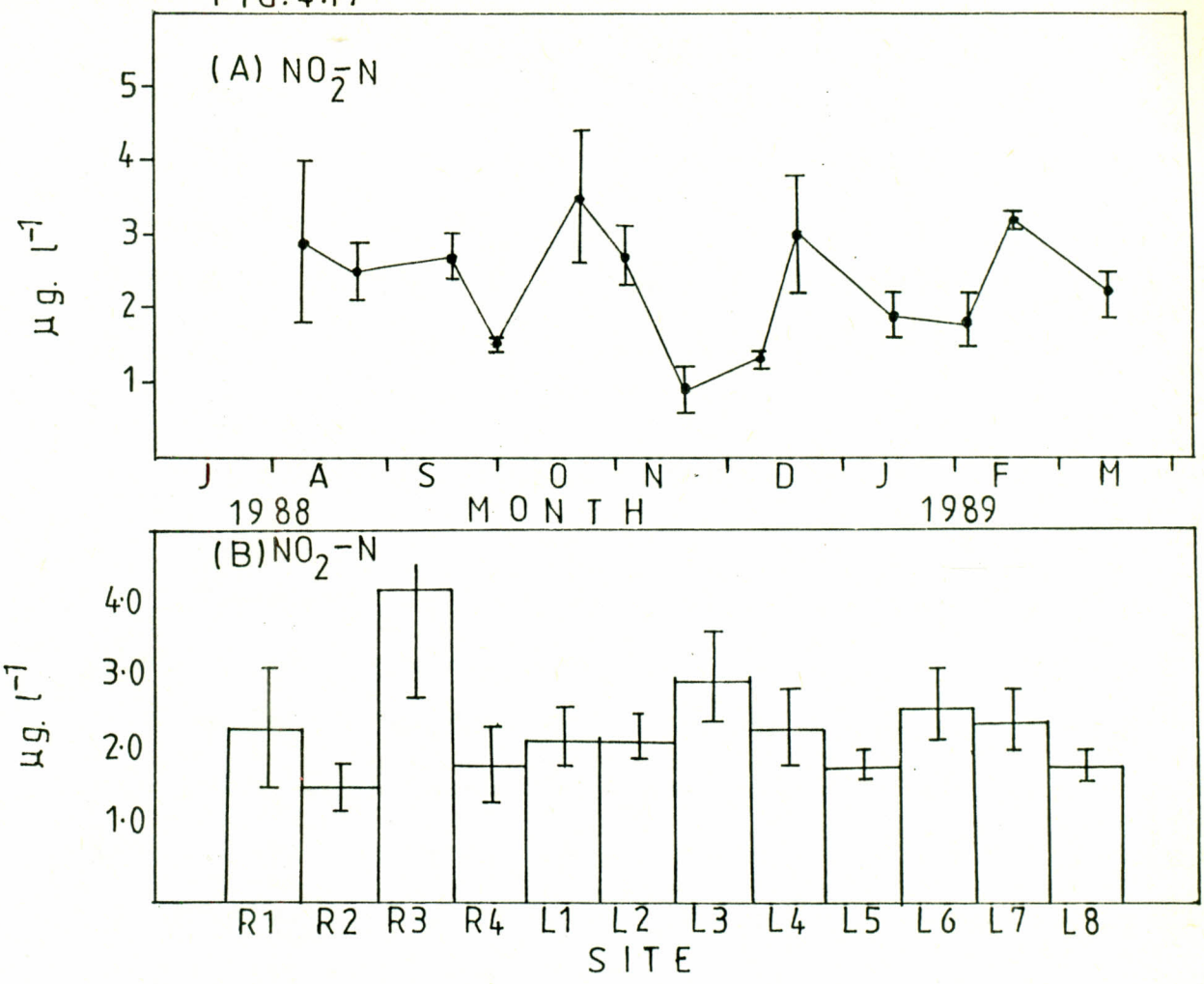
Fig. 4.17

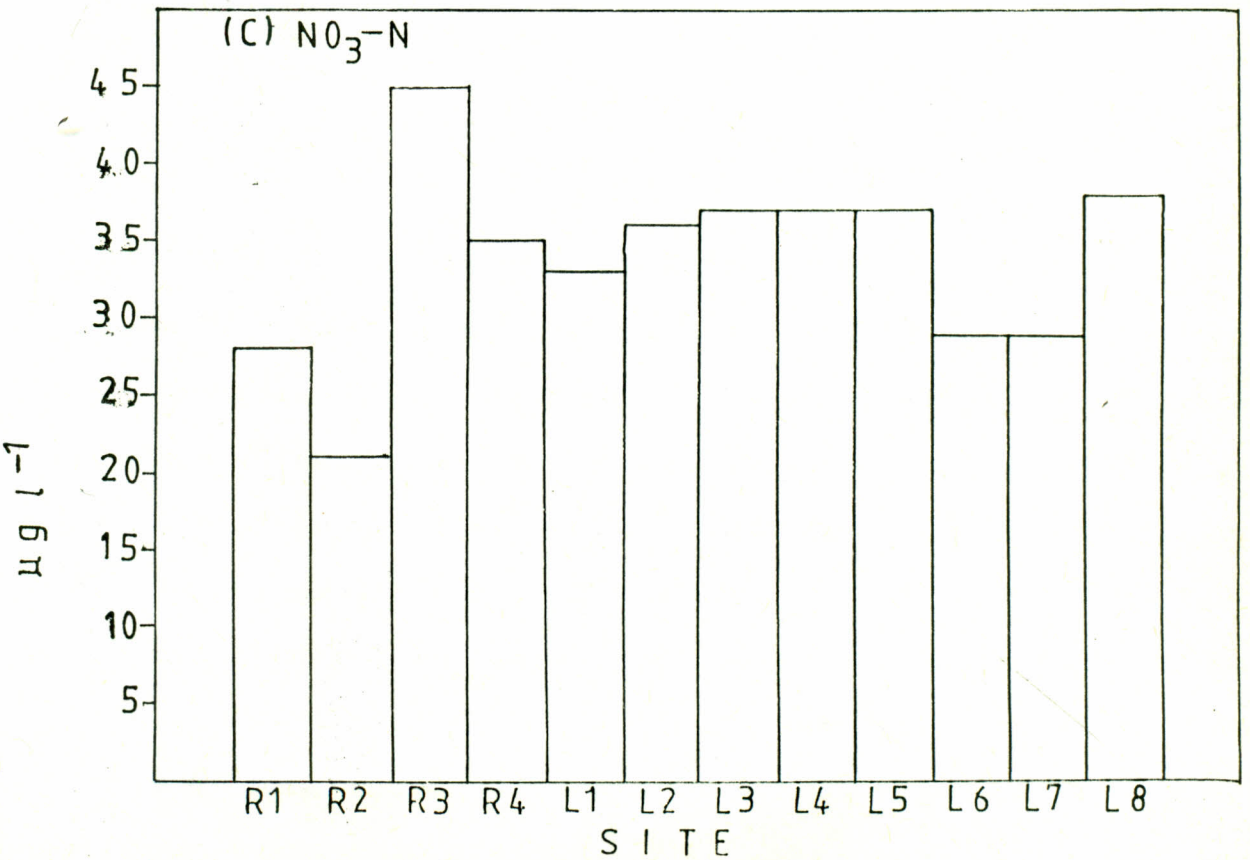
A. Temporal changes in mean lake nitrite nitrogen (NO_2-N) concentration.

B. Spatial variation in the mean nitrite nitrogen concentration of the lake sampling sites.

C. Spatial variation in the mean nitrate nitrogen (NO_3-N) concentration of the lake and river sampling sites. Vertical bars indicate $\pm$ 1 S E.

FIG. 4.17


(A) NO_2^-N
5
4
3
2
1
µg. l^{-1}
J
A
S
O
N
D
J
F
M
1988
MONTH
1989
(B) NO_2^-N
4·0
3·0
2·0
1·0
µg. l^{-1}
R1
R2
R3
R4
L1
L2
L3
L4
L5
L6
L7
L8
SITE


(C) NO_3^-N
45
40
35
30
25
20
15
10
5
µg l^{-1}
R1
R2
R3
R4
L1
L2
L3
L4
L5
L6
L7
L8
SITE

lake levels and the spatial variation of the different sampling sites. Mean NO_2-N concentration in the hot springs were; 5.1 µg l^{-1} in the W. Cliff springs (Fig. 3.1), 2.5 µg l^{-1} in the N.E. shore high conductivity springs and 69.9 µg l^{-1} in the N.E. shore low conductivity springs.

4.10.3 Nitrate nitrogen (NO_3-N)

NO_3-N measurements were carried out five times in the lake sampling sites and only twice in the rivers. This was due to the malfunctioning of the cadmium reduction equipment. From these measurements the mean lake concentration ranged from 29.1 µg l^{-1} in L_1 to 37.2 µg l^{-1} in L_3 (Fig. 4.17 C). In the rivers the mean levels were; 45.0 µg l^{-1} in R_3, 34.5 µg l^{-1} in R_4, 28.0 µg l^{-1} in R_1 and 20.7 µg l^{-1} in R_2.

4.10.4 Total nitrogen (TN) and dissolved nitrogen (DN)

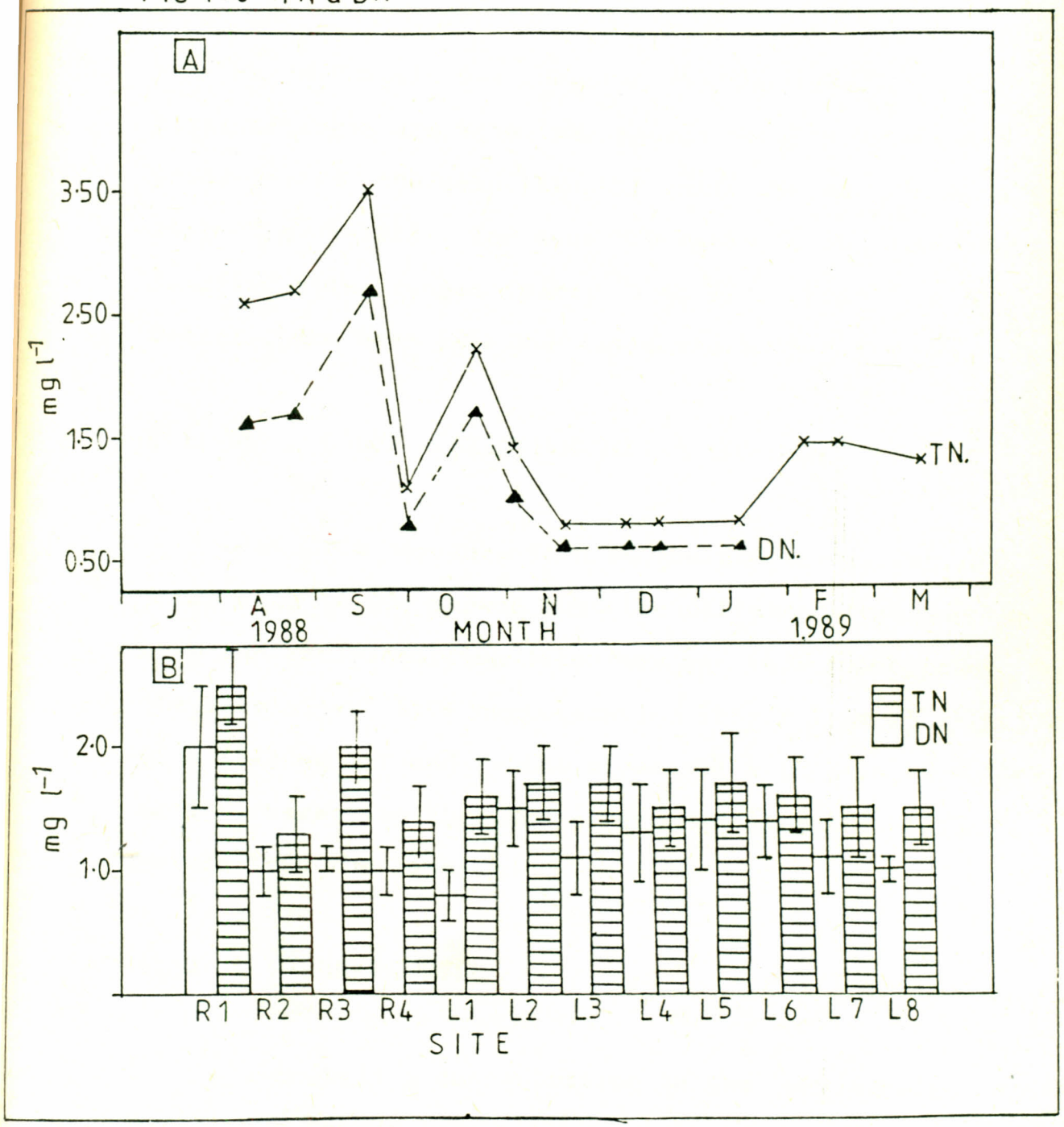
Mean TN and DN concentration in Lake Baringo ranged from 0.76 to 3.50 mg l^{-1} and 0.56 to 2.68 mg l^{-1} respectively (Fig. 4.18 A). Some river sites had higher mean TN and DN concentration than the lake sampling sites (Fig. 4.18 B). In the rivers, TN and DN ranged from 1.44 (R_4) to 2.51 (R_1) mg l^{-1} and 0.96 (R_4) to 1.97 (R_1) mg l^{-1} respectivel as compared to the lakes range of 1.45 (L_7) to 1.70(L_2) mg l^{-1} and 0.83 (L_1) to 1.51 (L_2) mg l^{-1} respectively. As in the case of phosphorus all forms of nitrogen showed no distinct temporal pattern.

Fig. 4.18

A. Temporal changes in mean lake total nitrogen (TN) and dissolved or filtrable nitrogen (DN) concentration.

B. Mean concentration of total nitrogen and dissolved nitrogen of the lake and river sampling sites. Vertical bars indicate ± 1 S E.

FIG 4.18 TN & DN


A
3·50
2·50
1·50
0·50
mg l⁻¹
TN.
DN.
J
A
S
O
N
D
J
F
M
1988
MONTH
1989
B
2·0
1·0
mg l⁻¹
TN
DN
R1
R2
R3
R4
L1
L2
L3
L4
L5
L6
L7
L8
SITE

4.10.5 Total nitrogen: total phosphorus ratio (N:P)

The N:P ratio was computed for the lake from the total nitrogen and total phosphorus results. Over the study period, the mean lake N:P ratio varied between 4.3 to 15.9 (Fig. 4.19 A). The mean N:P ratio of the different sampling sites ranged from 10.0 to 12.8 (Fig. 4.19 B). Overall, the mean lake N:P ratio was computed to be 11.4.

4.11 SOLUBLE REACTIVE SILICA (AS SiO_3)

Mean SiO_3 concentration at the different sampling sites (Fig. 4.20) showed that the difference between the lake and river sampling sites was not very pronounced. In the lake sites, SiO_3 concentration ranged from 23.1 (L_7) to 29.8 (L_4) mg l^{-1} and in the rivers 27.4 (R_1) to 32.9 (R_3) mg l^{-1} suggesting that the rivers had slightly higher values than the lakes.

4.12 CHLOROPHYLL *a*

Chlorophyll *a* concentration in the lake sampling sites had a wide temporal as well as spatial variation as shown in Figs 4.21 and 4.22. The highest and the lowest values were recorded in L_1 (38 and 0.7 µg l^{-1} respectively). The mean lake concentration varied from 8.7 to 15.9 µg l^{-1} (Fig. 4.22 A). With an overall mean of 12.4 µg l^{-1}, a coefficient of variation (standard deviation/mean) of 16.2% was computed. A correlation analysis of the temporal changes in

Fig. 4.19

A. Temporal changes in the mean lake total nitrogen: total phosphorus ratio (N:P).

B. Mean total nitrogen: total phosphorus ratio of the different lake sampling sites.

FIG. 4.19 N:P RATIO

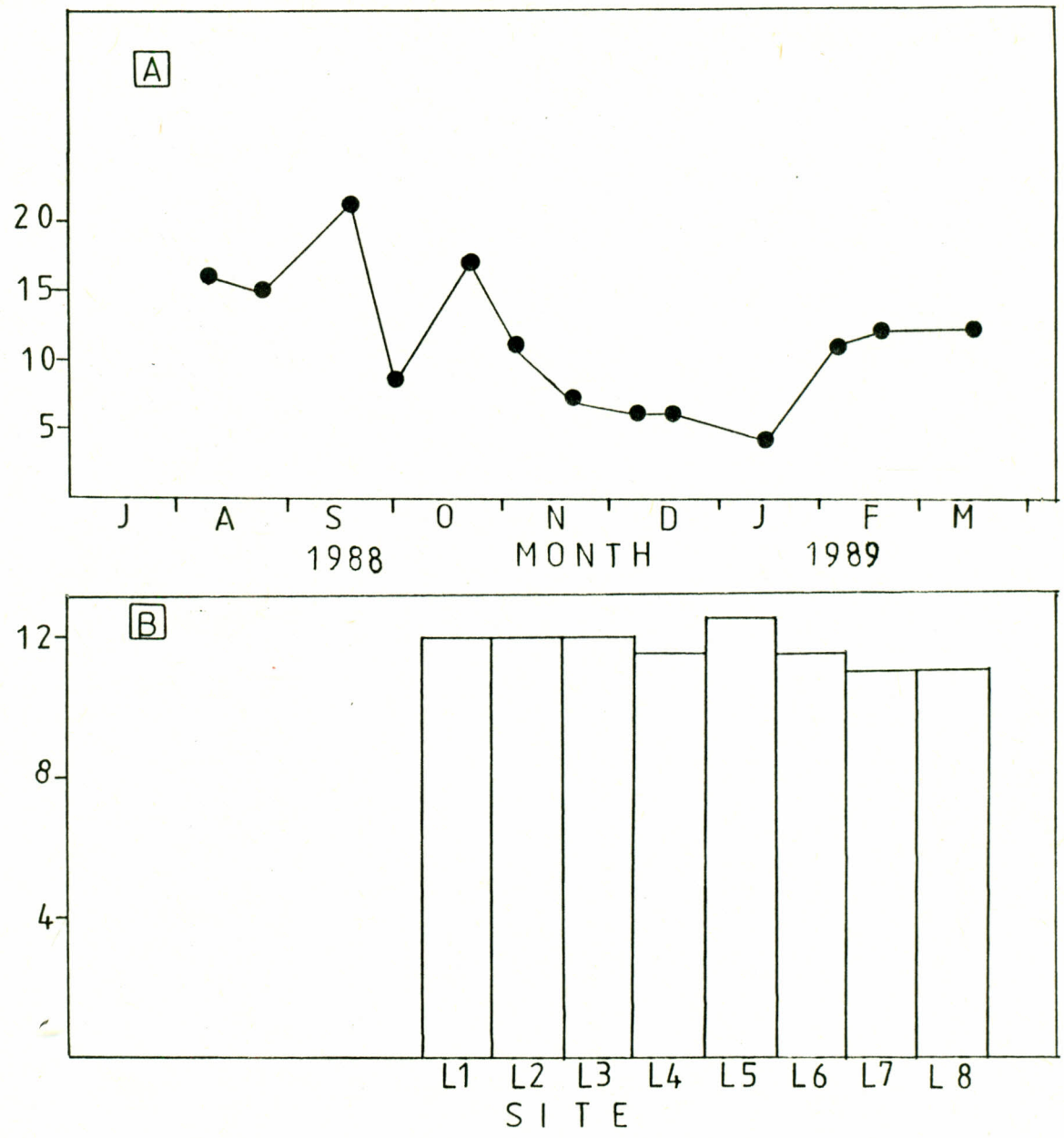


Fig. 4.20

Mean concentration of silica at the lake and river sampling sites. Vertical bars indicate ± 1 S E.

FIG. 4·20 Si O3

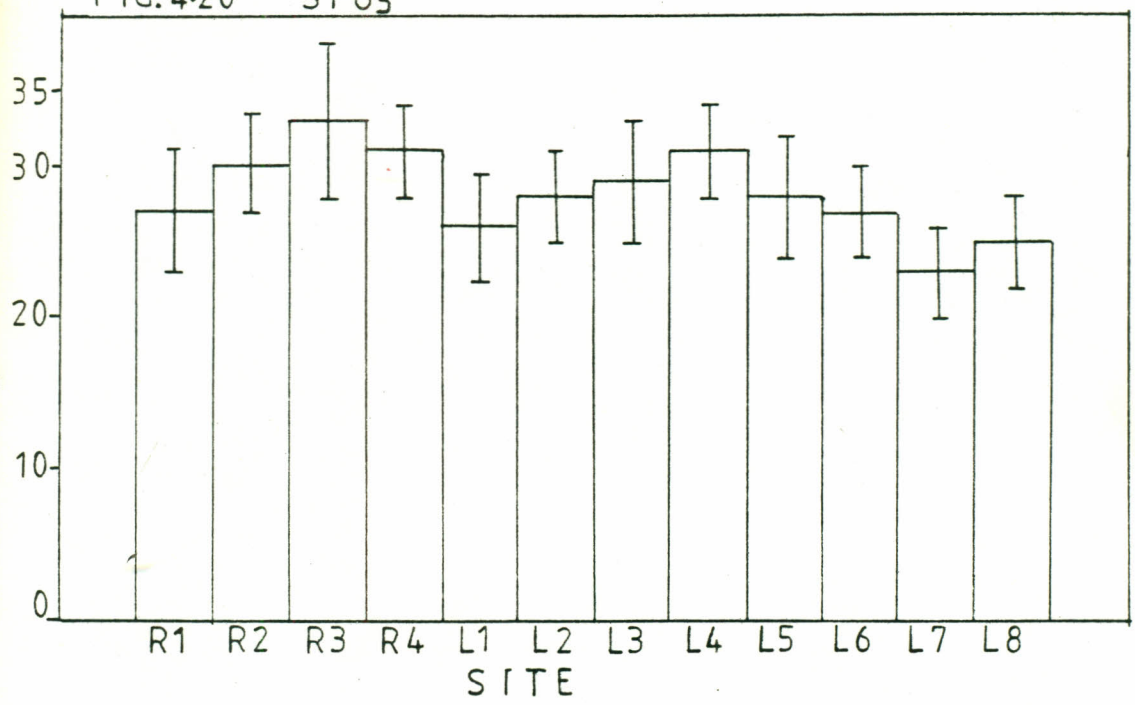


Fig. 4.21

Temporal changes in chlorophyll a concentration of some selected lake sampling sites.

FIG. 4·21

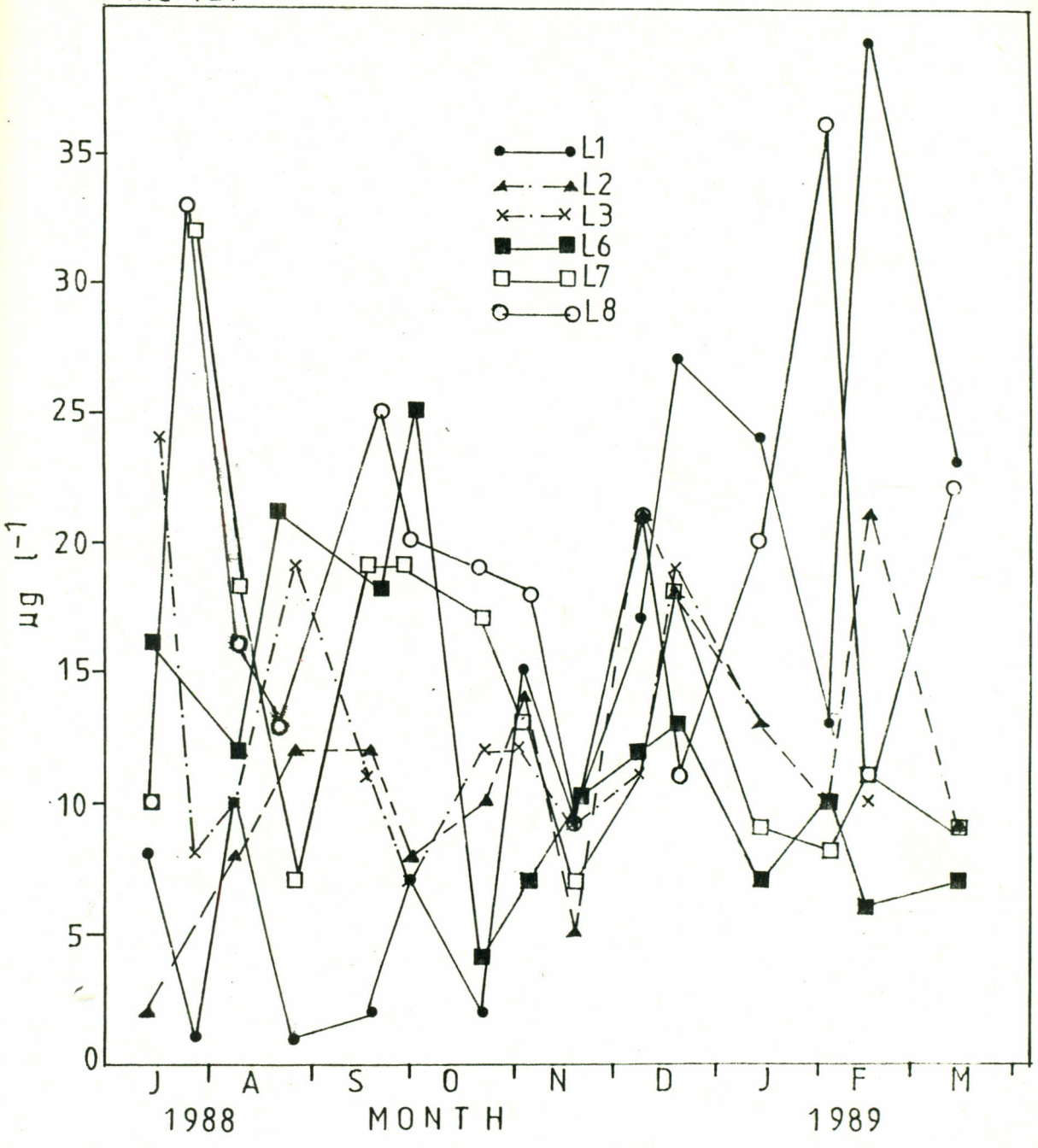
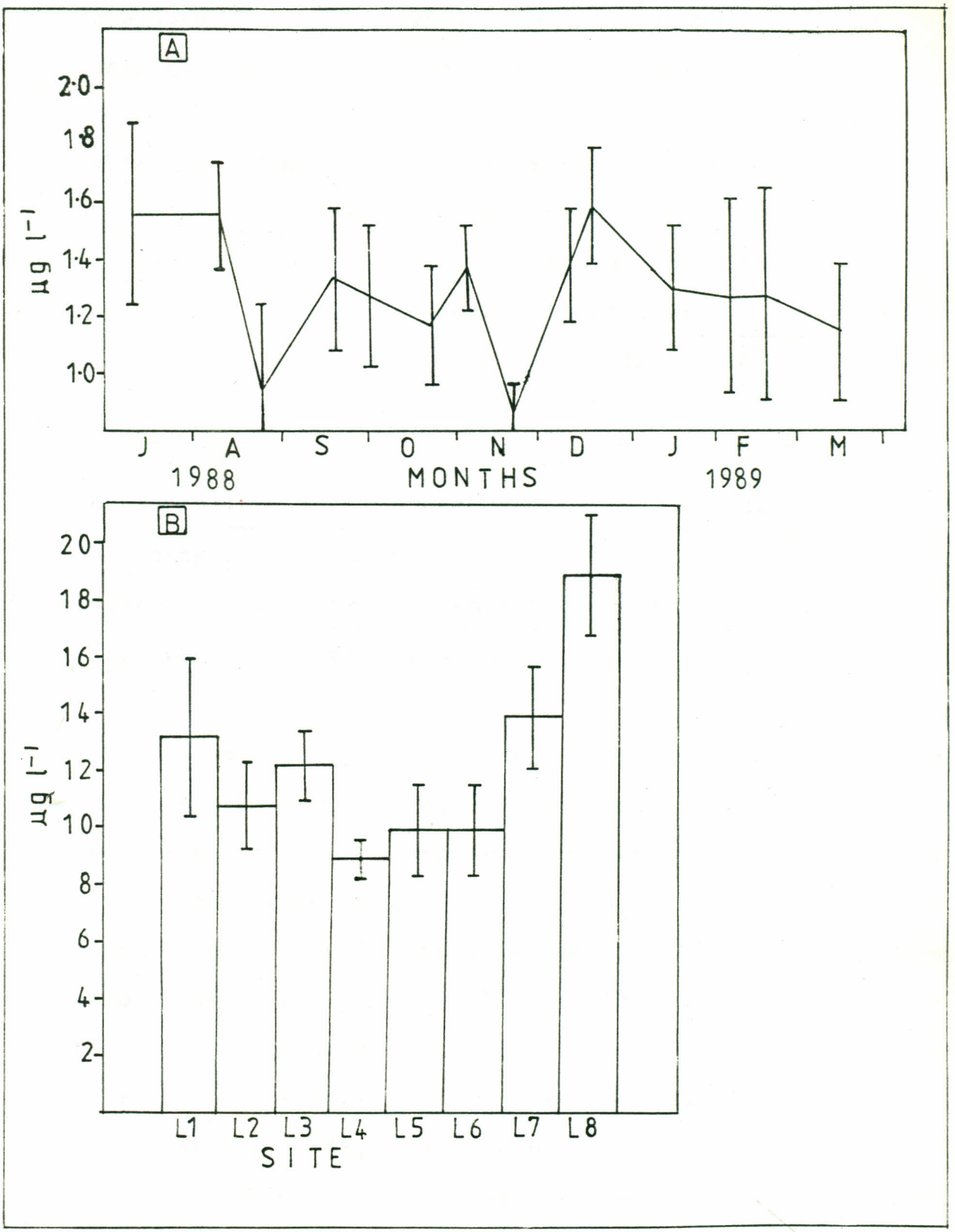

L1
L2
L3
L6
L7
L8
35
30
25
20
15
10
5
0
µg l⁻¹
J
A
S
O
N
D
J
F
M
1988
MONTH
1989

Fig. 4.22

A. Temporal changes in the mean concentration of chlorophyll *a* in the lake.

B. Mean concentration of chlorophyll *a* at the different lake sampling sites. Vertical bars indicate ± 1 S E.

FIG. 4·22 Chlorophyll a



chlorophyll a to; total phosphorus, total nitrogen, nitrogen: phosphorus ratio and total alkalinity showed an absence of a significant correlation at P=0.05 (Table 4.4).

Table 4.4 Summary of the correlation between the temporal changes in chlorophyll a concentration of the lake and changes in; total phosphorus, total nitrogen, nitrogen: phosphorus ratio, and alkalinity.

Correlation	r	t	p
Chlorophyll a: Total phosphorus	0.49	1.86	>0.05
Chlorophyll a: Total nitrogen	0.26	0.89	>0.05
Chlorophyll a: Nitrogen: phosphorus ratio	0.01	0.02	>0.05
Chlorophyll a: Total alkalinity	0.31	1.06	>0.05

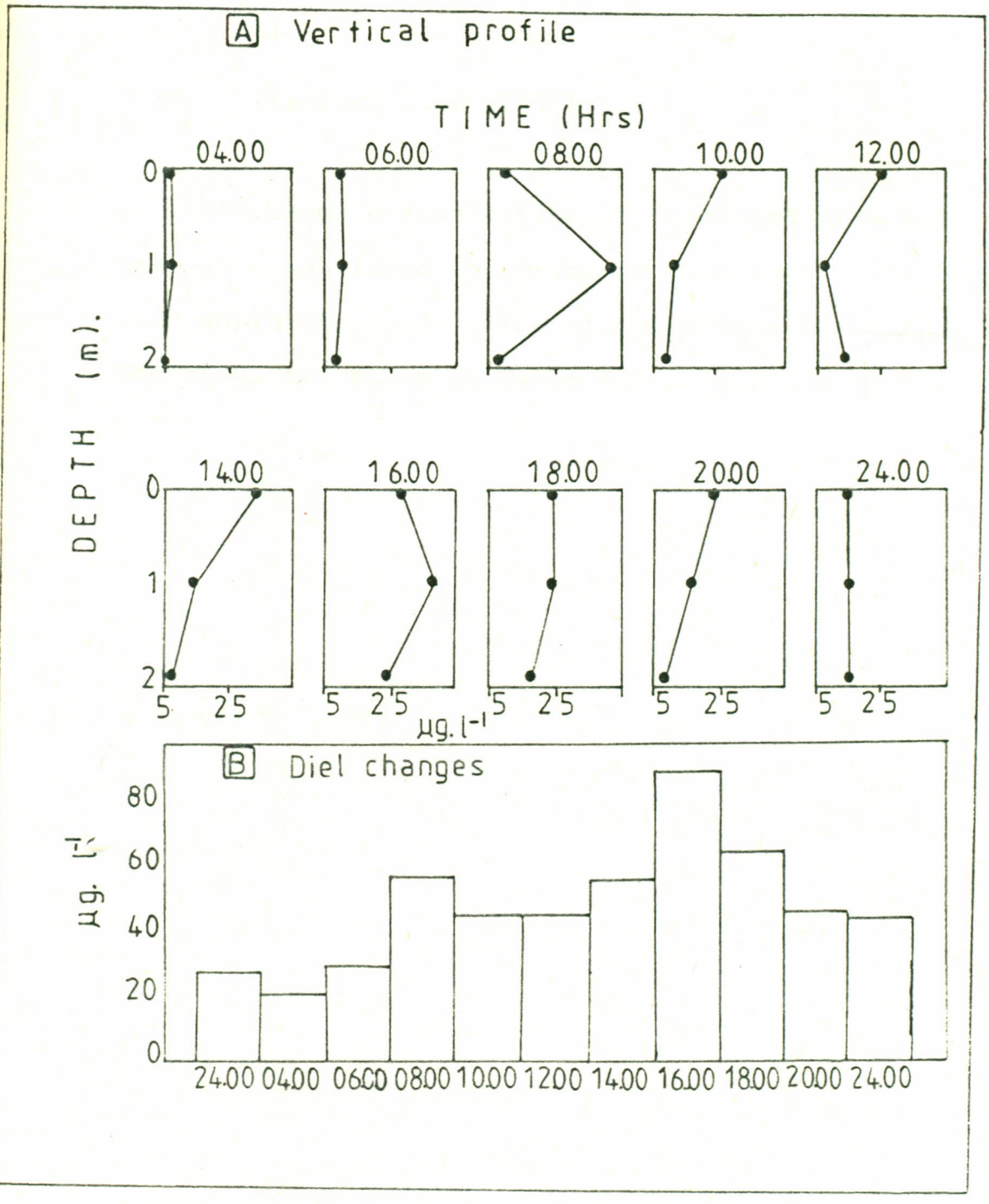
The variation in the mean concentration of chlorophyll a in the lake sampling sites is given in Fig. 4.22 B. From these results, it can be seen that the peripheral sampling sites, which were shallower (Table 4.3), had higher concentration of chlorophyll a than the other sites. They also showed a wider temporal fluctuation pattern. This fluctuation was most distinct in L_1 and L_8 which are close to river mouths (Fig. 3.1). Vertical measurement of chlorophyll a during the 24 hour study showed that the diel vertical distribution of algae was very variable (Fig. 4.23 A). Summing up the chlorophyll a concentrations of the surface water, 1.0 metre depth and 2.0 metre depth, and plotting the diel distribution of their sums (Fig. 4.23 B),

Fig. 4.23

A. Vertical distribution of chlorophyll *a* concentration in the lake over a 24 hour period as obtained on 10th March 1989.

B. Diel changes in the sum of chlorophyll *a* concentration at 0.0, 1.0 and 2.0 m down the water column as obtained on the above given date.

FIG. 4.23 Chlorophyll a



further evidence of the wide diurnal variation is observable.

4.13 PLANKTON COMPOSITION

Microscopic examination of fresh and preserved samples established the presence of a number phytoplankton and zooplankton taxa. The plankton taxa identified during the study are given in Table 4.5.

Table 4.5. The plankton composition of Lake Baringo. The species list was drawn from the analyses carried out during the study period (July 1988 to March 1989).

PHYTOPLANKTON	
Chlorophyta	Cyanophyta
Cosmarium sp.	Microcystis aeruginosa
Ankistrodesmus sp.	Pseudanabaena catenata
Oocystis sp.	Anabaena sp.
Botryococcus braunii	Merismopedia sp
Pediastrum sp.	
Scenedesmus sp.	Chrysophyta
Selenastrum sp.	Nitzschia sp
	Melosira sp.
Euglenophyta	
Euglena sp.	
ZOOPLANKTON	
Rotifera	Copepoda
Keratella sp.	Mesocyclops sp.
Brachionus sp.	

The phytoplankton assemblage in Lake Baringo was dominated by the coccoid cyanophyte Microcystis aeruginosa. Two other very common species were Pseudanabaena catenata and Nitzschia sp. These last two species appeared to be epiphytic on the mucilagenous coat of M. aeruginosa and hence the three species were closely associated. Temporal changes in the density of these species is presented in Section 4.14. Some species present at the beginning of the study (July, 1988) later become undetectable. Some species similarly not detected at the start of the study were later present. The concentration of these algal species was too low to allow for reliable quantitative estimation of their temporal changes. Botryococcus braunii, a green alga, was present at the start of the study period (July, 1988). By the end of September, however, it was very rare and by December, undetectable. Starting from September to the end of the study period, Anabaena sp., Scenedesmus sp. and Ankistrodesmus sp. became quite common. The other algal species included in Table 4.5 were so rare that it was not possible to detect whether they exhibit any temporal changes.

The most common Zooplankton species were Mesocyclops sp. and Keratella sp. In general, the density of the zooplankton species in the lake sampling sites was very low.

4.14 PHYTOPLANKTON DENSITY

Microscopic enumeration of the three most common phytoplankton species showed that the mean lake counts fluctuated greatly over time without any distinct temporal pattern of change (Fig. 4.24). Over time, these three species showed little variation in their relative proportions, perhaps owing to their association (Section 4.13). The algae in the lake normally collects on the lake surface during calm weather conditions. Gentle wind breezes at later hours pushes these algae to the leeward sections of the lake resulting in the formation of dense green patches of algae.

4.15 PHYTOPLANKTON PHOTOSYNTHETIC ACTIVITY

During the 24 hour study period (Section 3.6.2) the phytoplankton photosynthetic rate was estimated from the rates of oxygen release into the water. The vertical distribution of photosynthetic activity at different hours of the day are presented in Fig. 4.25 A. An areal photosynthetic rate of 3.8 g O_2 m^{-2} day^{-1} was calculated by planimetry of the depth profile (Fig. 4.25 B).

Fig. 4.24

Temporal changes in;

A. the mean lake counts of the three dominant algal species and,

B. the percentage composition of these three species,

1. Nitzschia sp.
2. Pseudanabaena catenata
3. Microcystis aeruginosa.

Vertical bars indicate ± 1 S E.

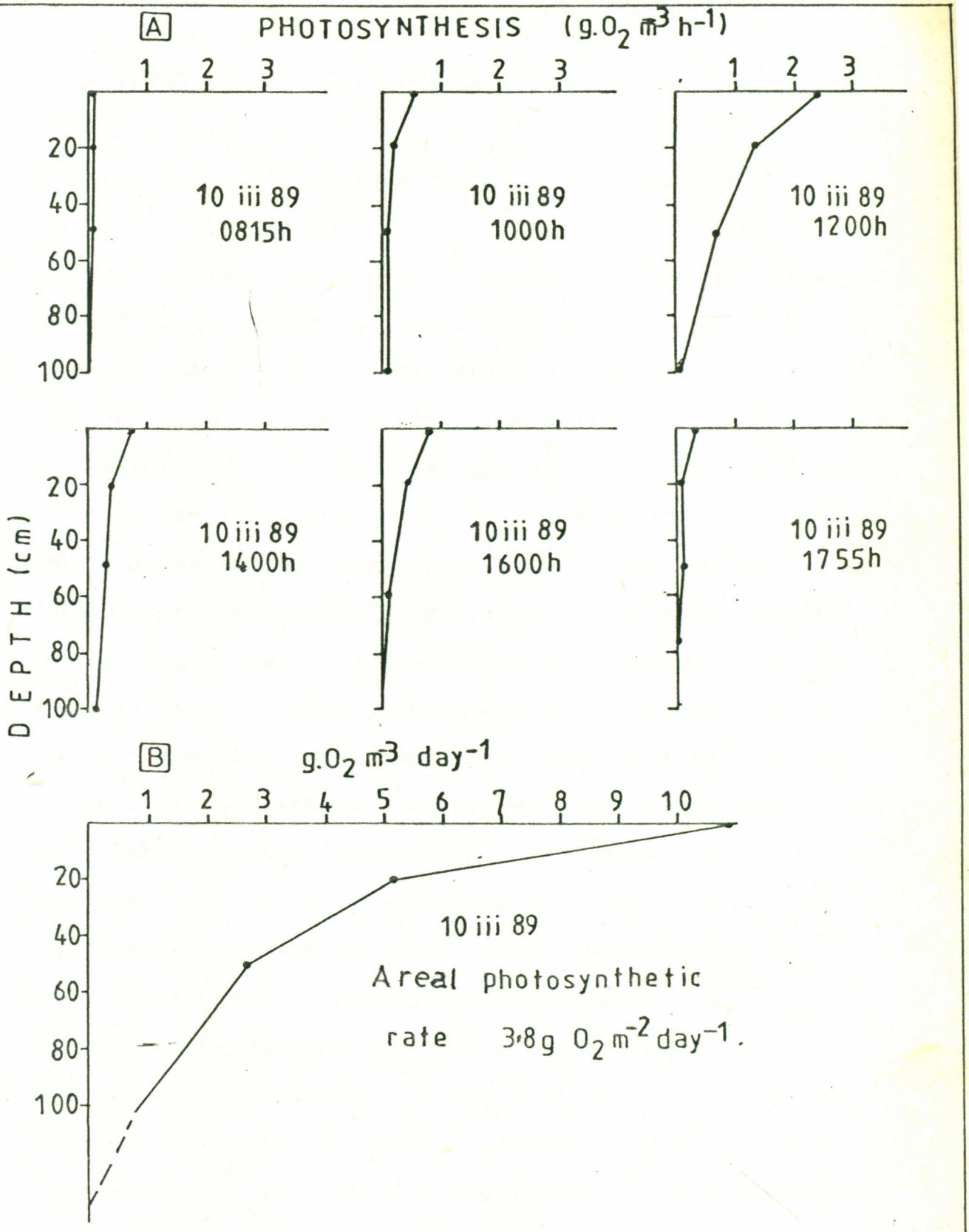
Fig. 4.25

A. Photosynthetic profiles in Lake Baringo as obtained at different hours of the day. Time at mid-point of incubation is listed below date.

B. The whole day's photosynthetic profile of the lake.

By planimetry of the depth profile given in B above, an areal photosynthetic rate of 3.8 g O_2 m^{-2} day^{-1} was obtained.

FIG 4·25


A
PHOTOSYNTHESIS (g.O2 m-3 h-1)
1 2 3
20
40
60
80
100
10 iii 89
0815h
10 iii 89
1000h
10 iii 89
1200h
10 iii 89
1400h
10 iii 89
1600h
10 iii 89
1755h
DEPTH (cm)
B
g.O2 m-3 day-1
1 2 3 4 5 6 7 8 9 10
10 iii 89
Areal photosynthetic
rate 3·8g O2 m-2 day-1.

CHAPTER 5. DISCUSSION AND CONCLUSION

5.1 PHYSICOCHEMICAL PROPERTIES

5.1.1 Physical conditions

The diurnal vertical pattern of temperature change in Lake Baringo (Fig. 4.3) shows that the lake has a thermal stratification pattern that follows a 24 hour cycle. This property of the lake was first described by Beadle (1932). A similar stratification pattern has been described for Lake George (Ganf and Horne, 1975). A diurnal stratification pattern has in fact been noted by a number of workers to be a general characteristic feature of tropical shallow lakes (e.g.: Beadle, 1974; Melack and Kilham, 1974 and Talling et al., 1973). There are, however, some isolated cases of shallow lakes that show distinct seasonal stratification patterns (Howard-Williams and Ganf, 1981). Such lakes are usually sheltered from wind effects. Over the day, Lake Baringo is exposed to changing wind patterns but the predominant ones are the westerlies and the easterlies. A calm period usually sets in around the middle of the day before the change of wind direction. During this period, thermal stratification sets in. Wind breezes and nocturnal convective cooling disrupts the lake's thermal stratification bringing about an isothermal condition.

The turbidity of Lake Baringo (mean Secchi depth 0.05 m) is created by suspended particles. These particles are mainly silt suspensoids. The high silt input by inflowing rivers coupled with the distinctive feature of shallow lakes, of the resuspension of the bottom sediments by wind turbulence, and the stability of clay particles in suspension have combined to bring about a condition of high turbidity in Lake Baringo. The conditions of high turbidity have been shown to affect a variety of physical, chemical and biological properties of aquatic ecosystems (e.g. Hart, 1986).

5.1.2 Conductivity and alkalinity

According to Beadle (1974), the classification of tropical lakes by Talling and Talling (1965) based on conductivity (Section 1.2.3.2.2) cannot be justified on biological grounds. He alternatively proceeds to distinguish three categories of lakes also based on the conductivity (i.e. salinity) range within which they fall into. The approximate ranges are, first K_{20} below about 40 $\mu S\ cm^{-1}$ (salinity = 0.035 per thousand), second K_{20} between 40 - 6,000 $\mu S\ cm^{-1}$ (salinity = 0.035 - 5 per thousand) and third, K_{20} above about 6,000 $\mu S\ cm^{-1}$ (salinity $\geq$ 5 per thousand). The three categories are, according to him, distinct biologically. He, however, admits that there are limitations imposed by such an arbitrary classification and that other

factors could play a greater role. The second category includes the great majority of lakes in the normal 'freshwater' range. Lake Baringo with a mean conductivity of 790 $\mu S\ cm^{-1}$ (Table 4.2) similarly falls in this category. The strong inverse correlation between both alkalinity and conductivity, and lake level (Table 4.1) confirms the dilution effects of river discharge and surface run-off. Although the temporal variation in lake conductivity is high when compared to other freshwater lakes such as Lake Naivasha (Njuguna, 1982), it is much smaller than in the case of saline lakes (Howard-Williams and Ganf, 1981). Though no actual measures of river volume were made, an inverse relationship between river volume and conductivity or alkalinity (Sections 4.5 and 4.8) was evident for the rivers draining into Lake Baringo. The existence of an inverse relationship between conductivity and river discharge volume has been reported to occur in other African rivers (Njuguna, 1982 and Njuguna and Gaudet, 1979). The increasing river conductivity and alkalinity on moving eastwards from R_4 through R_3 and R_2 to R_1 (Table 4.3 and Fig 3.2) is probably due to a differential influence of hot spring recharge and the geological variation of the rivers' watersheds.

The hot springs on Kokwe Island have been reported to have a high chloride content indicating a deep source at about 180° C (Baringo-Laikipia geological map, 1: 250,000. Topographic sheet NA-37-13, 1987). This observation must have been based on the high conductivity hot springs. The

low conductivity ones are probably superficial in origin as evidenced by their increased discharge after the rains. They probably get heated by contact with steam springs.

The strong positive correlation between conductivity and alkalinity (Table 4.1) observed in Lake Baringo is a familiar feature of East and Central Africa Rift Valley lakes (Talling and Talling, 1965). This phenomenon is attributable to the predominance of carbonates and bicarbonates among the ions. Being topographically endorheic, having underground saline inflows (hot springs) and also receiving salts from the rivers, it is likely that Lake Baringo has some means of regulating its freshness. Seepage outflow from the northern end has long been strongly suspected to be one such mechanism (Section 2.3).

5.1.3 pH

The well buffered nature of Lake Baringo is evident from the small temporal and diurnal variation in pH (Fig. 4.9). L1 (Fig. 3.1), which is close to the area where most of the inflowing rivers empty into the lake, and the rivers themselves, showed a wider temporal pH fluctuation owing to the dilution effects of rain water.

5.1.4 Dissolved Oxygen (DO)

The relatively low levels of DO measured in L1 (Fig. 4.10 A) at some periods during the study can probably be

attributed to the deoxygenating influence of organic allochthonous material brought in by inflowing river water from the swamp. Diurnal vertical measurements of DO concentration showed a slight surface increase during the day and a more - or -less uniform distribution during the night (Section 4.7). The increase during the day is attributable to increased DO release by photosynthesis and the decreased rate of circulation once stratification sets in. Continuous vertical mixing in the lake does not, however, allow for wide changes in DO concentration at all depths hence the orthograde curves of DO distribution down the water column (Fig. 4.11 B). A typical feature of the plankton-rich tropical African lakes is that large changes in DO occur over short periods of time (Howard-Williams and Ganf, 1981). Data from lakes Chad, Naivasha, Chilwa and George all show that DO levels throughout the entire water column can change from anaerobic to supersaturated within a day (e.g. Kalk et al., 1979 and Leveque, 1979). This condition was absent in Lake Baringo, possibly due to the fact that the stratification formed is normally weak and usually interrupted by complete vertical mixing, and the much lower photosynthetic rate in the lake (Section 5.2.4).

5.1.5 Phosphorus

In general, phosphorus is one of the more common phytoplankton growth-limiting elements. This is due to the geochemical shortage of phosphorus in many drainage basins together with the lack of a phosphorus equivalent to

nitrogen fixation (Goldman and Horne, 1983). The East African lakes, especially the saline ones, have been noted to have an extremely high concentration of orthophosphate (Hecky and Kilham, 1973). High concentration occurs in regions where soils are geologically unstable or ground cover absent. Erosion in the region brings about the removal of clay soils with the orthophosphate sorbed onto it. Compared to other East African shallow freshwater Rift Valley lakes (Table 5.1), Lake Baringo has high phosphorus levels. This may be attributed to the geological instability of the drainage basin and the serious erosion prevalent in the general area (Otieno and Rowntree, 1986). The absence of a distinct seasonal variation in the concentration of phosphorus (Fig. 4.14) may possibly be due to the modifying character of clay particles in suspension or in the lake sediments. It has been reported that when clay particles are resuspended, particularly in a mature lake, they will either release exchangeable phosphorus into the water or sorb the phosphorus depending on the relative proportion in the water to that already sorbed (Howard - Williams and Ganf, 1981; Goldman and Horne, 1983).

5.1.6 Nitrogen

Among the factors that possibly regulate nitrogen levels in Lake Baringo are; atmospheric precipitation, river discharge, surface run-off, seepage inflows, seepage outflows, nitrogen fixation, lake level changes, sedimentation, denitrification and the introduction of

Table 5.1 Some physical and chemical properties of some East African shallow and freshwater lakes

	LAKES			
	Baringo	Naivasha	George	Oloiden
Mean depth m	5.0 (a)	4.6 (c)	2.4 (d)	11.1 (c)
Secchi depth m	0.05 (a)	1.23 (b)		0.60 (b)
pH range	8.0 - 9.2(a)	7.3 - 8.6(b)		8.8 - 9.1(b)
Conductivity range $\mu S\ cm^{-1}$	690-1170	300 - 350 (b)	200 (d)	645-760 (b)
Total alkalinity meq l^{-1}	6.5 (a)	2.66 (b)	1.8 (d)	7.2 (b)
Orthophosphate mg l^{-1}	0.114 (a)			
Total phosphorus mg l^{-1}	0.140 (a)	0.056 (b)		0.045 (b)
Total nitrogen mg l^{-1}	1.59 (a)	1.43 (b)		2.60 (b)
N: P ratio	11.3 (a)	28.0 (b)		60.0 (b)

Sources

a - Present Study
b - Njuguna (1982)
c - Peters & MacIntyre (1981)
d - Beadle (1974)

allochthonous nitrogen by animals. The Lake Baringo area has many crocodiles, hippopotami and diverse avifauna. These wild animals plus the domestic ones that come to drink the lake water introduce a lot of organic matter into the lake hence influencing the nutrient balance.

The low nitrate nitrogen concentration in the lake compared to orthophosphate phosphorus (Table 4.3) may suggest that nitrates occur in limiting quantities, a phenomenon that has been reported for warm climates where phosphorus and silicon are present in relatively large quantities (Viner et al. 1981). This information is not, however, enough to draw conclusions on the limiting role of nitrates as other factors such as input fluxes from rivers, recycling rate and precipitation input may provide sufficient nitrates.

The actual amount of ammonia present in any aquatic system, at any one, time will depend on the balance between animal excretory rates, plant uptake and bacterial oxidation. This means that at any sampling site the concentration of ammonia nitrogen will depend on the relative proportion between the plants that assimilate it and the animals that excrete it. This relationship probably serves to explain the wide fluctuation in the levels of ammonia nitrogen in Lake Baringo (Fig. 4.16).

Nitrite sources are mainly bacterial oxidation of organic matter and denitrification. Under conditions of

complete and constant mixing, most nitrites are converted to nitrates, hence the low levels in Lake Baringo are possibly due to the constant and complete mixing of the lake.

The total nitrogen content of the lake is much higher than the inorganic forms of nitrogen. This is a common experience in tropical African lakes with high algal biomass (Lemoalle et al., 1981) and suggests a high loading rate of the required inorganic nitrogen compounds. The condition of high algal biomass does not apply to Lake Baringo which has high levels of total nitrogen compared to Lake Naivasha (Table 5.1) but lower phytoplankton biomass as chlorophyll a (Table 5.2)

5.1.7 Nitrogen phosphorus ratio (N:P)

The evolution of nutrient ratios involve a complex series of interrelated biological, geological and physical processes which include photosynthesis, nitrogen fixation, alkalinity, nutrient concentration, nutrient cycling, water renewal rates and turbulence (Schindler, 1978). Sakamoto (1966) has established that N:P ratios of 10 to 17 indicates that phosphorus, nitrogen or both may limit algal growth. Higher ratios indicates phosphorus limitation and lower ratios nitrogen limitation. With a mean N:P ratio of 11.6 (Section 4.10.5), and high levels of soluble reactive phosphorus and total nitrogen (Fig. 5.1), Lake Baringo appears not to be limited by either nitrogen or phosphorus.

The relatively low biomass may indicate that other factors such as light penetration (Section 5.1.1) will limit algal growth.

5.1.8 Silica

In lakes, silica is an important nutrient for the diatoms (Goldman and Horne, 1983). Some other algae and animals also require silicon in small quantities (Goldman and Horne, 1983). The source of silica in the East African Rift Valley lakes is discussed in Section 1.2.1.3. The high levels of silica in Lake Baringo (Section 4.11) implies that the lake has a potential for supporting a greater diatom biomass. Other factors, however, probably play the limiting role (Section 5.2.1). The higher concentration of silica in the inflowing rivers suggests that the source of lake silica is river inflow.

5.2 PHYTOPLANKTON AND PHYSICOCHEMICAL RELATIONS

5.2.1 Interaction with the physical conditions

The phytoplankton of Lake Baringo is dominated by the coccoid cyanophyte Microcystis aeruginosa (Section 4.13). This alga has also been reported to dominate the waters of Lake Oloiden (Njuguna, 1982), where it accounts for over 90% of the phytoplankton biomass, and Lake George (Ganf, 1973). This alga has the ability to regulate its buoyancy with gas vacuoles (Dinsdale and Walsby, 1972). The

vacuolation process occurs under conditions of low light intensity and this results in the rise of M. aeruginosa to the surface. The low light penetration in Lake Baringo (Table 5.1) means that only those species that can maintain themselves at the surface, or immediately find their way to the photic zone after wind disturbance, can survive well in the lake. The other common species, Pseudanabaena catenata and Nitzschia sp. appear to be epiphytic on the mucilagenous coat of M. aeruginosa. The other less common algal species (Table 4.5), with the exception of Botryococcus braunii, rely heavily on the water turbulence for resuspension to the photic zone. B. braunii contains oil droplets which reduce its cell density to the extent that the colonies remain afloat on the water surface (Prescott, 1968). The high water turbidity and the dominance of M. aeruginosa possibly contribute to the low zooplankton density in the open lake water. Increasing turbidity has been reported to interfere with the feeding of the zooplankton (Hart, 1986). Similarly, algal species such as Microcystis and Anabaena are inedible or inferior food items for herbivorous zooplankton (Kerfoot, 1980).

Chlorophyll a measurements and phytoplankton density results (Table 4.2) show a wide variation over time and in space (Figs 4.21 to 4.24) This wide variation can be attributed to the patchy distribution of the dominant algae. The patchy distribution is wind induced and is evident on the lake surface under calm weather conditions. Both windy and calm weather conditions alternate over the

day in Lake Baringo. Consequently, when stratification sets in, dense patches of algae accumulate on the leeward sections of the lake notably the swamps. This makes the estimation of the overall lake biomass very difficult. At no one time during the study period was there an accumulation of algal patches in any of the sampling sites. Hence the estimates of phytoplankton biomass (as chlorophyll a) and the density of the dominant algae (Table 4.2) may be underestimates of the actual lake levels. The high levels of chlorophyll a in the peripheral sampling sites (Section 4.12) may be due to their shallowness. Since water samples for analysis were integrated (Section 3.2) it is expected that, other factors being constant, the deeper the sampling site, the lower the chlorophyll a concentration. The wide fluctuation in chlorophyll a concentration of L_1 (Section 4.12) can be attributed to the wind and river influence. Wind action especially when blowing from the north increases the algal content of L_1 (Fig. 3.1). Increased river discharge similarly creates surface currents that pushes the algae northwards hence depressing the algal concentration at the site (L_1).

5.2.2 Interaction with total alkalinity and conductivity

The absence of temporal correlation between both alkalinity and conductivity and changes in chlorophyll a concentration (Table 4.4) suggests that the changes in conductivity and alkalinity are not sufficiently great to alter the phytoplankton biomass of the lake. The fact that

chlorophyll a concentration does not exhibit a distinct temporal pattern of change as in the case of conductivity and alkalinity is further evidenced by its relatively low coefficient of variation (16.2 %, see Section 4.12). According to Melack's grouping of African lakes based on the pattern of seasonal changes (Section 1.2.2), Lake Baringo falls in the second group (pattern B) with a coefficient of variation less that 20%. This group shows little or no seasonality in phytoplankton biomass and often diel changes exceeds or equals the seasonal changes. Lake Baringo, with a patchy algal distribution, makes the detection of unidirectional change in biomass difficult as it may be masked by the more pronounced patchiness. Though no temporal changes were detected in the case of phytoplankton biomass and the density of the dominant algae, the disappearance of B. braunii and the later on appearance of Anabaena sp., Melosira sp. and others (Section 4.13) suggests that there may be some qualitative changes that were not detectable by quantitative means. It is, however, difficult at this stage to suggest that changes in conductivity and alkalinity were responsible.

5.2.3 Nutrient phytoplankton interaction

Nutrient availability is one of the important factors that control the phytoplankton biomass in tropical African freshwater lakes. Compared to other freshwater lakes of East Africa, Lake Baringo has relatively high nutrient levels (Table 5.1) but, in contrast, the phytoplankton

biomass as chlorophyll a is much lower (Table 5.2). The reasonably high nutrient levels in Lake Baringo means that nutrient limitation to algal growth may not be common to the lake, (Section 5.1.7). Sakamoto (1966) has reported that M. aeruginosa is characteristic of lakes with high nitrogen content and that its blooms are associated with high N:P ratios in lakes. The total nitrogen concentration of Lake Baringo and the N:P ratio when compared with other M. aeruginosa dominated freshwater lakes such as Lake Oloiden (Table 5.1) are lower, hence the dominance of M. aeruginosa is probably attributable to other factors.

5.2.4 Phytoplankton primary production

Phytoplankton production is one of the principle determinants of the trophic structure of an aquatic ecosystem. Owing to the lack of resources, the measurement of the phytoplankton primary production rate was only carried out once in Lake Baringo. Since the dominant algae of Lake Baringo exhibits a patchy distribution, variation in the rates of photosynthesis over the day may be partly due to the changing concentration of phytoplankton and not wholly the results of changes in light intensity. The algal patches are undoubtedly regions of very high rates of primary production as evidenced by bubbles of oxygen escaping into the atmosphere from them. Compared to other freshwater lakes in East Africa, the depth distribution of photosynthetic rates in Lake Baringo do not exhibit the familiar feature of subsurface maxima (Melack, 1979a) and

Table 5.2 Phytoplankton biomass and production rates in some shallow freshwater East African lakes.

	LAKES			
	Baringo	Naivasha	George	Oloiden
Chlorophyll a $\mu g\ l^{-1}$	12.4 (a)	21.3 (c)	250 (f)	36.3 (c)
Areal net photosynthesis $g\ m^{-2}\ d^{-1}$	3.8 (a)	9.2 (c)	11.2 (c)	7.9 (c)
Fish yield $kg\ ha^{-1}\ yr^{-1}$	36.7 (b)	<4 (d)	152. (e)	

Sources
a - Present study
b - Kenya Ministry of Planning (1985)
c - Njuguna (1982)
d - Melack (1979 a)
e - Melack (1976 b)
f - Ganf and Viner (1973)

compares with the depth distribution of some alkaline lakes such as Nakuru and Elmenteita which have surface maxima (Melack and Kilham, 1974). This is probably due to the high light attenuation in the lake (Section 4.4). The areal daily production rate in Lake Baringo is less than that of most other East African freshwater lakes (Table 5.2). Much lower values for Lake Baringo were reported by Kallqvist (Section 1.2.3.2.3). As the nutrient levels in the lake are reasonably high, and the light attenuation also high (Section 5.1.1), it is possible that the main limiting factor to primary production in the Lake Baringo is the condition of high turbidity brought about the excessive silt in suspension. There is, however, a wide difference between the Secchi depth of the lake (Section 5.1.1) and the depth to which photosynthesis can occur. For most natural waters, the photic depth is usually 2 to 5 times the Secchi disc visibility depth (Lind, 1979). Lake Baringo with a mean Secchi depth of 0.05 m, had photosynthesis occuring up to a depth of 1.0 m (Fig. 4.25 A), a condition also reported by Beadle (1932) and Kallqvist (1980). This suggests that the Secchi depth measurement in turbid lakes may not give a good measure of the penetration of photosynthetically active radiation as photosynthesis occurs at a much deeper depth than that predicted by the Secchi depth measurements.

A positive correlation between fish yields and primary production has been observed for a number of tropical African lakes (Melack, 1976b). This study did not include

Lake Baringo which despite the lower rate of primary production has a fairly high fish yield especially when compared to lakes such as Lake Naivasha which has a higher primary production rate (Table 5.2). This condition of high fish yield and low primary production rates suggests that the lake's fishery is not a function of phytoplankton primary production. Ocassional studies carried out by the Fisheries Department (Pers. Comm. Baringo District Fisheries Officer, 1989) have established that the marginal areas support a higher fish biomass and a greater benthic faunal diversity than the open lake. The difference in the fish yields of Lakes Baringo and Naivasha (Table 5.2) should, however, be treated with caution since Lake Naivasha is near to an urban centre and may have suffered greater fishing pressures than Lake Baringo. Though the fringing vegetation of Lake Baringo has not been extensively studied, the crucial role that marginal areas play in controlling the overall fish yield of some East and Central African lakes has been reported e.g. in Lakes Chilwa (Kalk et al., 1979) and George (Burgis et al., 1973) These works have stressed that the marginal areas of shallow lakes are of fundamental importance to the overall lake metabolism.

5.3 CONCLUSIONS

From the results and the discussion given above, the following conclusions can be drawn with respect to the phytoplankton and physicochemical dynamics of Lake Baringo.

i) The lake exhibits a diurnal mixing pattern. Mixing is

mainly wind induced and aided by nocturnal convective cooling.

ii) A combination of the lake's shallowness, the introduction of large quantities of silt by inflowing rivers and the resuspension of silt by wind induced waves and currents results in a condition of high turbidity in the lake. This results in high light attenuation through the water column.

iii) The lake is well buffered. Resistance to pH change is a consequence of the predominance of bicarbonates and carbonates among the anions.

iv) As the lake is topographically endorheic and receives saline inflows, it must therefore have some means of regulating its freshness. Seepage outflow is strongly suspected to be one such mechanism.

v) The strong positive correlation between the temporal changes in conductivity and alkalinity confirms the predominance of carbonates and bicarbonates in the lake.

vi) Regular wind disturbance ensures that the lake is well oxygenated at all times.

vii) High levels of soluble reactive phosphorus can possibly be attributed to the high loading rate from the

lake's basin.

viii) Relatively high levels of total nitrogen and low concentrations of nitrates implies that the lake possibly has a high nitrate loading rate.

ix) The phytoplankton community in the lake is dominated by the coccoid cyanophyte, Microcystis aeruginosa. The success of this alga is possibly due to the ability to regulate its buoyancy. The other two common species, Pseudanabaena catenata and Nitzschia sp. appear to be epiphytic on the mucilagenous wall of M. aeruginosa.

x) A characteristic feature of the dominant phytoplankton is a patchy distribution which is wind induced. This patchy distribution results in wide temporal, spatial and diel variation in chlorophyll a concentration.

xii) The lake did not exhibit a distinct temporal pattern of change in phytoplankton biomass (as chlorophyll a). The subsequent disappearance of Botryococcus braunii and the appearance of Melosira sp. and others, however, suggests that some qualitative changes did occur over time. This was possibly due to the changes in the ionic concentration of the water as evidenced by the overall decline in conductivity and alkalinity.

xi) The mean phytoplankton biomass and the photosynthetic rate in Lake Baringo is generally much lower than that of other shallow East African Rift Valley lakes. The most likely limiting factor to increased phytoplankton biomass is light. Light attenuation in the lake is very high and is mainly the result of the great amounts of silt suspensoids in the water.

xiii) The relatively high fish yields in the lake, despite the low rate of primary production, can be attributed to the important role played by the fringing vegetation which has been reported to be a high fish production area.

5.4 RECOMMENDATIONS

With increasing development in Kenya, problems of water pollution are beginning to emerge. The importance of water in the country cannot be overemphasized. Hence it is important to preserve its quantity and quality. Shallow lakes are known to be more sensitive to pollution than deep lakes hence they need urgent attention. In order to formulate appropriate management strategies and to decide on rational ways of exploiting a lake's resources, complete as possible information on its hydroclimate and biological interactions should be obtained. In Lake Baringo the following information on the lake is vital to the formulation of these strategies:

i) a greater understanding of the wind regimes over the day i.e. strength, direction and duration. The nature of wave action and currents that bring about water circulation need to be determined.

ii) precise measurement of the photic depth and its temporal changes is necessary. This can be achieved through measures of underwater penetration of photosynthetically active radiation.

iii) a quantification of the chemical and nutrient budgets of the lake is required. Chemical flux rates, nutrient loading rates and the mechanisms by which the lake regulates its freshness should be determined.

iv) detailed examination of the composition, temporal and spatial variation of the aquatic macro-organisms and micro-organisms should be carried out. This should include the determination of the mechanism by which they survive the condition of high silt content of the water.

vi) establishment of the lakes overall production dynamics. The contribution of both the marginal area and the open water should be determined.

vii) an understanding of the macrophyte ecology is required.

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APPENDIX .

APPENDIX A: Sampling dates starting from 12th July 1988 and ending on 15th March 1989. All measurements carried out in any given week are taken to represent one sampling round

		SAMPLING SITE											
	WEEK	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	R_1	R_2	R_3	R_4
1988	1	12/7	12/7	15/7	13/7	15/7	14/7	13/7	14/7	18/7	11/7	11/7	11/7
	3	27/7		27/7				24/7	24/7	24/7	19/7	20/7	20/7
	5	8/8	8/8	8/8		9/8	9.8	9.8	9/8		5/8	5/8	
	7	20/8	20/8	20/8		21/8	21/8	20/8	21/8	21/8	17/8	17/8	
	10	18/9	18/9	18/9	20/9	19/9	19/9	18/9	19/9	24/9	16/9	16/9	16/9
	12	30/9	30/9	30/9	1/10	1/10	1/10	30/9	1/10		28/9	28/9	28/9
	15	22/10	22/10	22/10	21/10	21/10	21/10	22/10	21/10	27/10	19/10	19/10	19/10
	17	3/11	3/11	3/11	5/11	5/11	5/11	3/11	5/11		1/11	1/11	1/11
	19	18/11	18/11	18/11	20/11	20/11	20/11	18/11	20/11	31/1	17/11	17/11	17/11
	22	9/12	9/12	9/12	8/12	8/12	8/12	9/12	8/12		2/12	2/12	2/12
	24	9/12	9/12	9/12	20/12	20/12	20/12	19/12	20/12		18/12	18/12	18/12
1989	27	13/1	13/1	13/1	14/1	14/1	14/1	13/1	14/1		12/1	12/1	12/1
	30	3/2	3/2	3/2	2/2	2/2	2/2	3/2	2/2		31/1	31/1	31/1
	32	15/2	15/2	15/2	14/2	14/2	14/2	15/2	14/2	13/2	13/2	13/2	13/2
	36	14/3	14/3	14/3	13/3	13/3	13/3	14/3	13/3	13/3	13/3	13/3	13/3

L_1 - L_8 Lake sampling sites

R_1 Mukutan River

R_2 Ol-Arabel River

R_3 Molo River

R_4 Perkerra River

APPENDIX B: Temporal changes in the physicochemical and biological properties of the different sampling sites. (See Appendix A for the exact dates when the different lake and river sampling sites were visited.)

B.1: Water level (mean weekly) as obtained at the Rangeland Gauging station 2 EHI located at Kampi ya Samaki)

WEEK	0	1	2	3	4	5	6	7	8	9	10	11	12	13
LEVEL(m)	1.36	1.40	1.76	1.88	2.00	2.24	2.65	2.76	2.82	2.89	2.82	2.84	2.90	2.99

WEEK	14	15	16	17	18	19	20	21	22	23	24	25	26	27
LEVEL(m)	3.07	3.10	3.10	3.11	3.10	3.09	3.09	3.06	3.01	2.91	2.86	2.81	2.83	2.83

WEEK	28	29	30	31	32	33	34	35	36
LEVEL(m)	2.88	2.85	2.82	2.88	2.86	2.84	2.83	2.74	2.70

B. 2: Electrical conductivity ($\mu S\ cm^{-1}$)

	WEEK														
SOURCE	1	3	5	7	10	12	15	17	19	22	24	27	30	32	36
R_1	340	210		310		450	490						580	620	610
R_2	240	330	190	280	280	170	280	250	320	360	350	380	410	400	515
R_3	150	120	120	130	140	180	140	210	190	190	250	330	500	300	610
R_4	120	100		80	90	100	80	100	120	130	150	150	170	155	200
L_1	1135	250	120	440	570	660	530	640		730	730	760	730	750	780
L_2	1080	800	770	510	780	680	710	680		750	750	770	760	770	80(
L_3	1145	980	970	890	790	800	730	690		730	750	770	760	770	81(
L_4	1200				800	740	680	720	740	730	740	780	740	760	79(
L_5	1200		1040	810	770	760	690	720	770	730	740	780	760	770	795
L_6	1223	1200	1150	1040	850	780	760	730	780	750	750	780	770	760	79(
L_7	1215	1150	1030	980	840	830	740	720		750	740	770	770	775	82(
L_8	1150	900	680	620	710	730	650	720	720	750	740	790	760	770	80(

B. 3. pH

WEEK

SOURCE	1	3	5	7	10	12	15	17	19	22	24	27	30	32	36
R_1	7.4	7.6		7.7		6.2	8.4						8.2	7.8	8.0
R_2	8.0	8.1	7.7	7.6	8.3	7.0	8.6	8.4	8.4	8.2	8.3	8.5	8.9	8.9	8.8
R_3	7.5	7.1	8.1	6.9	7.5	7.5	7.5	7.7	7.8	7.7	7.7	7.9	8.3	7.7	8.7
R_4	7.4	7.2			7.7	7.3	7.6	7.7	7.8	7.7	7.5	7.6	8.8	7.9	8.6
L_1	8.7	6.9	6.9	8.0	8.2	8.4	8.2	8.1	8.7	8.5	8.4	8.1	8.6	9.2	9.0
L_2	8.8	8.1	8.1	9.0	9.0	8.6	8.5	8.1	8.7	8.6	8.7	8.8	8.6	9.1	8.9
L_3	8.8	8.4	8.8	8.9	8.4	8.8	8.9	8.6	8.7	8.7	8.8	8.2	8.7	8.3	8.8
L_4	8.9				8.7	8.7	8.5	8.6	8.5	8.8	8.7	8.8	8.6	8.6	8.9
L_5	8.8		8.9	8.6	8.8	8.9	8.4	8.5	8.4	8.7	8.8	8.9	8.7	8.4	9.0
L_6	9.0		9.0	9.0	8.8	9.0	8.6	8.6	8.6	8.7	8.7	8.9	8.9	8.2	9.2
L_7	8.8	8.9	8.9	9.0	8.8	9.0	8.8	8.6	8.7	8.9	8.7	8.9	8.6	8.2	8.8
L_8	8.9	8.8	8.5	8.5	8.6	8.8	8.3	8.7	8.7	8.5	8.5	8.1	8.8	9.0	9.1

B.4. D.O levels (mgl^{-1})

WEEK

SOURCE	1	3	5	7	10	12	15	17	19	22	24	27	30	32	36
L_1	6.3	5.3	6.8		5.1	5.1	4.0	3.6	6.1	5.6	5.1	6.1	6.3	5.7	6.3
L_2	6.5		6.5			7.2	6.8	6.5	7.5	6.6	6.3	6.6	6.5	6.0	6.3
L_3	6.5	7.3	7.0		7.4	7.1	6.7	7.0	7.1	6.8	6.2	7.1	6.8	7.0	6.4
L_4	6.5					6.6	5.6	7.6	7.3	6.5	6.6	6.2	6.4		7.4
L_5	7.6		7.4		6.9	6.5	6.2	7.2	7.2	6.2	6.6	6.4	6.3	6.6	6.2
L_6			7.6	7.6	7.6	6.9	6.0	6.0	6.7	6.3	6.6	6.3	6.2	6.5	7.0
L_7	6.9		7.2	7.6			7.5	7.2	7.2	6.5	6.1	6.4	6.4	6.3	6.8
L_8	6.9	5.9		7.6	6.3	6.2	5.8	6.1	6.7	6.2	6.1	6.1	6.6	6.0	7.6

B. 5: Alkalinity changes ($meql^{-1}$)

SOURCE: \ WEEK	1	3	5	7	10	12	15	17	19	22	24	27	30	32	36
R_1	7.4	1.6		3.6		3.7	4.9						5.7	5.9	5.5
R_2	1.6	0.3	1.7	2.5	2.1	1.8	2.7	2.7	3.0	3.1	3.2	3.3	3.8	3.6	4.8
R_3	1.1	0.3	1.2	0.9	0.6	1.5	1.3	1.8	1.7	1.7	2.3	2.8	6.0	2.7	6.1
R_4	1.2	4.3			0.9	1.1	1.1	0.9	0.9	1.2	1.5	1.0	1.7	1.2	1.7
L_1	8.6	2.5	1.3	3.7	5.0	5.5	4.9	5.8	6.2	5.9	6.0	6.2	6.4	6.5	6.4
L_2	8.7		4.0	3.4	6.2	6.2	6.4	6.2	6.4	5.9	6.1	6.3	6.0	6.6	6.3
L_3	8.9	7.0	7.4	6.8	6.6	6.5	6.4	6.4	6.3	6.1	6.2	6.3	6.3	6.7	6.4
L_4	9.3				6.6	7.1	6.5	5.8	6.5	6.0	6.0	6.4	6.5	6.4	6.2
L_5	8.8		8.2	6.4	6.5	7.4	6.1	6.7	6.1	5.9	6.1	6.5	6.8	6.6	6.2
L_6	9.3		9.2	8.3	7.1	7.4	6.4	6.7	6.4	6.1	6.2	6.0	6.5	6.8	6.3
L_7	9.8	9.4	8.0	7.8	6.6	6.8	6.4	6.4	6.4	6.0	6.0	6.3	6.3	6.7	6.4
L_8	9.5	6.8	5.0	5.5	6.0	7.4	5.9	6.3	6.4	6.0	5.9	6.3	6.6	6.6	6.2

B. 6: Orthophosphate phosphorus (PO_4-P) levels (mgl^{-1})

SOURCE: \ WEEK	1	3	5	7	10	12	15	17	19	22	24	27	30	32	36
R_1				.100		0.68	.046						.070	.082	.090
R_2		.017		.061	.068	.044	.012	.040	.036	.016	.026	.038	.024	.046	.028
R_3		.080			.086	.052	.042	.062	.060	.075	.068	.080	.075	.070	.075
R_4		.070			.060	.062	.060	.040	.034	.036	.032	.038	.032	.060	.036
L_1		.075	.014	.148	.122	.070	.080	.100	.104	.108	.080	.125	.122	.100	.074
L_2			.120	.140	.130	.150	.112	.088	.112	.113	.098	.150	.115	.082	.086
L_3		.130	.140	.160	.133	.085	.110	.100	.116	.115	.088	.154	.106	.090	.092
L_4					.130	.145	.130	.094	.076	.124	.120	.158	.096	.090	.084
L_5			.088	.150	.135	.146	.096	.089	.081	.108	.094	.140	.098	.086	.096
L_6			.130	.154	.153	.130	.112	.125	.080	.130	.118	.158	.094	.068	.086
L_7			.140	.160	.135	110	.122	.112	.124	.122	.100	.158	.100	.090	.070
L_8		.150	.156	.150	.135	.135	.104	.130	.090	.111	.124	.158	.084	.082	.082

B.7: Dissolved Phosphorus (DP) and total phosphorus (TP)

SOURCE		WEEK 1	3	5	7	10	12	15	17	19	22	24	27	30	32	36
R_1	DP				.120		.075	.066								
	TP				.122		.078	.091						.135	.195	.140
R_2	DP				.070	.074	.066	.016	.060	.040	.035	.030	.042			
	TP				.132	.130	.106	.040	.072	.080	.054	.054	.070	.056	.076	.061
R_3	DP		.100			.106	.060	.060	.070	.065	.080	.090	.095			
	TP		.120			.120	.075	.070	.100	.120	.100	.110	.120	.100	.102	.115
R_4	DP		.100			.068	.072	.068	.056	.046	.052	.040	.075			
	TP		.112			.078	.080	.075	.070	.062	.065	.054	.090	.100	.081	.100
L_1	DP		.090	.100	.152	.130	.082	.085	.114	.120	.122	.102	.130			
	TP		.096	.200	.154	.137	.090	.094	.120	.130	.140	.125	.145	.137	.140	.096
L_2	DP			.122	.144	.160	.160	.120	.100	.120	.122	.100	.155			
	TP			.136	.189	.180	.164	.132	.120	.150	.133	.120	.160	.140	.106	.100
L_3	DP	.146	.155	.150	.165	.140	.090	.125	.110	.138	.125	.090	.180			
	TP	.150	.180	.188	.168	.177	.104	.130	.120	.144	.140	.105	.206	.127	.096	.106
L_4	DP					.140	.150	.150	.136	.085	.132	.135	.162			
	TP					.148	.164	.158	.140	.100	.164	.160	.170	.110	.114	.102
L_5	DP			.100	.160	.150	.156	.114	.094	.092	.116	.112	.165			
	TP			.110	.190	.180	.160	.122	.100	.102	.125	.120	.175	.110	.101	.110
L_6	DP	.150		.142	.165	.165	.141	.121	.140	.090	.145	.138	.170			
	TP	.168		.150	.175	.180	.152	.130	.150	.108	.155	.145	.180	.115	.078	.096
L_7	DP			.153	.172	.140	.124	.129	.119	.134	.130	.114	.169			
	TP			.160	.180	.163	.134	.137	.128	.140	.145	.130	.180	.110	.122	.11
L_8	DP	.160	.154	.176	.158	.147	.148	.112	.142	.113	.125	.134	.171			
	TP	.170	.161	.184	.170	.155	.160	.129	.158	.124	.130	.150	.180	.127	.137	.11

B.8: Chlorophyll a (mg l^{-1})

SOURCE	TIME 1	3	5	7	10	12	15	17	19	22	24	27	30	32	36
L_1	8.0	0.7	10.2	0.7	2.3	7.4	2.3	14.5	9.0	17.1	27.3	24.4	13.2	38.0	22.5
L_2	1.5		8.0	1.2	12.0	7.6	9.9	13.9	4.5	20.7	17.7	13.2	9.6	20.5	9.3
L_3	23.8	7.5	10.2	18.8	11.1	6.7	12.2	12.3	8.9	10.7	18.6	13.2	10.4	10.0	9.1
L_4					10.4	8.9	5.7	9.1	13.2	9.8	10.9	8.6	6.4	8.9	5.8
L_5	24.9		21.0	3.5	8.1	7.7	7.0	5.8	8.6	7.7	11.2	8.7	8.7	8.9	7.0
L_6	16.3		12.4	21.3	17.9	24.6	4.4	7.0	9.7	12.2	12.9	6.7	9.9	5.5	7.0
L_7	10.3	32.0	18.0	7.4	19.2	18.9	17.3	12.7	6.8	11.1	17.5	8.9	7.7	11.2	9.0
L_8	10.3	32.8	15.6	13.1	25.3	20.0	18.9	18.3	8.7	21.2	10.9	20.3	35.9	10.2	22.4

APPENDIX C: Diurnal changes (over a 24 hour period) in some physicochemical and biological properties of Lake Baringo. The information was obtained on the 10th March 1989.

C.1: Temperature depth profile

DEPTH (m)	TIME 0000	0400	0600	0800	1000	1200	1400	1600	1800	2000	2400
0.0	24.0	23.7	23.6	24.0	25.9	29.8	31.0	28.5	25.6	25.1	24.6
0.1	24.0	23.7	23.6	24. 0	25.5	29.8	30.9	28.5	25.6	25.1	24.6
0.2	24.0	23.7	23.6	24.0	24.8	28.6	30.7	28.5	25.6	25.1	24.6
0.3	24.0	23.7	23.6	24.0	24.5	28.3	29.9	28.4	25.6	25.1	24.6
0.4	24.0	23.7	23.6	24.0	24.4	27.9	29.3	28.4	25.6	25.1	24.6
0.5	24.0	23.7	23.6	23.7	24.4	27.7	28.4	28.4	25.5	25.1	24.6
0.6	24.0	23.7	23.6	23.7	24.3	27.7	28.0	27.7	25.5	25.1	24.6
0.7	24.0	23.7	23.6	23.7	24.2	27.7	27.9	27.4	25.4	25.1	24.6
0.8	24.0	23.7	23.6	23.7	24.2	27.1	27.8	27.1	25.3	25.1	24.6
0.9	24.0	23.7	23.6	23.7	24.1	24.5	27.8	26.6	25.2	25.1	24.6
1.0	23.8	23.7	23.6	23.6	24.1	24.4	27.4	26.5	25.2	25.1	24.6
1.1	23.8	23.7	23.6	23.6	24.1	24.4	27.3	26.1	25.0	25.0	24.6
1.2	23.8	23.7	23.6	23.6	24.1	24.4	27.3	26.1	25.0	25.0	24.6
1.5	23.8	23.7	23.6	23.6	24.1	24.4	27.3	26.1	25.0	25.0	24.0
2.0	23.8	23.5	23.6	23.6	24.1	24.4	25.5	24.6	25.0	23.3	24.6
3.0	23.8	23.5	23.6	23.5	24.0	24.4	24.9	24.4	24.0	23.9	24.5

C.2: pH

DEPTH(m)	TIME 0000	0400	0600	0800	1000	1200	1400	1600	1800	2000	2400
0.00	9.0	8.7	8.4	9.2	8.9	9.0	8.9	8.8	8.4	8.9	9.0
0.25	8.7	8.2	8.8	9.0	8.8	9.1	8.7	8.9	8.8	8.8	8.9
0.50	8.6	8.0	8.7	8.9	8.5	8.8	8.3	8.8	8.8	8.8	8.9
1.00	8.6	8.0	8.7	8.8	8.4	8.5	8.3	8.8	8.7	8.8	8.9
2.00	8.6	8.1	8.7	8.7	8.5	8.4	7.9	8.6	8.7	8.8	8.9
3.00	8.5	7.8	8.8	8.6	8.4	8.4	8.5	8.7	8.7	8.8	9.0

C.3: Dissolved oxygen (mgl^{-1})

DEPTH(m)	TIME 0000	0400	0600	0800	1000	1200	1400	1600	1800	2000	2400
0.00	8.3	8.7	8.3	7.5	7.4	7.9	7.4	7.1	6.9	6.9	6.4
0.25	7.4	8.2	8.1	7.6	6.9	7.6	7.0	7.2	6.8	6.6	6.7
0.50	7.9	8.0	8.3	7.5	7.0	7.1	6.8	7.2	6.8	6.6	6.8
1.00	6.8	8.0	8.2	7.5	6.5	7.0	6.8	7.0	6.7	6.5	6.8
2.00	6.5	8.1	8.1	7.5	6.5	6.4	6.5	6.5	6.6	6.2	6.8
3.00	7.4	7.8	7.9	7.4	6.6	6.5	6.2	6.5	6.4	6.2	6.6

C. 4: Chlorophyll a (μg^{-1})

DEPTH(m)	TIME 0000	0400	0600	0800	1000	1200	1400	1600	1800	2000	2400
0.00	12.8	6.7	10.5	8.1	26.4	26.4	35.1	27.6	24.1	23.5	14.8
1.0	8.9	8.4	10.8	41.8	10.7	6.6	15.1	39.2	23.8	15.6	15.1
3.0	6.1	5.8	8.7	8.1	8.4	13.0	6.7	23.8	17.1	8.1	14.8